938507.0083

DOE/OR/02-1119&D1&V1

East Fork Poplar Creek — Sewer Line Beltway Remedial Investigation Report

Sections 1 - 4

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PUBLIC RELEASE

6-041693-052

930501.0003

East Fork Poplar Creek – Sewer Line Beltway Remedial Investigation Report

Volume I
Sections 1-4

April 1993

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Submitted to the
U.S. Department of Energy
under contract DE-AC05-90OR21851

92-165MS/042293

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ACRONYMS

This master list contains acronyms for all sections.
Not all acronyms on this list will appear in this volume.

AEA	Atomic Energy Act
AET	adverse effects threshold
AF	Adherence Factor
AFDW	ash-free dry weight
ALARA	as low as reasonably achievable
ANOVA	analysis of variance
AMS	Aerial Measuring System
ARAP	Aquatic Resources Alteration Permitting
ARAR	applicable or relevant and appropriate requirement
ASME	American Society of Mechanical Engineers
AT	Averaging Time
AWQC	ambient water quality criterion
B*a*	Biotransfer Factor from Feed to Beef Tissue
BAF	bioaccumulation factor
BC	Bear Creek
BCF	Bioconcentration Factor
BEIA	Biomedical and Environmental Information Analysis
BLS	Below Land Surface
BLUE	best linear unbiased estimator
B*m*	Biotransfer Factor from Feed to Milk
BMAP	Biological Monitoring and Abatement Program
BN	Brown-Norway
BRA	Baseline Risk Assessment
BTF	Biotransfer Factor
B*v*	Biotransfer Factor from Soil to Plant
BW	body weight
CAA	Clean Air Act
CAD	computer aided design
CAVEAT	Computer Assisted Validation and Evaluation Assessment Tool
CCC	criterion continuous concentration
CCS	Contract Compliance Screening
CDC	Centers for Disease Control
CDF	Cumulative Density Function
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
CLP	Contract Laboratory Program
CMC	criterion maximum concentration
CMS	corrective measures study
COCs	contaminants of concern

COE	U.S. Corps of Engineers
Colex	column exchange
COR	Contracting Officer's Representative
CR	Chestnut Ridge
CRAC	Central Risk Assessment Council
CRAVE	Carcinogen Risk Assessment Verification Endeavor
CRDL	contract required detection limit
CSFs	Cancer Slope Factors
CVAA	Cold Vapor Atomic Absorption
CWA	Clean Water Act
CY	calendar year
D&D	decontamination and decommissioning
DCGs	derived concentrations guides
DER	duplicate error ratio
DO	dissolved oxygen
DOE	Department of Energy
DOE-OR	U.S. Department of Energy Oak Ridge Operations
DOI	U.S. Department of Interior
DOT	U.S. Department of Transportation
DQO	Data Quality Objective
EA	environmental assessment
EDE	effective dose equivalent
EFH	Exposure Factors Handbook
EFK	East Fork kilometer
EFPC	East Fork Poplar Creek
EG&G/EM	EG&G Energy Measurements, Inc.
EIS	environmental impact statement
EMSL	Environmental Monitoring Systems Laboratory
EO	Executive Order
EP	equilibrium partitioning
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
ERP	Environmental Restoration Program
FDA	U.S. Food and Drug Administration
FFA	Federal Facility Agreement
FFCA	Federal Facility Compliance Agreement
FR	*Federal Register*
FS	feasibility study
FWS	Fish and Wildlife Service
GIS	geographical information system
GN	Glomerulonephritis
HAs	Health Advisories
HAZWRAP	Hazardous Waste Remedial Actions Program
HC	Hinds Creek
HEAST	Health Effects Assessment Summary Table
HEC	Human Equivalent Concentration

HI	Hazard Index
HQ	Hazard Quotient
HSWA	Hazardous and Solid Waste Amendments
IAP	ion activity product
ICP	inductively coupled plasma
ICRP	International Commission on Radiological Protection
INM	in need of management
IRIS	Integrated Risk Information System
LCS	laboratory control samples
LDR	land disposal restriction
LEFPC	Lower East Fork Poplar Creek
Li	lithium
LLW	low-level waste
LOAEL	Lowest-Observable-Adverse-Effect Level
M&O	management and operating
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MF	Modifying Factor
MFO	mixed function oxidase
MLE	Most Likely Exposure
MOU	memorandum of understanding
MS	matrix spike
MSL	mean sea level
MSS	matrix spike sample
NAs	Natural Areas
NAS	National Academy of Sciences
NAA	neutron activation analysis
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NCR	Nonconformance Report
NCRP	National Council on Radiation and Protection Measurements
NEPA	National Environmental Policy Act
NERP	National Environmental Research Park
NESHAPs	National Emission Standards for Hazardous Air Pollutants
NHP	New Hope Pond
NHPA	National Historic Preservation Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No-Observable-Adverse-Effect Level
NPDES	National Pollution Discharge Elimination System
NPL	National Priorities List
NRC	U.S. Nuclear Regulatory Commission
NRDAs	Natural Resource Damage Assessments
NSDWS	National Secondary Drinking Water Standards
NSPSs	new source performance standards
NWP	nationwide permit
ODW	Office of Drinking Water

ORAU	Oak Ridge Associated Universities
ORGDP	Oak Ridge Gaseous Diffusion Plant
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
ORSA	Oak Ridge Sportsman Association
ORSTP	Oak Ridge Sewage Treatment Plant
ORTF	Oak Ridge Task Force
OSHA	Occupational Safety and Health Administration
OU	operable unit
PA/SI	preliminary assessment/site investigation
PAHs	polycyclic aromatic hydrocarbons
PARCC	precision, accuracy, representativeness, completeness, and comparability
PCBs	polychlorinated biphenyls
PCDFs	polychlorinated dibenzofurans
PDF	Probability Density Function
ppm	parts per million
PRGs	preliminary remediation goals
QA	quality assurance
QAPjPs	Quality Assurance Project Plans
QAPP	Quality Assurance Program Plan
QAMS	Quality Assurance Management Staff
QC	quality control
RAs	Reference Areas
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
RfCs	reference concentrations
RfDs	reference doses
RFI	RCRA facility investigation
RI	remedial investigation
RI/FS	Remedial Investigation/Feasibility Study
RME	Reasonable Maximum Exposure
RMPE	Reduction of Mercury in Plant Effluents
ROD	record of decision
ROW	right of way
RPD	Relative Percent Difference
SAIC	Science Applications International Corporation
SAP	sampling and analysis plan
SARA	Superfund Amendments and Reauthorization Act
SCS	Soil Conservation Service
SDWA	Safe Drinking Water Act
SE	standard error
SEN	Secretary of Energy Notice
SI	saturation index
SLB	Sewer Line Beltway
SMCLs	secondary maximum contaminant levels
SO_2	sulphur dioxide

SOP	standard operating procedure
SQCs	sediment quality criteria
SVOC	semivolatile organic compound
SWMUs	solid waste management units
TBC	to be considered
TCA	Tennessee Code Annotated
TCL	target compound list
TCLP	toxity characteristic leaching procedure
TDEC	Tennessee Department of Environment and Conservation
TEF	Toxicity Equivalence Factor
THQ	Target Hazard Quotient
TIC	Tentatively Identified Compound
TIR	tentatively identified radionuclides
TOC	total organic carbon
TRL	target radionuclide list
TSC	Technical Support Contractor
TSCA	Toxic Substances Control Act
TSD	treatment, storage, and disposal
TSPs	total suspended particles
TU	trap units
TVA	Tennessee Valley Authority
TWA	Time Weighted Average
TWRA	Tennessee Wildlife Resources Agency
UCL	Upper-bound Confidence Limit
UEFPC	Upper East Fork Poplar Creek
UF	Uncertainty Factor
USGS	U.S. Geological Survey
URF	Unit Risk Factor
VOCs	volatile organic compounds
WQC	water quality criteria

DOE/OR/02-1119&D1

Draft
Executive Summary
for
the East Fork Poplar Creek - Sewer Line Beltway Remedial Investigation Report

Prepared for
U.S. Department of Energy
under contract DE-AC05-90OR21851

April 1993

92-165MS/051093

East Fork Poplar Creek – Sewer Line Beltway Remedial Investigation Report

Executive Summary

April 1993

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Submitted to the
U.S. Department of Energy
under contract DE-AC05-90OR21851

92-165MS/042793

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ACRONYMS

ARAR	applicable or relevant and appropriate requirement
AWQC	ambient water quality criteria
BMAP	Biological Monitoring and Abatement Program
BRA	baseline risk assessment
BTF	biotransfer factor
CDI	chronic daily intake
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLP	Contract Laboratory Program
CMS	corrective measures study
COC	contaminant of concern
DOE	U.S. Department of Energy
DOE-OR	DOE Field Office - Oak Ridge
DQO	data quality objective
EFPC	East Fork Poplar Creek
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
ERA	ecological risk assessment
FDA	U.S. Food and Drug Administration
FFA	Federal Facilities Agreement
FS	feasibility study
HEAST	Health Effects Assessment Summary Tables
HI	hazard index
HQ	hazard quotient
IRIS	Integrated Risk Information System
MCL	maximum contaminant level
MLE	most likely exposure
NAA	neutron activation analysis
NCR	nonconformance report
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
ORAU	Oak Ridge Associated Universities
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OU	operable unit
PAH	polycyclic aromatic hydrocarbon
PARCC	precision, accuracy, representativeness, completeness, and comparability
PCB	polychlorinated biphenyl
PRG	preliminary remediation goal
QA	quality assurance
QC	quality control
RCRA	Resource Conservation and Recovery Act

ACRONYMS (continued)

RfC	reference concentration
RfD	reference dose
RFI	RCRA facility investigation
RI	remedial investigation
RME	reasonable maximum exposure
SAIC	Science Applications International Corporation
SAP	Sampling and Analysis Plan
SDWA	Safe Drinking Water Act
SLB	Sewer Line Beltway
TCLP	toxicity characteristic leaching procedure
TDEC	Tennessee Department of Environment and Conservation
TVA	Tennessee Valley Authority
UCL	upper 95% confidence limit
USGS	U.S. Geological Survey

EXECUTIVE SUMMARY

ES.1 INTRODUCTION

On December 21, 1989, the U.S. Environmental Protection Agency (EPA) placed the U.S. Department of Energy's (DOE's) Oak Ridge Reservation (ORR) on the National Priorities List. On January 1, 1992, a Federal Facilities Agreement (FFA) between the DOE Field Office in Oak Ridge (DOE-OR), EPA Region IV, and the Tennessee Department of Environment and Conservation (TDEC, formerly the Tennessee Department of Health and Environment) went into effect. This FFA establishes the procedural framework and schedule by which DOE-OR will develop, coordinate, implement, and monitor environmental restoration activities on the ORR in accordance with applicable federal and state environmental regulations.

The DOE-OR Environmental Restoration Program for the ORR addresses the remediation of areas both within and outside the ORR boundaries, including Oak Ridge National Laboratory (ORNL), the former Oak Ridge Gaseous Diffusion Plant (K-25 Site), the Y-12 Plant, Oak Ridge Associated Universities (ORAU), the Clinch River, and East Fork Poplar Creek (EFPC). The subject of this report is a 23-km (14.2-mile) stretch of EFPC flowing from Lake Reality at the Y-12 Plant, through the city of Oak Ridge, to Poplar Creek on the ORR and its 2.71 km^2 (670 acres) of floodplain. Both EFPC and its floodplain have been contaminated by hazardous, radioactive, and mixed waste releases from the Y-12 Plant since the mid-1950s, with early estimates of some 16 million ft^3 of sediments and soils being impacted. The primary contaminant of concern (COC) is mercury, with other heavy metals, radionuclides, and organics known to be present.

Because the EFPC site—designated as an ORR operable unit (OU) under the Comprehensive Environmental Response, Compensation, and Liability Act of 1983 (CERCLA)—is included on the National Priorities List, its remediation must follow the specific procedures mandated by CERCLA, as amended by the Superfund Amendments and Reauthorization Act in 1986. Because EFPC involves off-site release of contaminants from the Y-12 Plant, its remediation also must conform with the procedures of Sect. 3004(v) of the Resource Conservation and Recovery Act of 1980 (RCRA), as amended by the Hazardous and Solid Waste Amendments of 1984. Because the actions taken to remediate EFPC may affect the environment, the potential environmental impact of those actions must be publicly addressed in accordance with the National Environmental Policy Act (NEPA). The remedial investigation (RI) of EFPC, conducted from 1990 to 1992, integrated the requirements of these three primary federal regulations, as outlined in the FFA for the ORR, as well as those of other federal and Tennessee state regulations.

The primary steps included in a CERCLA RI are (1) to collect data to characterize, or describe, site conditions; (2) to determine the nature and extent of contamination at the site; and (3) to assess current and future risks to human health and the environment if no remediation occurred. RCRA calls for similar activities to be performed under a RCRA facility investigation (RFI). After the RI is completed, work begins on the feasibility study (FS) - Environmental Impact Statement (EIS). The purpose of the FS-EIS is to provide decision makers with sufficient information to adequately compare the alternatives for site cleanup, to select a remedy for the site, and to demonstrate compliance with CERCLA remedy selection requirements. Risk assessment is performed during the FS to determine whether the proposed alternatives will significantly reduce the risk to human health and/or the environment. Again, the objectives of the RCRA-required corrective measures study (CMS) are very similar to those of the CERCLA-required FS. NEPA, however, requires that adequate information on the environmental effects of the alternatives be available to aid decision making. In addition, the NEPA "no action" alternative is always considered as a basis to judge the effectiveness and feasibility of all other alternatives. The integrated FS-CMS-EIS considers effects not only on the site itself but also on surrounding communities; considers socioeconomic impacts; and discusses interactive or cumulative effects with other site activities.

This report presents the results of the RI performed for the EFPC OU, which includes the lower 23 km (14.5 miles) of EFPC, its 2.71-km^2 (670-acre) floodplain, and the Oak Ridge Sewer Line Beltway (SLB), which was constructed of contaminated materials from the floodplain. EFPC originates as an on-site surface water drainage system at the Y-12 Plant. From its point of origin as a drainage ditch at the Y-12 Plant to where it feeds into Lake Reality, the creek is referred to as Upper EFPC. Beginning at the outfall of Lake Reality, Lower EFPC travels through the city of Oak Ridge before re-entering the ORR and joining Poplar Creek. As a result of discharges from the Y-12 Plant, EFPC and its floodplain were contaminated with such materials as mercury, uranium, thorium, chromium, zinc, and lead. In addition, the SLB, which was constructed between 1982 and 1983, received soil from the floodplain as fill and topsoil.

An RI-RFI work plan for the EFPC OU, which incorporates both CERCLA and RCRA requirements, was submitted as a two-part Sampling and Analysis Plan (SAP) in December 1991. Part I included CERCLA requirements such as a conceptual model and data quality objectives that had not been included in the original RFI Plan. Part II was the more traditional SAP following CERCLA guidelines. Field sampling, laboratory analysis, and data evaluation began

in autumn of 1990 and continued through summer 1992. A public awareness and participation program has been implemented throughout the RI phase, including briefings to the public and to the staff of EPA Region IV and TDEC.

Phase Ia of the RI-RFI was designed to determine the nature of contamination and to identify the COCs—primarily radionuclides, organic compounds, mercury and other metals, and polychlorinated biphenyls (PCBs) and pesticides. Completion of this phase of the RI required installation of 12 groundwater monitoring wells and the quarterly sampling of 22 wells to characterize the groundwater quality and hydrogeology of the floodplain. Surface water samples, creek sediments, and surface and subsurface soil samples were taken along the watershed and at a noncontaminated reference site for the determination of 182 inorganic, organic, and radionuclide analytes as well as geotechnical parameters and soil chemistry related to treatability studies.

Phase Ib, which began in the summer of 1991, was designed to establish the extent and level of contamination. More than 3000 field samples were collected and analyzed, and soil gas surveys were conducted to monitor mercury volatilization. The work conducted under Phases Ia and Ib of the RI-RFI was successful in that it enabled determination of the nature and extent of contamination, definition of the potential for migration, and definition of the exposure pathways. The numbers of field and quality control (QC) samples collected during the two phases of the RI-RFI are summarized below.

Sample Type	Number of Samples		
	Phase		
	Ia	Ib	Total
Field	569	3445	4014
QC	304	405	709
Total	873	3850	4723

As part of the RI-RFI, baseline human health and ecological risk assessments also have been completed and are documented in this report. The primary objectives of the baseline risk assessments (BRAs) are to determine whether current and future exposure potential presents an

"imminent and substantial" endangerment to human health and the environment, and to evaluate the need for site remediation. The BRAs examine the (1) presence of chemicals and radionuclides in EFPC, (2) potential routes of exposure to human and ecological receptors, and (3) likelihood of adverse health or ecological effects resulting from contact with contaminated environmental media.

Results of the three primary steps involved in the EFPC RI—site characterization, determination of the nature and extent of contamination, and risk assessment—are presented in the following sections. The EFPC site characterization is presented first, followed by a discussion of the nature and extent of contamination. The assessment of risk is discussed in two sections, the first describing the human health BRA and the second describing the ecological BRA. This executive summary closes with a summary and conclusions section that details the primary results of the RI/BRA and provides recommendations for consideration in the follow-on FS-CMS-EIS development.

ES.2 SITE CHARACTERIZATION

ES.2.1 Environmental Setting

EFPC is a perennial stream located in Anderson and Roane Counties in Oak Ridge, Tennessee, ~40 km (25 miles) west of Knoxville (see Fig. ES.1). Its headwaters are contained in 137- to 183-cm (54- to 72-in.) underground collection pipes that extend from the west end to the central area of the Y-12 Plant, where the above-ground portion of the creek begins. From the Y-12 Plant site, EFPC flows northward through a gap in Pine Ridge and enters Gamble Valley and the city of Oak Ridge. From there, the stream flows northwestward along Illinois Avenue through commercial and light industrial areas in Oak Ridge, then trends generally westward, parallel to Oak Ridge Turnpike in East Fork Valley, through primarily residential, agricultural, and undeveloped forest areas, until it joins Poplar Creek. EFPC is, ultimately, a tributary to the Clinch River, which is impounded behind Watts Bar Dam.

From the point at which it exits Lake Reality to its confluence with Poplar Creek, EFPC measures ~23 km (14.2 miles). Stream depths range from <1 m to 3 m (3 to 9 ft). The 100-year floodplain bounding the creek varies in width from several meters in its upper reaches to ~500 m (1640 ft) and encompasses ~2.71 km^2 (670 acres). The course and streambed of EFPC have been modified as a result of Oak Ridge development; the creek has been channelized in some sections of town, and riprap has been added to protect the banks. Box culverts and

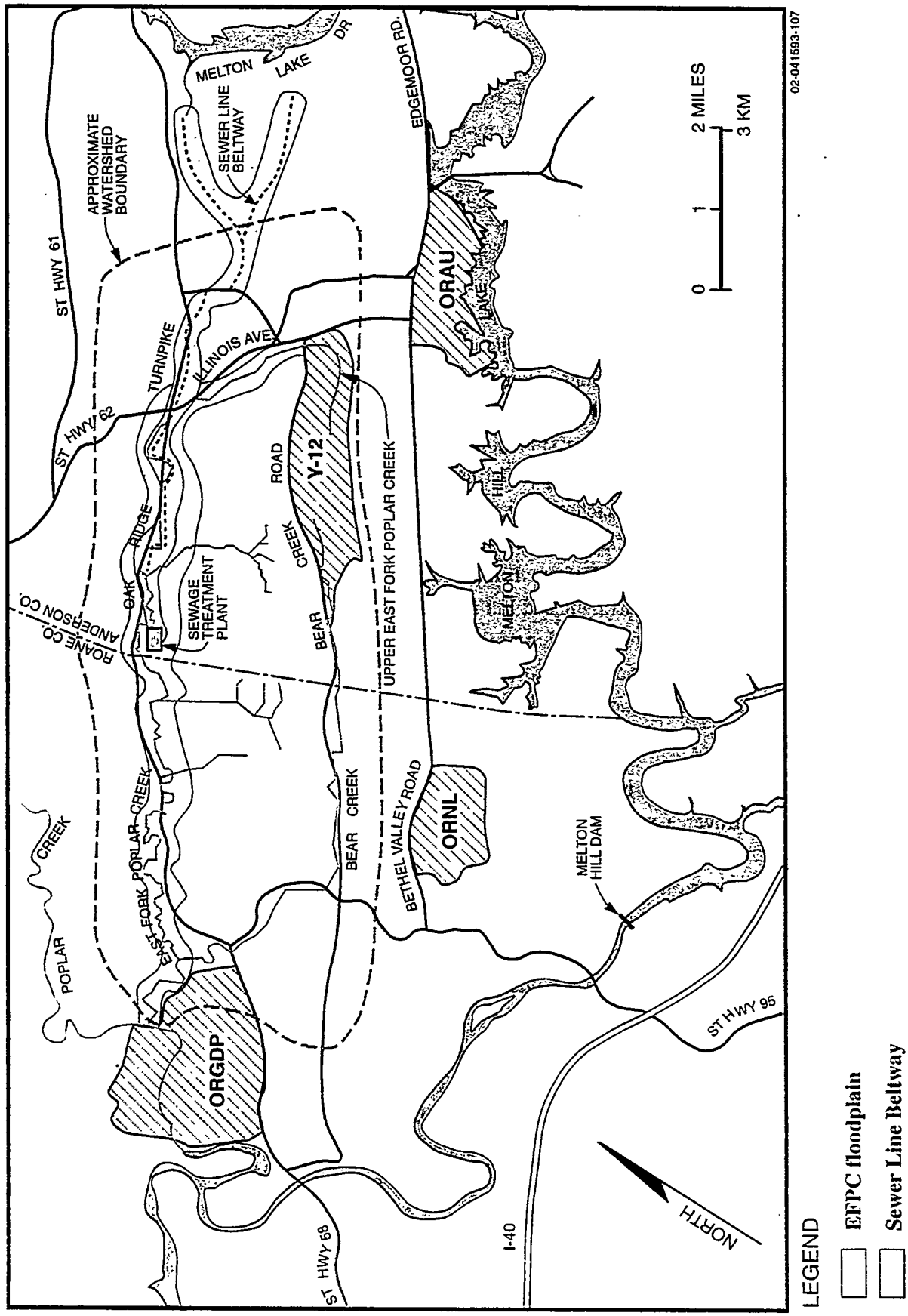

Fig. ES.1. Location map for EFPC and SLB.

bridge piers are present in EFPC at roadway crossings and numerous drainage ditches, and lateral culverts traverse the floodplain and discharge to the creek. Major tributaries to EFPC include Tuskegee Branch, Mill Branch, Gum Hollow Branch, Pinhook Branch, and Bear Creek. The average flow for EFPC over a 25-year period of record is 1.5 m^3/sec (51.4 ft^3/sec), with artificial flows from the Y-12 Plant and Oak Ridge Sewage Treatment Plant contributing some 40% of that flow. These contributions and the general urban and agricultural discharges to the watershed impact the water quantity and quality of the EFPC study area.

Because sediments and soils from EFPC and its floodplain were used as fill material for portions of the SLB, the entire SLB, which encompasses >16 km (>10 miles) of sanitary interceptor sewers and force mains, is included in the EFPC RI. Construction of the SLB involved use of contaminated fill in pipe trenches in some locations down to 15 cm (6 in.) and use of floodplain soils as topsoil dressing along the line in many areas. The upper portion of the SLB consists of two branches, one paralleling Emory Valley Road and the other paralleling Warehouse Road. The two branches converge near the Daniel Arthur Rehabilitation Center into a single system that parallels Oak Ridge Turnpike to the Oak Ridge Sewage Treatment Plant (Welch 1987). Because the SLB from Illinois Avenue to the treatment plant falls within the EFPC floodplain, it is not distinguished in this report but rather is incorporated as part of the floodplain discussion. Only that portion of the SLB located west of Illinois Avenue is discussed independently. Several locations along the SLB already have been the subject of remedial actions due to the need for construction in limited areas. In those cases, contaminated soils/sediments were removed and appropriately packaged for disposal.

EFPC, for about 25% of its length, traverses DOE property. The remainder of the creek and all of the SLB traverse properties are owned by private citizens or the local government. Although the land that falls within the 100-year flood boundaries of EFPC is mostly undeveloped, developed areas occur on adjacent land just outside the floodplain. As a result, land use in the vicinity of the site is diverse, including residential, commercial, agricultural, and open (undeveloped) use. The residential category includes single- and multi-family housing units and schools. The commercial category includes offices, retail stores, restaurants, meeting places, and other establishments. Agricultural land use within the floodplain itself is limited to grazing of livestock and horses, with no current use for raising crops or family gardens. Open land use areas are those areas involving only incidental use, either through recreation or trespass. Although the agricultural areas are actually similar to open areas with regard to exposure pathways, the BRAs take into account the ingestion of crops or livestock raised on the floodplain, which represents a far more conservative case than reality.

As a basis for investigation, the EFPC and its floodplain were divided into nine segments based on geography, uniformity of land use, and similarity of contaminant levels. Present land use for the nine segments is estimated to be 7% residential, 2% commercial, 52% agricultural, and 31% open land. The remaining 8% of the EFPC site, including the creek itself and all roads and rights-of-way, is unclassified. The total number of residences within 150 m (500 ft) of the EFPC and SLB is 1062, with an estimated population of 2622. The Oak Ridge 1988 Comprehensive Plan and current trends toward commercialization and residential development, however, suggest that areas within and adjacent to the floodplain now designated as open space are likely to convert to residential land use in the future. As a result, projected future use of the EFPC floodplain is estimated to be 29% residential, 12% commercial, 42% agricultural, 8% open, and 9% unclassified. Figures ES.2a and 2b show the present and future land use by segment for EFPC and its floodplain.

The EFPC watershed and SLB are located in the Valley and Ridge Physiographic Province of the Appalachian Mountains. This geologic structure produced a topography dominated by narrow elongated ridges and valleys, which trend to the northeast/southwest. The prominent valleys and ridges traversed by EFPC and the SLB are, from north to south: East Fork Valley, East Fork Ridge, Gamble Valley, Emory Valley, Pine Ridge, and Bear Creek Valley. Elevations within the study area range from 400 m (1300 ft) at Pine Ridge to 225 m (740 ft) at the mouth of EFPC. Four different geologic units directly underlie EFPC along its course. These units include, in order of encounter downstream, the Conasauga Group, the Rome Formation, the Chickamauga Group, and the Knox Group. Soil types mapped in the EFPC floodplain belong to the Newark, Newark Variant, Hamblen, Sequatchie, Pope, and Roane Series.

The EFPC site is characterized by cleared areas, shrubs and herbaceous plants, and second-growth trees, which form thick stands up to the creek banks in many locations. Because of different land uses in the past, the woods are in various stages of ecological succession. The floodplain contains areas that have been filled to allow commercial development, and in places the creek has been channeled. Other portions of the floodplain contain agricultural tracts or grass and old field habitats. Terrestrial biota such as deer, raccoons, birds, and insects occur in these habitats. The creek contains several species of fish as well as benthic and other organisms typical of aquatic habitats characterized by limestone rip-rap to smooth and muddy stream bottoms.

Wetlands were inventoried by the U.S. Army Corps of Engineers along the entire length of the EFPC floodplain. Seventeen wetland areas were identified that exhibited all three regulatory wetlands criteria (COE 1992), comprising a total of ~ 5 ha (12 acres). The majority of those

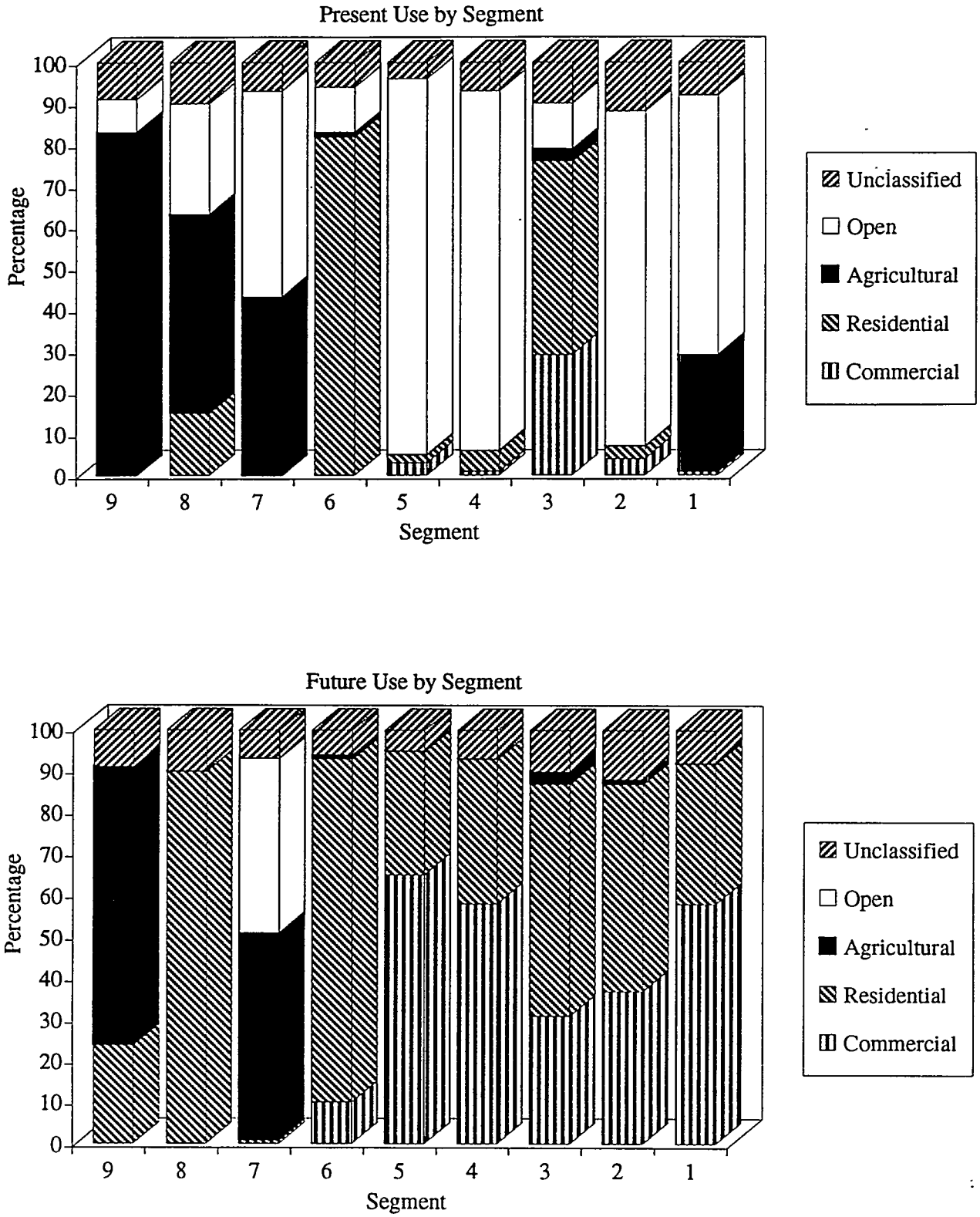

Fig. ES.2a. Present and future land use by segment for EFPC and its floodplain.

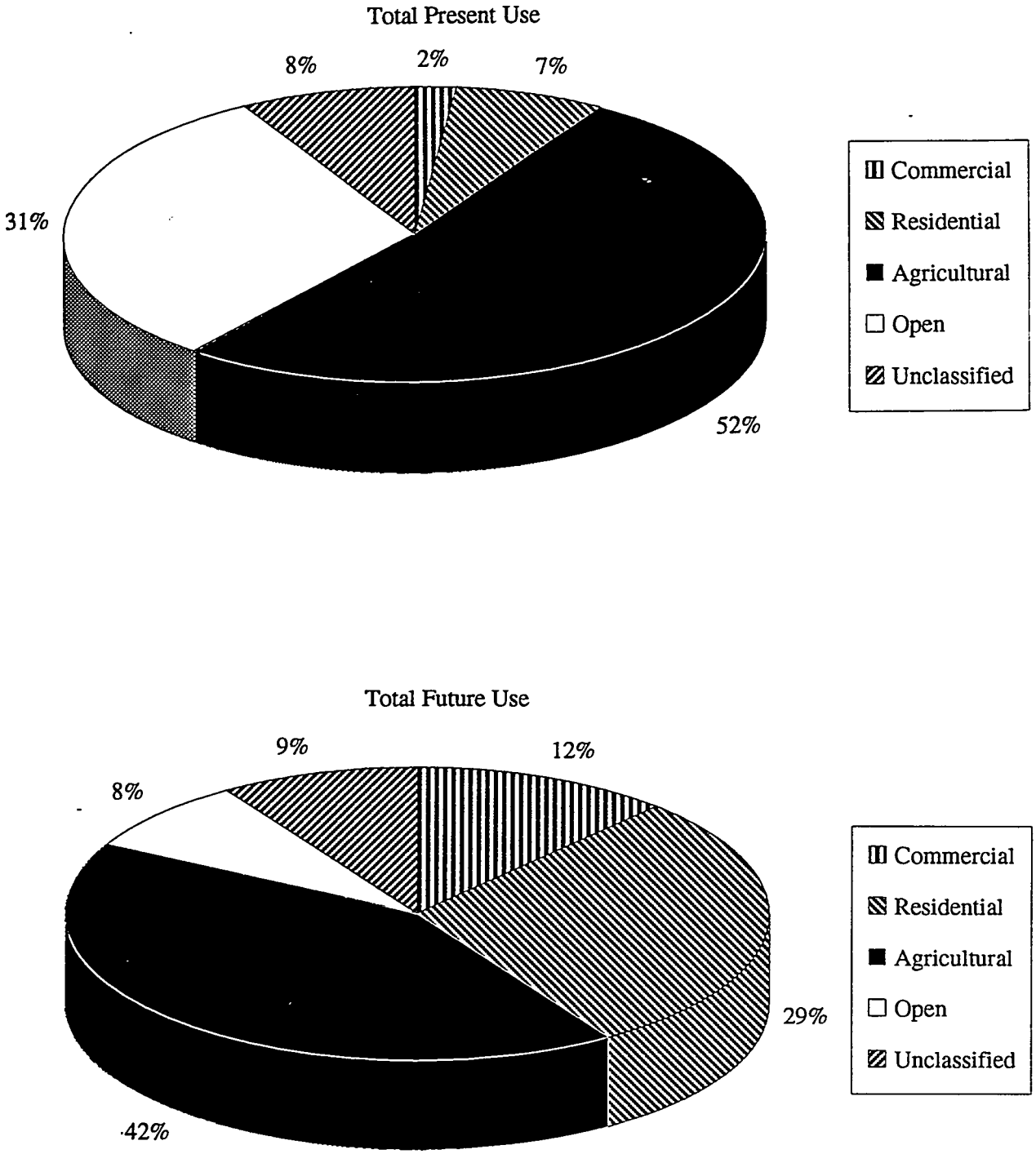

Fig. ES.2b. Total land use percentages, present and future.

identified wetlands were < 1 acre in size. Additionally, there are habitats that could support endangered and threatened species if they were present.

The primary climatic attribute affecting possible contaminant transport at the EFPC site is precipitation (and the associated runoff). Precipitation in this area of the Tennessee Valley is seasonally distributed, with peaks occurring in late winter, early spring, and mid- to late summer and lows occurring in the fall. Runoff is greatest in the winter, when evapotranspiration is low and precipitation is high. Precipitation not lost as evapotranspiration or as quick surface and shallow-groundwater runoff percolates through the soil and eventually recharges the groundwater system.

Sediment movement during storm events is the primary natural route of past, present, and future contaminant transport at the EFPC site. The flow of surface water over and through areas of contaminated soils and sediments provides a potential for further transportation and redeposition of material within EFPC. It also provides for direct solubilization of contaminants retained in the contaminated soils and sediments.

EFPC is the primary feature of a hydrologically interconnected network within the EFPC watershed. Within this network, EFPC surface water can recharge the shallow groundwater in a losing reach or, conversely, groundwater can recharge EFPC surface water in a gaining reach. This interrelationship between surface water and groundwater was considered important because of the potential for continuing movement of contaminants between the two systems.

The shallow aquifer in the EFPC floodplain consists primarily of alluvial silt and clay with lesser amounts of sand and gravel. Thickness of the shallow aquifer ranges from essentially zero to as much as 6 m (20 ft). Water levels in the shallow aquifer fluctuate seasonally in response to variations in recharge and evapotranspiration.

The bedrock aquifer is composed primarily of limestone that contains clay and shale partings, but also includes lithologies composed of sandstone, calcareous siltstone, shale, and dolomite. These lithologies typically have tightly bound matrices and insignificant intergranular permeability. However, a moderately well-developed secondary permeability system provides for transmission of water within the bedrock. This secondary system is composed of fractures that commonly intersect one another, providing a significant degree of interconnection in the bedrock aquifer.

Although both lateral flow within the bedrock aquifer and flow from EFPC surface water to groundwater are likely, historic sampling of groundwater monitoring wells within the EFPC floodplain conducted by both the Y-12 Plant and by the U.S. Geological Survey (USGS) suggests that groundwater flow is not a pathway of concern.

ES.2.2 Applicable or Relevant and Appropriate Requirements

As the basis for comparison with existing site conditions, a comprehensive set of applicable or relevant and appropriate requirements (ARARs), which arise from various local, state, and federal laws and regulations, has been developed and documented in this RI report. The ARARs listing was developed in accordance with CERCLA requirements for adherence to the applicable federal or more stringent state environmental laws to ensure protection of human health and environment. In addition to the CERCLA requirements, NEPA requirements have been integrated into the overall EFPC RI/FS process and provided critical guidance in implementing the site investigations.

As defined by CERCLA for the RI process, both chemical- and location-specific ARARs must be developed. Chemical-specific ARARs have been identified and documented for groundwater and surface water contaminants, soil and sediment, and in general for radioactive contaminants in all media. For groundwater and surface water, these ARARs arise from the National Secondary Drinking Water Standards and the Tennessee Water Control Act. From those sources, chemical-specific maximum contaminant levels, secondary drinking water standards, and water quality criteria for the primary EFPC contaminants are documented in this report. Although not ARARs, regulatory guidance for soils and sediments is available and documented from TDEC through proposed rules, from EPA for PCBs and lead, and from the National Oceanic and Atmospheric Administration (NOAA) for a variety of chemicals, as generic action levels. For radioactive contamination, guidance from EPA and from DOE is available and documented for comparison with site conditions. Location-specific ARARs also have been defined to cover floodplains; wetlands; aquatic resources and natural areas; endangered, threatened, or rare species; and archeological and historic resources. Details of the specific guidance provided by Federal Executive Orders, the Clean Water Act, Tennessee Water Quality Control Act, Fish and Wildlife Coordination Act, Endangered Species Act, and the Archaeological Resource Recovery Act for these location-sensitive requirements are also provided in this RI report.

ES.2.3 Nature and Extent of Contamination

Several past studies have collected data concerning the type, extent, and levels of contamination in the EFPC floodplain. Routine monitoring of the Y-12 Plant effluents and EFPC sediments and groundwater has been conducted to varying degrees since 1977, and biological monitoring has been provided at selected locations along the creek since 1984. A major investigative effort was undertaken in 1983 as part of the Oak Ridge Task Force. It involved large-scale sediment, soil, water, groundwater, and vegetation sampling in an early effort to understand the potential public health impact of the watershed contamination. These and other ancillary studies provided critical information for the planning of the CERCLA RI efforts. However, due to the lack of CERCLA-required rigor and documentation, the results from these studies could be used only for screening-level assessments and developing conceptual models to define sampling strategies, not as the basis for the human health and ecological risk assessments.

The conceptual model for contaminant transport in the EFPC watershed is based on the premise that soil contamination in the EFPC floodplain is closely linked with hydrologic events. Contaminants from the Y-12 Plant were washed down EFPC during high-flow conditions following rainstorms. At least some of the contaminants were adsorbed onto sediment particles and were transported downstream in a suspended phase (TVA 1985). Other contaminants were transported in a dissolved phase. During flood events, the creek flows out of its banks and spreads out across the floodplain, depositing contaminated sediments on vegetation and soils. Hence, the EFPC RI focused on the evaluation of surface water, creek sediments, floodplain soils, and groundwater as potentially affected media. Sampling and laboratory analysis to support the RI was conducted in two phases. Phase Ia, which began in the autumn of 1990, was designed to determine the nature of contaminants and to identify the potential COCs. This phase involved a screening-level assessment for 182 analytes identified from the primary groups of metals, volatile and semivolatile organic compounds, pesticides/herbicides, PCBs, and radionuclides. Phase Ib, which began in the summer of 1991, was designed to establish the extent and level of contamination. Both Phase Ia and Ib were conducted under Level IV Data Quality Objectives (established for data utilized in the BRA), with all analytical analyses performed under the EPA Contract Laboratory Program (CLP) or approved equivalent.

The potential COCs were identified using Phase Ia sampling data and a toxicity concentration scoring system, which ranks potential health effects of chemicals on the basis of measured concentrations and established toxicity measures without making quantitative assumptions about exposures and dose (EPA 1989a). For purposes of evaluation, all chemicals were divided into four groups according to available toxicity measures: (1) carcinogenic compounds (chemicals for

which oral cancer slope factors are available); (2) chemicals that have been evaluated only for systemic toxicity [noncarcinogenic chemicals with oral reference doses (RfDs)]; (3) radionuclides (with pathway-specific unit risk factors); and (4) chemicals for which no toxicity measures are available. A toxicity score was calculated for each chemical in the first three groups, and each chemical was ranked by its percentage of the total score for the group. Those highest-ranked compounds that together represented 99% of the toxicity score for a particular group were considered potential COCs. In addition, chemicals were included as chemicals of concern if their maximum concentrations in groundwater or surface water were greater than the maximum contaminant level established under the Safe Drinking Water Act (SDWA) or federal or state ambient water quality criteria for the protection of freshwater organisms established under the Clean Water Act.

As shown in Table ES.1, the COCs for all EFPC media are extensive. The contaminant listing of some 13 heavy metals, 9 polycyclic aromatic hydrocarbons (PAHs), 2 PCBs, and 11 radionuclides, while large in number of compounds, can be more easily interpreted if one considers the relative toxicity percentage of those compounds. For the heavy metals, mercury was by far the most significant contributor, with >85% of the total toxicity. Similarly, for radionuclides, total uranium (^{234}U, ^{235}U, and ^{238}U) accounted for 98% of the total activity. The subcategories of PAHs and PCBs were, in essence, indistinguishable in terms of risk. Hence, the somewhat overwhelming listing of 35 COCs can be more easily managed by focusing on mercury, uranium, PAHs, and PCBs as representative of the primary contaminant groups.

As noted in Table ES.1, the potential COCs for soils and sediments were identical. The metal COCs for groundwater are similar, except that silver was not detected and barium was included. PAH and PCB concentrations were not significant in groundwater. Total radium was found at significant levels in groundwater, but ^{137}Cs was not. Potential COCs for surface water were developed independently for base and storm flow conditions. Surface water under base flow conditions had contaminant levels which yielded essentially no COCs. All metals and organics detected are below existing SDWA maximum contaminant levels (MCLs) and meet federal ambient water quality criteria for the protection of freshwater organisms. Although the concentrations of uranium isotopes and ^{137}Cs were low, they were included in the risk assessment, along with several radionuclides not measured in Phase Ia, to ensure comprehensive treatment of radionuclide contamination. COCs for surface water during storm flow included those identified for base flow as well as several identified for sediments.

Table ES.1. Potential COCs by environmental medium

Contaminant	Medium				
				Surface water	
	Soil	Sediment	Groundwater	Base flow	Storm flow
Metals					
Arsenic	x	x	x		x
Barium			x		
Beryllium	x	x	x		
Cadmium	x	x	x		
Chromium	x	x	x		x
Copper	x	x	x		x
Lead	x	x	x		x
Manganese	x	x	x		x
Mercury	x	x	x		x
Nickel	x	x	x		
Silver	x	x			
Vanadium	x	x	x		x
Zinc	x	x	x		x
PAHs					
Benzo(a)anthracene	x	x			x
Benzo(a)pyrene	x	x			x
Benzo(b)fluoranthene	x	x			x
Benzo(k)fluoranthene	x	x			x
Carbazole	x	x			x
Chrysene	x	x			x
Dibenzo(a,h)anthracene	x	x			x
Indeno(1,2,3-cd)pyrene	x	x			x
Pyrene					x

Table ES.1. (continued)

Contaminant	Medium				
	Soil	Sediment	Groundwater	Surface water	
				Base flow	Storm flow
PCBs					
Aroclor-1254	x	x			
Aroclor-1260	x	x			
Radionuclides[a]					
Cesium-134	x	x	x	x	x
Cesium-137	x	x			
Neptunium-237	x	x	x	x	x
Protactinium-233	x	x	x	x	x
Total Radium			x	x	x
Thorium-228	x	x	x	x	x
Thorium-230	x	x	x	x	x
Thorium-232	x	x	x	x	x
Uranium-234	x	x	x	x	x
Uranium-235	x	x	x	x	x
Uranium-238	x	x	x	x	x

[a]Radionuclides are included as COCs because they were not covered adequately during Phase Ia sampling and analysis.

ES.2.3.1 RI implementation and results

Data quality objectives (DQOs) were established during the initial scoping process for the EFPC RI and revised prior to Phase Ib of the RI. The DQO development generally followed the three-stage process outlined by EPA. Meetings were held in 1990 with the primary data users: Region IV EPA, TDEC, DOE, Energy Systems, and the EFPC RI team. Historical data, primarily from the Oak Ridge Task Force and the Tennessee Valley Authority (TVA) study, were reviewed, and a conceptual model was developed. The structure of a phased investigation was conceived, and the overall project objectives were established.

Both qualitative and quantitative DQOs were established for the EFPC RI. Of the PARCC parameters (precision, accuracy, representativeness, completeness, and comparability), analytical precision and accuracy were controlled by adopting EPA CLP criteria and QC frequency and types. Data verification and validation of the resulting analytical data packages ensured that the laboratories produced an acceptable quality level for results. Sampling precision was evaluated by the use of collocated samples (field replicates) and split samples (field duplicates). Representativeness of data from the EFPC RI was accomplished by selecting sampling methods and performing repetitive sampling events to accurately represent the characteristic population. Intervals for soil sampling were chosen to obtain the strata with the highest concentrations of contaminants in order to achieve the most conservative representation and to optimize the number of samples required. To achieve comparability, the EFPC RI utilized one laboratory to perform its CLP analyses and the same sampling methods for each medium. DQOs for completeness for the EFPC RI were set at 90% for the laboratory completeness for both Phase Ia and Ib. Percent completeness for field sampling was established at 90% for Phase Ia but only 70% for Phase Ib.

Data uses were identified as primary inputs into the site characterization study, the human health and ecological risk assessments, the initial screening of alternatives, the FS, and the EIS. A decision was made to obtain the highest quality data possible for critical studies. The data collection program was compiled into a sampling and analysis plan for each phase of the RI. During the design of the data collection activities for Phase Ib, assistance was obtained from the EPA-Environmental Monitoring Systems Laboratory in Las Vegas. The question of adequate sampling density/data quantity to properly characterize the floodplain was supported by EPA modeling studies using the historic data set. Procedures were adopted or written to guide field activities and data management tasks, and analytical methods were selected for each environmental sampling activity. Phase Ib relied upon neutron activation analysis (NAA), a non-CLP method, for the large-scale soil sampling of the floodplain to determine the extent and distribution of contamination. DQOs for NAA were established to meet the precision and

accuracy of CLP methods but with an exception for analytical sensitivity. The desired lower limit of detection for mercury in floodplain soils was determined to be 11 mg/kg. This limit was established to meet any potential remedial action level or risk-based need.

As discussed briefly above, the RI was conducted in two phases (Ia and Ib) from 1990 to 1992. Phase Ia of the RI involved collection of base flow surface water and sediment samples from EFPC and its tributaries to define source contributions. Storm flow samples were collected from EFPC during two flood events and from selected tributaries during one flood event. Analyses were performed for filtered and unfiltered samples to distinguish contaminants attributable to suspended particles from those in solution. Groundwater was sampled for four consecutive quarters from 22 monitoring wells. Soil samples for contaminant analyses and undisturbed geotechnical samples for soil chemistry and engineering parameters were taken from three areas of known contamination (NOAA, Bruner's Center sites, and Sturm sites). Corresponding sampling and analysis was performed for a reference site (Hinds Creek) to allow comparison with an equivalent noncontaminated site. Hinds Creek was selected as a site that possessed the same soil and bedrock types but was devoid of any contamination including urban contaminants. This was necessary to provide for a true comparison against a non-contaminated reference site without complications of municipal impacts.

Phase Ib was initiated to determine the extent and distribution of the COCs and to provide additional data to support the human health and ecological risk assessments. While the focus was on large-scale sampling of the floodplain soils, several supplementary studies also were conducted. A second round of surface water sampling at certain creek sites was performed to allow comparison of data from two different periods. Soil samples were investigated by optical and electron microscopic methods to ascertain mercury form and association. Lysimeters were installed to obtain adsorbed pore water from the unsaturated zone within the floodplain; however, recovery was insufficient to permit analysis for total or methylmercury concentrations. As a substitute, methylmercury analyses were performed on a set of soil samples taken from the study areas. The proportion of total methylmercury to total mercury in the soils averaged about 0.003% (which was in agreement with published results.) As part of the ecological study, analysis was performed of the methylmercury attributable to the suspended sediment fraction in surface water of Lake Reality. The proportion of methylmercury in the suspended sediments to total mercury in unfiltered water samples (0.008%) was equivalent to the proportion in soils.

Extensive sampling of all primary affected media was conducted along the entire length of the EFPC floodplain and the SLB. As shown in Table ES.2, the Phase Ia sampling plan specified soil, sediment, surface water, and groundwater sampling at 5 permanent creek sampling sites, 20 tributaries to EFPC, 3 primary floodplain study sites, and 2 locations on the Hinds Creek reference site. Phase Ib expanded the soil and sediment sampling by conducting soil/sediment sampling in transects across the floodplain at 100-m (330-ft) intervals. Soil samples were taken along each transect at 20-m (66-ft) spacing from the creek bank to the elevation of a 100-year flood. Surface and subsurface core samples were taken to a depth of 123 cm, with >3000 samples collected and analyzed from the 159 transects. Stream sediment samples were collected at odd-numbered transects. Every three sequential sediment samples were composited for analysis to represent 600 m of the creek. Twenty-seven sediment analyses numbered from 003 to 152 provide results for the full suite of analytes. Soil sampling along the SLB was accomplished during Phase Ib, primarily to determine the extent of contamination (contaminant types and levels were well established through the creek sampling program). The results of this extensive sampling and analysis effort along the EFPC and SLB are summarized by principal media as follows.

Soils. Of all the media, the floodplain soils have the largest volume and highest concentration of contaminants. Contamination includes a suite of inorganic metals (including mercury), a number of PAHs, PCBs, and several radionuclides (uranium and thorium). Because mercury accounts for 85% of the total toxicity, most attention was directed toward this metal. It was found to be a predictor of the occurrence of the other metals and radionuclides and was used as a surrogate to determine the distribution and extent of contamination (with the exception of the organic compounds).

As illustrated in Fig. ES.3, mercury and most other inorganic contaminants decrease significantly in the lower half of the creek, although isolated sites are present throughout with elevated concentrations. In fact, mercury and the other inorganic contaminants are situated in defined areas of the floodplain and not randomly scattered throughout its length. The creek bank within a few meters of the water has received at least some contamination along its entire length. The concentrations along the bank decrease as distance from the Y-12 Plant increases. Only four extended areas within the floodplain (NOAA site, Bruner's Center site, Sturm site, and Grand Cove Subdivision) display significantly elevated concentrations of mercury and other metals. Areas that are frequently inundated, such as upstream reaches of the creek behind culverts and roadway underpasses, also show elevated levels. Except for these areas, excessive levels found adjacent to the creek drop off drastically with distance from the creek. For the uranium isotopes,

Table ES.2. EFPC RI—media sampling by location

Sample type	Tributaries[a]			Creek stations[b]					Study sites[c]			Stream segments[d]										Ref.[e]	
	BC	CC	TA-TR	LA	LB	LC	LE	LR	NO	BR	WA	1	2	3	4	5	6	7	8	9	SLB	HC2A	HC2B
Soils									×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Sediments	×	×	x	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×	×
Surface water																							
Base flow	×	×	×[f]	×	×	×	×				×											×	×
Storm flow		×	×[g]	×	×		×																
Groundwater							×		×	×	×												
Geotechnical soils/sediments				×	×	×			×	×	×											×	×

[a]Tributaries: Major tributaries—Bear Creek (BC) and Civic Center (CC)
Minor tributaries—TA to TR (18 total)
[b]Permanent creek sampling stations: Lower East Fork LA, LB, LC, LE, and LR
[c]Floodplain study sites: NOAA (NO), Bruner's Center sites (BR), and Sturm (WA)
[d]Segments (transects): Segment 9 (transects 1-59), 8 (60-64), 7 (65-92), 6 (93-98), 5 (99-105), 4 (106-115), 3 (116-121), 2 (122-143), 1 (144-159)
[e]Hinds Creek reference site: HC2A and HC2B
[f]At tributaries TF, TJ, and TO
[g]At tributaries TF and TO

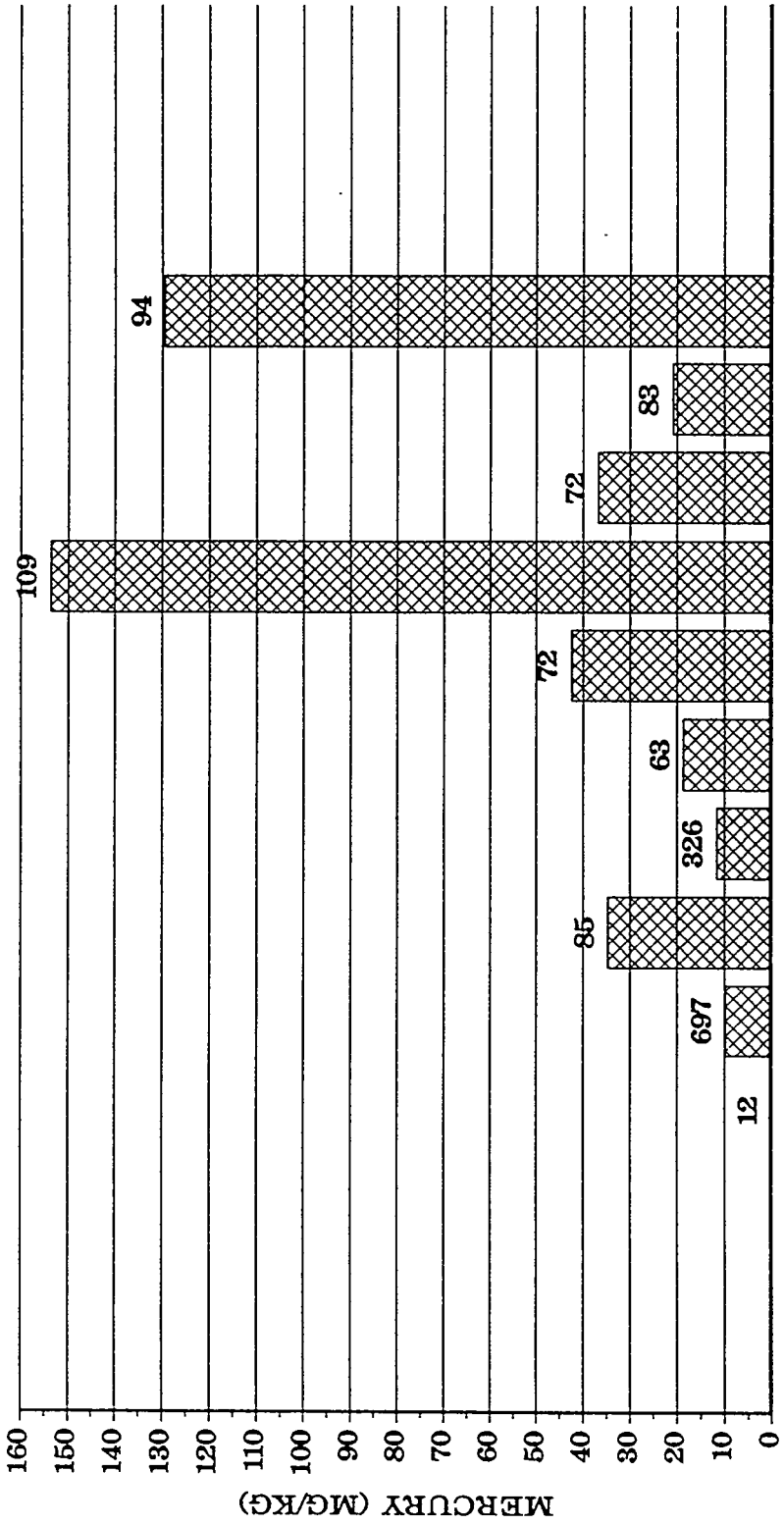

Fig. ES.3. Mean *Mercury* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

concentrations were relatively low throughout the length of the creek (see Fig. ES.4), with little discernable pattern of distribution. PCB and PAH concentrations also were found to be low (mean concentrations per segment of <2 mg/kg and <5 mg/kg, respectively). Their appearance is more general and widespread, possibly related to municipal contributions in addition to the Y-12 Plant source. Their presence is most common in the upper segments of the floodplain near commercial development and urban runoff.

Geotechnical investigations were undertaken to determine soil morphology and chemistry, hydraulic parameters for the unconsolidated zone aquifer, and relationships between particle size distribution and contaminants. The particle size distribution results revealed that mercury is fairly evenly distributed across all size fractions, not concentrated in the fine fraction as previous investigations reported (TVA 1985). As shown in Fig. ES.5, mercury levels are highest in Horizon 2 and decrease in Horizon 1, probably reflecting the decreased output of mercury into the EFPC system by the Y-12 Plant in recent years. Similarly, no relationship between uranium concentrations and particle size was apparent. The highest uranium concentrations occur in Horizons 1 and 2, with uranium highest in the fine fraction in Horizon 1 but in the coarse fraction in Horizon 3. Uranium levels for the deepest three horizons are relatively constant with particle size classes.

Even with the large number of surface and subsurface samples analyzed from the floodplain, the spatial variability was found to be significant, and little direct correlation between overall contaminant concentrations and individual sampling points could be made. To make sense of this large volume of data, a mathematical tool was used to help estimate contaminant concentrations between sampling points. The EFPC RI employed a geostatistical method that used an interpolation technique called kriging to calculate mercury concentrations for 20- $\times$ 20-m blocks. The extent of contamination was delineated by contouring mercury concentrations for 50- to 200-ppm intervals. Boundaries were interpolated between sample points by following the same topographic elevation as the sampling locations. Soil volumes were estimated for portions of the EFPC floodplain with mercury concentrations >50 and 200 ppm, using the surface area of the contoured estimates and the depth for each sampled horizon (0-41, 41-82, and 82-123 cm). A summary of these volume-estimating results is provided in Table ES.3. As can be seen from these data, volumes of soil in excess of 150,000 m^3 (5 million ft^3) are estimated to reside in the EFPC floodplain, with mercury concentrations exceeding 50 mg/kg. The volumes calculated for mercury easily bound the range of volume estimates for all other COCs.

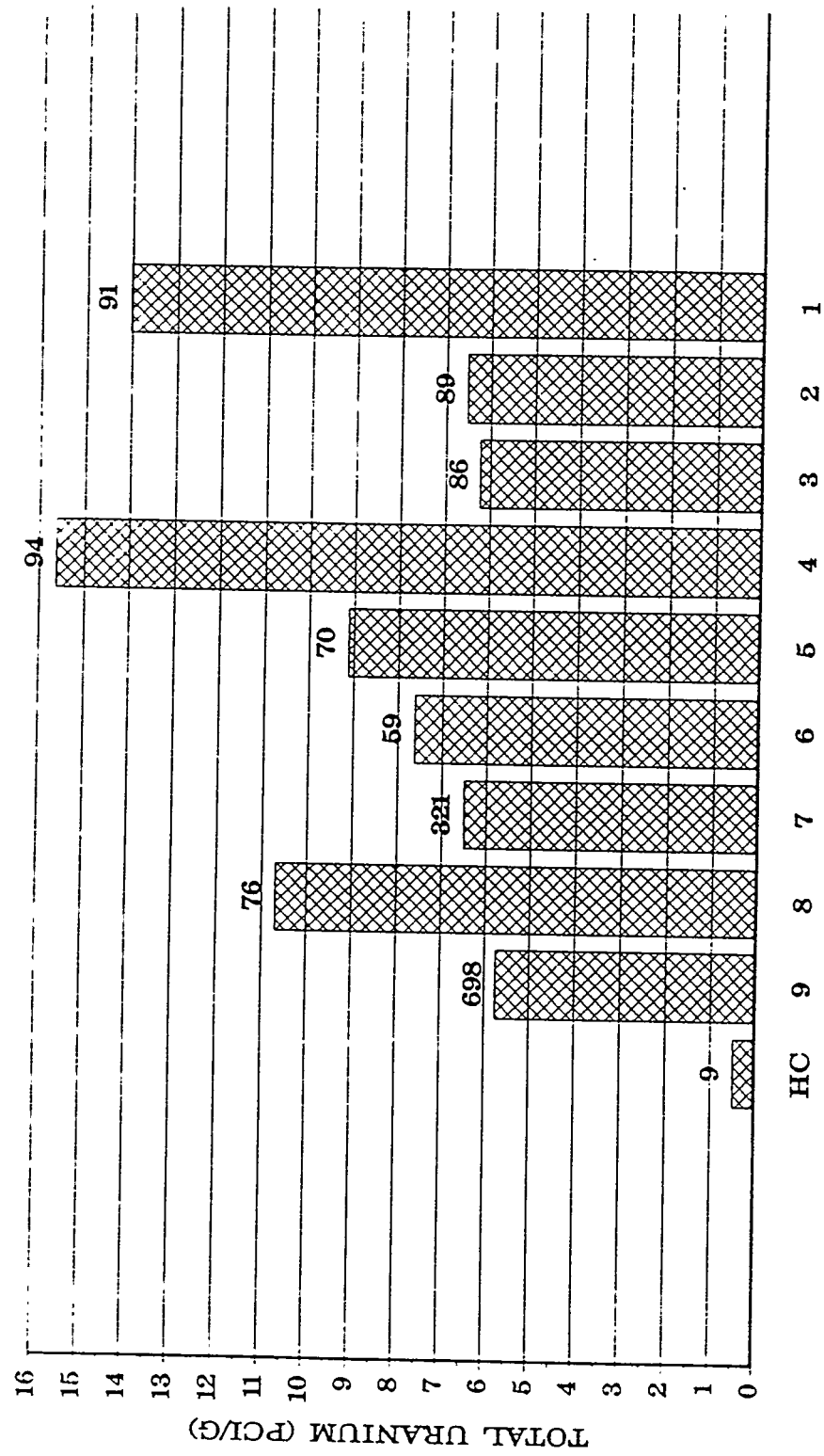

Fig. ES.4. Mean *Total Uranium* concentrations (pCi/g) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

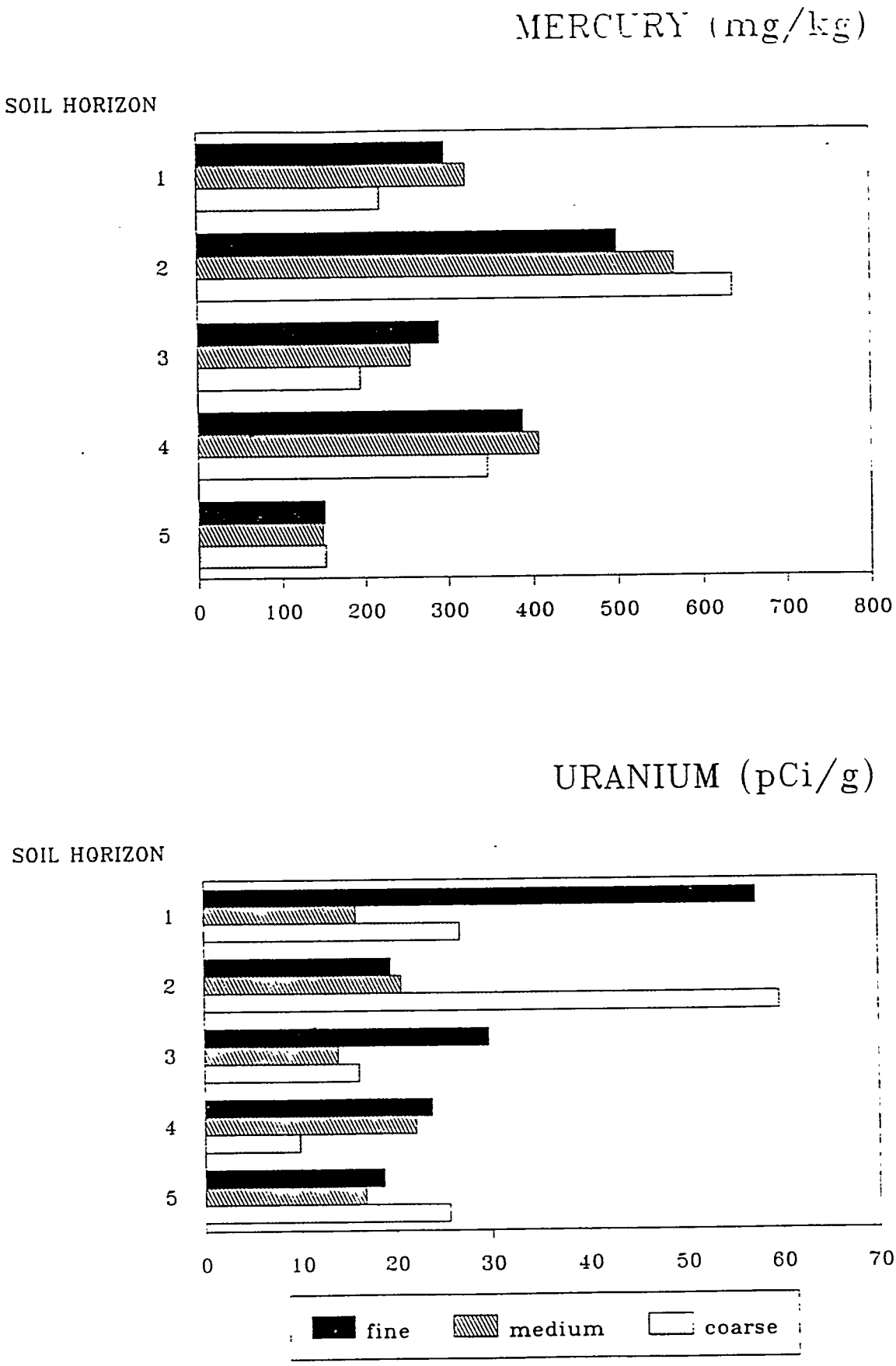

Fig. ES.5. Mean uranium activity and mercury concentrations in EFPC floodplain soils by horizon.

Table ES.3. Volumes of mercury-contaminated soils in EFPC and SLB

EFPC horizons	Soil Volume (1000 m^3)	
	≥50 ppm Hg	≥200 ppm Hg
1 (0-41 cm/0-16 in.)	123.8	23.6
2 (41-82 cm/16-32 in.)	26.4	9.6
3 (82-123 cm/32-48 in.)	0	0
Total (1000 m^3)	150.2	33.2
(1000 ft^3)	5,303.3	1,171.2

SLB areas	Length (m)			Volume[a] (m^3)
	Contaminated	Total	%	
Tulane	15	91	17%	3.5
Fairbanks	396	1615	25%	92.0
Emory Valley	823	2438	34%	191.2
Total (1000 m^3)				286
(1000 ft^3)				10,125

[a]Assumptions: depth 0.152 m (6 in.); width 1.52 m (5 ft)

Soil contamination along the SLB was found to be isolated to three principal areas (Tulane, Fairbanks, and Emory Valley Road areas). As expected, the measured contaminant types and levels were similar to the distribution found along the creek. Table ES.3 provides estimates of the contaminated soil volumes found at the three primary locations. The volumes of soil potentially requiring remediation at those sites (286 m^3) are small compared to the EFPC floodplain totals.

Sediments. As would be expected, creek sediments contain the same contaminants as floodplain soils but at lower concentrations. Because of the transient nature of sediments, the distribution of metals is not as predictable as it is for soils. The same general patterns do exist, however. The upper reaches of the creek show somewhat elevated levels of the various metals (especially mercury) compared to other sections of the creek. Figure ES.6 shows the measured mercury concentrations by transect sampling location, with most locations exhibiting < 10 mg/kg in the creek sediments. The few locations showing higher levels of mercury still had contaminant levels below the respective floodplain soils levels (see Fig. ES.3). For total uranium, sediment levels were consistently low (all < 12 pCi/g), with a less discernable pattern of contaminant location along the stream length (see Fig. ES.7). The significantly higher concentration of metals (including mercury) and uranium in the EFPC sediments compared to the tributary sediments seems to confirm a Y-12 Plant source for this in-stream contamination. The results of the PCB and PAH sampling indicate contaminant source(s) in the upper third of the creek, immediately downstream of the Y-12 Plant and along the commercial areas of Oak Ridge. The results are indicative of virtually every urban environment and do not necessarily point to the Y-12 Plant as the sole source of these low-level organic contaminants. A sampling results anomaly is observed immediately downstream of the confluence of Bear Creek and EFPC. This area displays slightly elevated concentrations of several contaminants compared to adjacent segments of the creek. This occurrence is thought to result from either the input of Bear Creek or the "pooling" of the sediments from creek back flow. Back flow of EFPC occurs when the Watts Bar Reservoir level is raised and temporary reverse flow takes place in the lower reaches of EFPC.

To determine the location and distribution of sediments within EFPC, mapping was done in the spring of 1992. Field crews walked the creek from Lake Reality to the confluence of EFPC and Poplar Creek. They identified and measured depths at locations of sediment accumulation. Many reaches of EFPC were found to be barren of sediment and have a bedrock base. The accumulations of sediments that do exist are primarily coarse-grained in nature. Apparently, the normal stream velocity and frequent storm events carry fine-grained sediments downstream to Poplar Creek. Because of the transient nature of sediments within the creek, the data derived

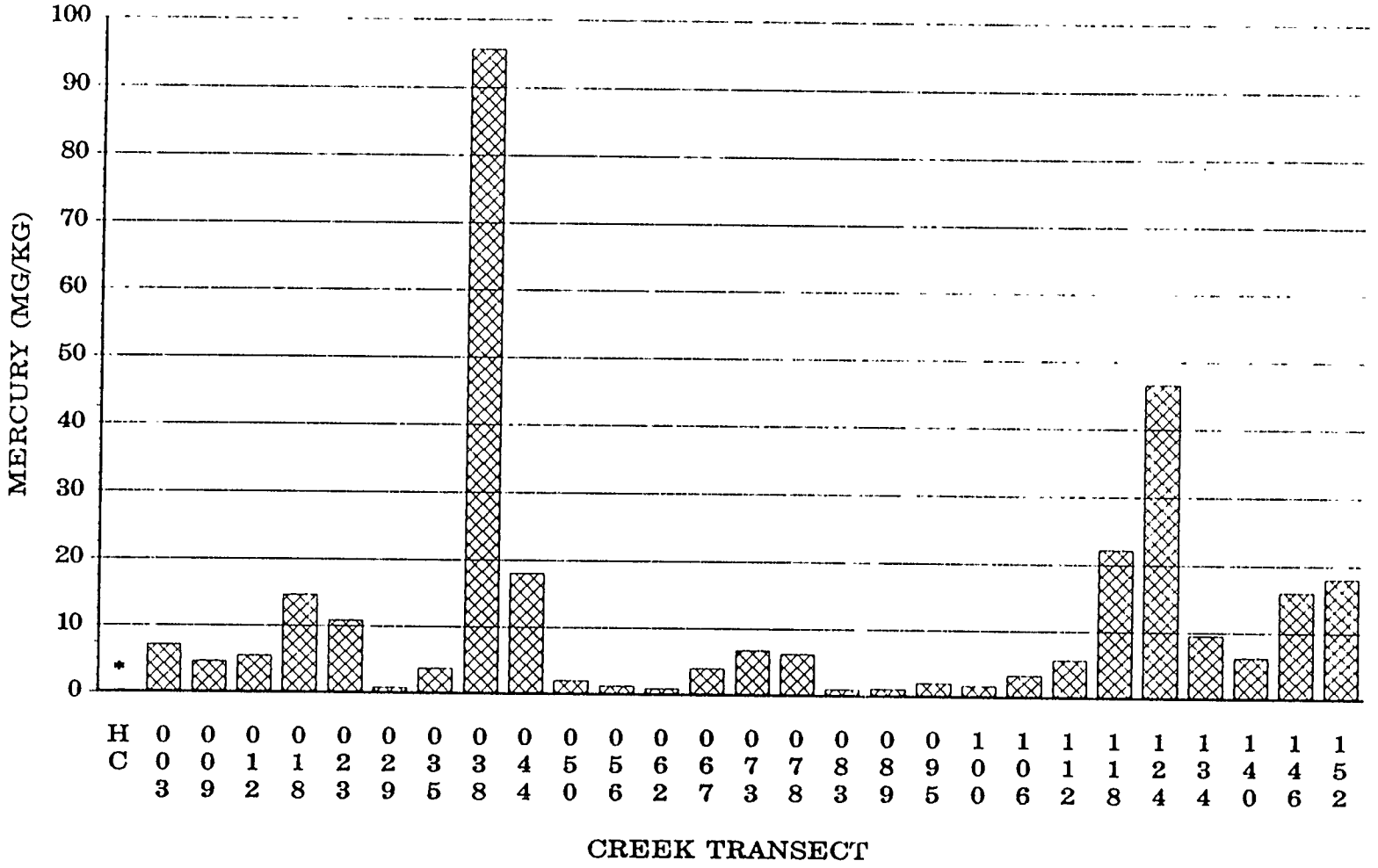

Fig. ES.6. Mercury concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

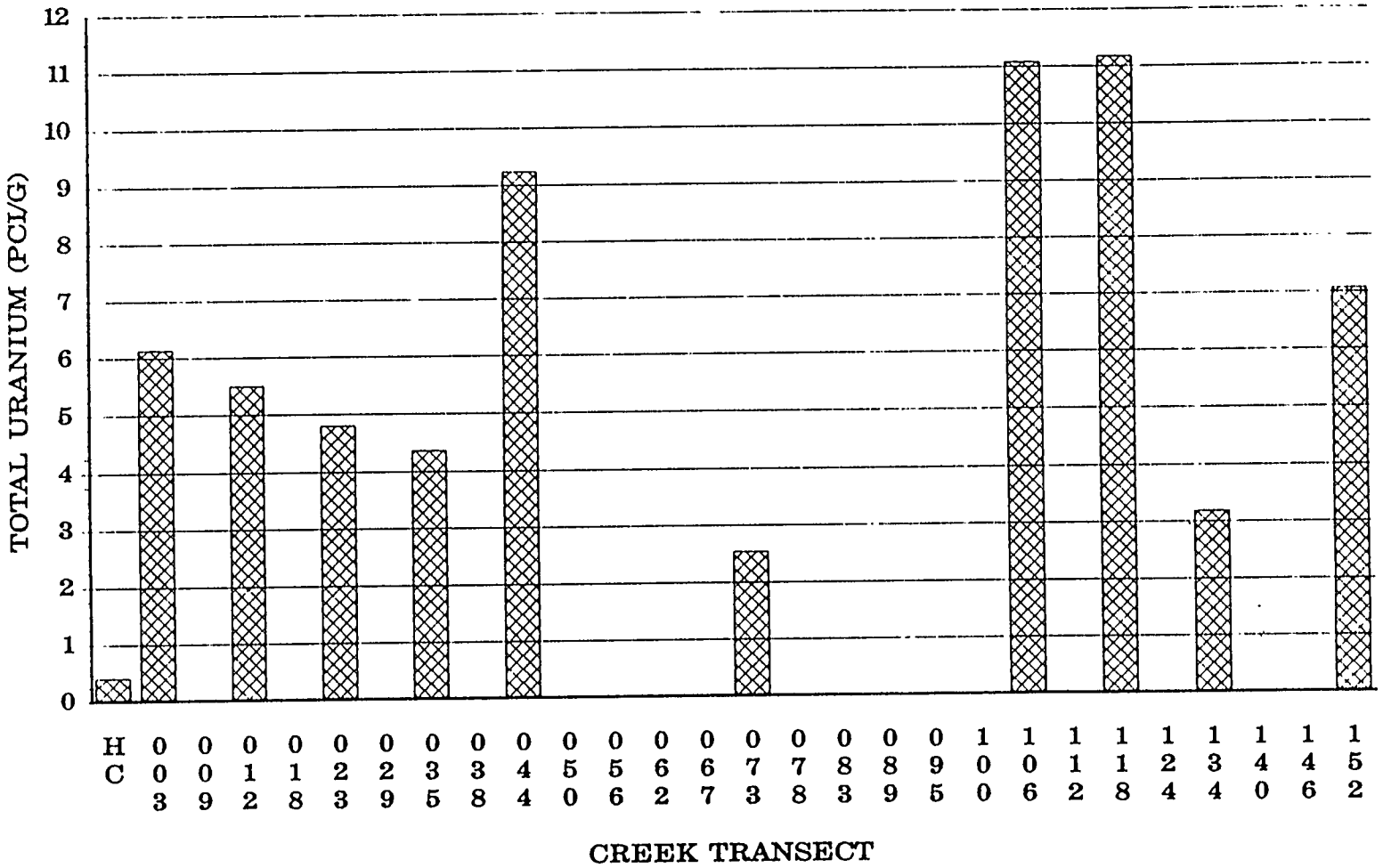

Fig. ES.7. Total uranium concentrations (pCi/g) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

from this mapping represent only a gross estimation of sediment location and thickness at a single point in time. Based on this study, an estimated 5.4×10^4 m^3 (1.9×10^6 ft^3) of sediments are present in the creek, only a portion of which would be considered contaminated based on the sampling information presented earlier.

Surface Water. Surface water was sampled under two scenarios as part of the RI, base and storm flow, to determine present contaminant source contributions to the EFPC watershed. This sampling included locations at the discharge of Lake Reality to measure Y-12 Plant input to the system, at the confluence of EFPC with Poplar Creek to measure output from the system, and at one location adjacent to an area of known high floodplain soil contaminant concentrations. Also, surface water samples were obtained for the six ecological study sites. Except for isotopic uranium and very low concentrations of mercury, no potential COCs were identified during base flow conditions at any of these creek stations. Three sites also were sampled to characterize potential runoff of pesticides, herbicides, and residual hydrocarbon products from selected residential and commercial areas of Oak Ridge. In addition, two major tributaries—an unnamed tributary (which drains a residential and commercial area near the Civic Center) and Bear Creek (which drains the western half of the Y-12 Plant site)—were sampled. Concentrations at these sites were very similar to the low values obtained for the EFPC sites.

Collection of surface water samples from three EFPC sites during two storm events and from three residential and commercial tributaries during one storm event allowed comparison of base flow and storm flow concentrations of total and dissolved contaminants. Several metals (arsenic, chromium, copper, lead, manganese, mercury, nickel, vanadium, and zinc) were detected at EFPC locations in much higher concentrations during storm flow than during base flow. Detection of no or minimal dissolved concentrations of most metals indicates primarily particle-bound transport. Total activity of uranium isotopes was observed in detectable quantities only in EFPC but it was present during both base flow and storm flow. Noteworthy by their absence in either storm or base flow, in total or dissolved concentrations, are beryllium, cadmium, and PCBs. No pesticides, herbicides, or high concentrations of heavy metals were detected in adjoining watersheds. Also noteworthy is the presence of chromium, copper, lead, vanadium, and zinc in storm flow samples at the Civic Center tributary and the absence of these contaminants at the other tributaries. This appears indicative of urban impacts on EFPC water quality.

Groundwater. Groundwater was investigated to determine whether it is a pathway for contamination migration. The conceptual model for groundwater indicates that the EFPC valley is an alluvial aquifer receiving surface water from Bear Creek Valley and recharge from the

watershed along Black Oak and East Fork ridges. Deep groundwater flow paths are not postulated to cross surface water divides. Twenty-two wells were sampled for the full suite of analytes for four consecutive quarters. In addition, water level, precipitation, and geochemical data were collected to support interpretation of the analytical results for contaminants. Four of the 22 wells were deep wells screened in the bedrock aquifer. Groundwater field parameters and analytical results were examined to define whether a shallow aquifer exists separately from an underlying bedrock aquifer. Hydrogeochemical modeling was utilized which demonstrated two findings. First, no difference could be ascertained between deep vs shallow groundwaters; therefore, no aquitard is inferred to exist between the two aquifers. Second, the geochemistry of the EFPC groundwaters is such that mercury is not likely to persist in a dissolved phase and will precipitate out, most likely, as a mercury sulfide.

Filtered and unfiltered samples were analyzed to compare total and dissolved concentrations of metals because contaminant transport in groundwater is mainly concerned with those contaminants that are found in solution under ambient pH, temperature, and other environmental conditions. As for surface water, most of the detectable concentrations of potential COCs found in groundwater were associated with total rather than dissolved analytes. Total concentrations exceeding SDWA levels were found for beryllium, copper, lead, manganese, mercury, nickel, radium, and vanadium, but only manganese, which is a common element in local groundwaters, had dissolved concentrations exceeding the SDWA levels. This association of contaminants with total analyses suggests that the particle-reactive contaminants are attached to fine-grained particles in the total sample and are not necessarily mobile in groundwater. Equilibrium geochemical modeling of the analytical results from the groundwater monitoring wells using MINTEQA2 (EPA 1987) supported the contention that mercury concentrations measured in groundwater samples are related to particulate-bound mercury. A survey was conducted to ascertain the use of groundwater as a potable water supply. No wells are located within the floodplain, and groundwater is not being used as a water source.

Biomonitoring. A number of historical and ongoing studies, especially the Biological Monitoring and Abatement Program (BMAP), have measured population densities and contaminant body burdens within the aquatic and terrestrial biota of the EFPC watershed. In general, these studies have found elevated levels of mercury and PCBs in fish, with the highest concentrations in the upper reaches of EFPC nearest the Y-12 Plant. Relative abundance estimates of fish collected in the creek indicated that greater densities were present in the upper reaches of the stream, in the area most accessible to the public and also where the highest

contaminant concentrations were observed. Other related studies of garden plots and mice populations have added to the accumulating knowledge of heavy metal (particularly mercury) interactions in the environment. This information base was the starting point for the comprehensive EFPC ecological risk assessment performed for the RI. Further discussion of the scope and results of that assessment is provided in subsequent sections of this Executive Summary.

Air Pathway. Atmospheric contaminant concentrations occurring in the general environment around the ORR and the surrounding region are monitored or sampled continuously by an air monitoring network. Measurements of air concentrations of 15 radioactive parameters, fluorides, sulfur dioxides, total suspended particulates, and mercury indicate that the ORR operations are not measurably impacting the regional air quality (including the EFPC floodplain). Ambient air monitoring of EFPC-specific locations for mercury also has been conducted by ORNL researchers at sites selected for known high mercury soil concentrations. This monitoring included both high-sensitivity and high-volume measurements. Concentrations were at levels similar to those at an uncontaminated reference site, indicating that mercury volatilization cannot be distinguished from background levels.

Direct Radiation. Historically, most of the large-area radiation survey information on the ORR and in the surrounding area has been provided by the Aerial Measuring System, an aerial radiological surveillance capability maintained by DOE. The most recent Aerial Measuring System survey of the EFPC watershed was conducted during the period of March-April 1992. Measurements were made from a helicopter at an altitude of 46 m (150 ft) and calibrated to terrestrial exposure rates at 1 m above ground level. Gross gamma counts were recorded to determine the ground level exposure rates and spectral windows were used for photopeak count rates to identify specific man-made radionuclides. While the majority of the floodplain measurements were less than the background level of 13 μR/h, one site was identified with rates between 13-20 μR/h. This site correlates with an area of known contamination (Bruner's Center sites) but is not statistically different from background, given the measurement error inherent in the method.

ES.2.3.2 Data quality assessment

A primary goal of the EFPC quality assurance (QA) program is to ensure that the results of analysis of all environmental samples are fit for their intended use. To this end, a QA Program Plan, a QA Project Plan, and field procedures were compiled to guide the investigation. Audits and surveillances were conducted to determine the adequacy of field and laboratory performance

against the QA plan and procedures. For the project as a whole, there have been 85 surveillances performed covering field activities as well as procedural activities such as training and document review. In total, 564 nonconformance reports (NCRs) were written concerning quality deficiencies, and all but a few (which do not affect data use) have been resolved.

Analytical data generated under this project have been subjected to a rigorous process of data verification, validation, and review. Upon receipt of data reports from the laboratory data, the verification staff performed a systematic examination of the reports following standardized data checklists to ensure the content, presentation, and administrative validity of the data. Discrepancies identified during this process were recorded and documented utilizing the QA Program NCR system.

During the data validation phase, data were subjected to a systematic technical review by examining all analytical QC results and laboratory documentation, following the appropriate functional guidelines for laboratory data validation. The primary objective of this phase was to assess and summarize the quality and reliability of the data for the intended use and to document factors which may affect the usability of the data. As an end result of this phase of the review, data were qualified based on the technical assessment of the evaluation criteria. Qualifiers were generated for each analytical result to indicate the usability of the data for intended uses. For the overall purposes of this investigation, however, data were either accepted or rejected as meeting Level IV quality requirements. With certain exceptions (such as defining the extent of contamination), data from this RI have been designed to meet the highest qualification for their intended use in the human health risk assessment.

To date, procedures for radiological analyses and procedures for radiological data validation have not been firmly established in the same manner as with the inorganic/organic analyses under CLP. EFPC radiochemical analyses data were validated using "Laboratory Data Validation Guidelines For Evaluating Radionuclide Analyses" (SAIC, Rev 4, 1992) and "Laboratory Data Validation Guidelines For Evaluating Neutron Activation Analyses" (SAIC, Rev 2, 1992). These documents were developed with the intent to provide data validation guidelines for radioanalytical data equivalent to those provided by EPA under CLP guidance. These documents provide a systematic process for reviewing the data against the DQOs to provide assurance that the data are adequate for their intended use.

On a project-wide basis, 96% of the data were accepted as usable based on the formal validation process. Of the major analytical groupings, only the toxicity characteristic leaching procedure (TCLP) and NAA have overall rejection rates exceeding 10%. NAA provided

acceptable data for 89% of the analyses, while TCLP provided 82%. Specific analytes that were below the 90% level included:

Anions	- Sulfide (68%)
NAA	- Antimony (87%) - Arsenic (69%)
Semivolatiles	- 2,4-Dinitrophenol (89%)
TCLP	- phenols (25%) - other organics (66-75%) - silver (85%)

None of the above analytes were considered critical to the investigation. Sulfide was part of the water analyses and not a COC. A large number of antimony and arsenic results (including CLP analyses) are available for soils, even given an 87% and 69% acceptance rate with NAA. The single semivolatile organic compound listed above is only one of several phenols and was not a COC. The organics from the TCLP samples were not compounds of particular interest. In summary, only a very limited number of analyses did not meet the laboratory objective, and no assessments for the investigation were restricted due to lack of data.

Overall, precision for soils analysis as well as water analysis is considered adequate for the EFPC project. Accuracy on a project-wide basis was deemed acceptable for both CLP analysis and NAA. While some of the data were qualified as usable but estimated, or unusable due to poor matrix spike recoveries, the accepted data are sufficient for use by all phases of the project.

The radiological isotopes of most interest were the uranium series. From the combined use of NAA and alpha spectroscopy, large amounts of uranium data are available for these isotopes. Of all the radiological results, thorium was the most disappointing, with $<50\%$ of the analyses validated as usable data. However, the available results do not indicate that a problem exists, and additional thorium results were not required. Moreover, thorium should accumulate in the same general area as uranium; therefore, uranium can act as a surrogate for remedial decisions concerning thorium.

The number of samples taken for analysis to characterize the primary media within the EFPC OU are summarized as follows:

Medium	No. samples
groundwater	159
surface water	77
floodplain soils	4181
creek sediments	195
miscellaneous	111
TOTAL	4723

ES.3 RISK ASSESSMENT

Using the data collected during Phases Ia and Ib of the RI, a risk assessment was performed to characterize the current and potential risks to human health and the environment that may be posed by contaminants released to and/or migrating within environmental media. The overall objective of risk assessment is to provide risk-based information for deciding whether remediation of EFPC is needed because of potential threats to human health or the environment. The risk assessment was performed and is presented in two parts: a human health risk assessment and an ecological risk assessment.

ES.3.1 Human Health Risk Assessment

The risk assessment process uses concentrations of COCs measured in environmental media to predict what individuals might be exposed to under current and future land use scenarios if the EFPC site were not remediated.

To estimate concentrations of COCs, the data quality is first evaluated, and those data that were rejected during the data validation process are excluded from use for the risk assessment. During this step, **data collection and evaluation**, data are examined to determine whether they are of sufficient quality for use in the risk assessment. Those that are not are excluded from further consideration. Next, concentrations of COCs are summarized by calculating the mean and upper 95% confidence limit of the mean (UCL) for each current and future land use type for each medium.

These summary statistics, mean and UCL, are then used to estimate individual exposures. This **exposure assessment** is the second step in the risk assessment process. During this phase, assumptions are made on the amount of the COCs that an individual is exposed to, the duration of the exposure, and the frequency of exposure for each pathway.

The next step, **toxicity or hazard assessment**, looks at the capacity of the COC for causing cancer or other adverse effects in laboratory animals and in humans. Hazard identification is a qualitative description based on factors such as the kind and quality of data on humans or laboratory animals and availability of ancillary information from other studies. During this phase, dose-response relationships are considered with respect to extrapolation from laboratory studies to humans and uncertainty in the data. Many of these data come from the EPA Integrated Risk Information System (IRIS), a data base that represents EPA consensus on specific chemicals.

The final step, **risk characterization**, integrates conclusions about hazard and dose response with those from the exposure assessment. In addition, confidence about these conclusions, including information about the uncertainties associated with the final risk summary, is highlighted.

ES.3.1.1 Data collection and evaluation

Concentrations of potential COCs were aggregated and statistically manipulated to derive a meaningful estimate of the exposure point concentrations. In human health risk assessment, the exposure point concentration is most commonly an estimate of lifetime average daily intake or dose. Following EPA guidance, the lifetime average daily intake or dose was calculated based on two summary statistics for concentrations of COCs in environmental media: (1) the arithmetic mean and (2) the UCL. Both of these statistics are required by EPA for exposure estimates. The mean is also referred to as the most likely exposure (MLE) estimate. The UCL is referred to as a reasonable maximum exposure (RME) estimate and is defined by EPA as "the highest exposure that could reasonably be expected to occur for a given exposure pathway at a site."

MLE and RME estimates are calculated for an "exposure unit," which is a geographic area within which a receptor would realistically be expected to spatially and temporally aggregate exposure to contaminants. For this reason, two different methods were used for summarizing concentrations of COCs: one for surface water, groundwater, and sediments, and a second one for floodplain soils.

For surface water, groundwater, and sediments, all validated data from the entire length of the creek were summarized by a single mean and UCL for each COC and media. The decision to use this approach was made with the consensus of EPA Region IV, DOE, and Martin Marietta Energy Systems, Inc. Central Risk Assessment Council. This aggregation was used because the receptor (a resident near EFPC) is free to wander the creek and may be exposed to surface water and sediments at any location along the stream. The groundwater is viewed as an interconnected system with no one currently using groundwater as a source of drinking water.

Rather than summarizing soil data of concentrations of potential COCs along the entire creek, the floodplain was divided into nine segments based on an understanding of the nature and extent of the contamination and a knowledge of current and projected future land uses. Summary statistics (mean and UCL) were calculated for each COC in soil by segment.

The SLB was divided into three segments based on high levels of mercury contamination. COCs were summarized for each of these three segments and for the open land use scenario, as it was the only one applicable for these three segments. The risk assessment for the SLB, which is not yet complete, will be included in the next draft of this report.

ES.3.1.2 Exposure assessment

The purpose of the exposure assessment is to identify the receptors at potential risk from contact with contaminants, to determine the exposure pathways of importance, and to quantify intake, or dose, for all contaminants and pathways of concern. The exposure scenarios for the EFPC BRA, based on land use type, include (1) current and future exposure in the agricultural setting, (2) current and future exposure to residential populations, (3) current and future exposure in the commercial setting, and (4) current and future exposure resulting from occasional use of open land. The receptor groups at greatest risk of exposure were assumed to be children and adults who reside in the community along EFPC. For each exposure scenario and receptor group, the intensity, duration, and frequency of exposure were characterized. Because of the difficulty in realistically quantifying human exposure, the exposure evaluations were based on a series of point estimates using both RME and MLE values. EPA Region IV requested that RME values, which purposely overestimate the exposure in an actual population, be used as the principal basis for risk estimates for the EFPC BRA. Although the RME estimate is not a "worst case scenario," because the RME is not used for all input variables, maximizing several of the input variables will result in an estimate that may be above actual values seen in the population. Because these exposure point estimates (MLE and RME) do not adequately describe the

uncertainty associated with the risk estimates, Monte Carlo simulations were used to generate probabilistic estimates that resulted in a risk distribution rather than a single point estimate.

Current and future exposure pathways for residential receptors are

- dermal exposure to surface water while swimming,
- dermal exposure to surface water while wading,
- incidental ingestion of surface water while swimming,
- dermal exposure to sediments while wading,
- dermal exposure to soil,
- incidental ingestion of soil,
- ingestion of homegrown produce, and
- ingestion of recreationally caught fish.

Current and future exposure pathways for the agricultural setting include those identified for residential exposure plus

- ingestion of home-raised beef,
- ingestion of home-produced milk (future exposure only),
- ingestion of groundwater and inhalation of groundwater vapors (future exposure only), and
- inhalation of particulates while mowing.

Risks to both children and adults were assessed for both the current and future exposure scenarios. Two age groups of children were assessed: 3 to 12 years for RME and 6 to 9 years for MLE.

The open land use scenario is designed to account for occasional exposure to EFPC soils, surface water, and sediment by individuals who are not residents of the EFPC community. Exposure to both children and adults was assessed, with the assessment of children focusing on ages 9 to 19 for the RME and on ages 12 to 15 for the MLE. For children, exposure pathways included only the first six pathways identified above for residential receptors and were of shorter durations and lesser frequencies than for adults.

Because commercial zones are now built on paved areas a distance from the creek and are located outside the floodplain, the exposure assessment assumed no exposure of commercial receptors to contaminants under the current land use scenario. Because commercial exposure is limited to future use of groundwater by the business community, the only pathway evaluated was ingestion of groundwater by adult receptors. This is an overly conservative assumption because

the availability of municipal water makes it unlikely that groundwater will be a source of drinking water, either now or in the future.

Ideally, exposure factors should be derived from estimates of site-specific activities and behavior patterns of receptor groups at potential risk of exposure. Because of the size of EFPC, such information has not been developed for the EFPC BRA and could be meaningfully developed only through a large-scale survey of Oak Ridge residents. In the absence of such data, EPA guidance was used whenever possible in selecting or deriving values for exposure variables. The principal sources of information used are *Superfund Exposure Assessment Manual* (EPA 1988), *Exposure Factors Handbook* (EPA 1989b), *Risk Assessment Guidance for Superfund: Human Health Evaluation Manual* (EPA 1989a), *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors* (EPA 1991), and *Dermal Exposure Assessment: Principles and Applications* (EPA 1992a). Exposure factors for adults were assumed to remain relatively constant over the duration of exposure. However, because exposure factors vary as children grow to adulthood, weighted-averaged values were used to characterize RME and MLE for children over a specified period of time.

To estimate uncertainty in the exposure assessment, a probabilistic method employing Monte Carlo simulation was used. Exposure variables were characterized by probability density functions that reflect the inherent variability in the exposure factors. In looking at the probability density functions for the exposure variables, it is apparent that the RME point estimates are generally quite conservative and fall in the upper tail (>95%) of the probability distribution. This is expected given the desire of the regulatory agencies (in light of the inherent variability and uncertainty in risk assessment) to err on the side of protection of human health.

ES.3.1.3 Toxicity or hazard assessment

Toxicity assessment involves evaluating the inherent toxicity of the COCs and identifying and selecting toxicological measures for use in estimating risk to receptors. Because the BRA for EFPC required the evaluation of both hazardous and radiological releases, toxicity measures were selected for both chemical compounds and radionuclides. The toxicity measures used for chemical compounds are

- RfDs for oral exposure -- acceptable intake values for subchronic and chronic exposure (noncarcinogenic effects),
- reference concentrations (RfCs) for inhalation exposure -- acceptable intake values for subchronic and chronic exposure (noncarcinogenic effects),

- carcinogenic slope factors for oral exposure, and
- carcinogenic slope factors for the inhalation route.

EPA derives RfDs for noncarcinogens from estimates of the no-observable-adverse-effect level or lowest-observable-adverse-effect level in humans or test animals. The inhalation RfC is also derived from the no-observable-adverse-effect level, but requires conversion of the levels observed in animals to human equivalent concentrations before data sets and effects levels can be evaluated and compared.

The assessment of the potential for noncarcinogenic effects (i.e., the use of RfDs and RfCs to assess risk) is based on the assumption of a threshold below which health effects are not expected to occur. Carcinogenesis, however, is thought to be a phenomenon for which the presumption of threshold effects is inappropriate (EPA 1989a). Therefore, rather than estimate an effects threshold for these chemicals, EPA first assigns a weight-of-evidence classification and then calculates its cancer potency, or slope factor. Weight-of-evidence classifications include (1) human carcinogen, (2) probable human carcinogen based on availability of limited human data, (3) probable human carcinogen based on availability of sufficient data in animals but inadequate or no data for humans, (4) possible human carcinogen, (5) not classifiable as to human carcinogenicity, and (6) evidence of noncarcinogenicity for humans. EPA develops a cancer slope factor, which is a plausible upper-bound estimate of the slope of the dose-response curve in the low dose range, for all chemical compounds that have been classified as definite, probable, or possible human carcinogens.

EPA has not developed RfDs or slope factors for dermal exposure. In the absence of these factors, the toxicity measures for oral exposure were used in the EFPC BRA to calculate dermal exposure, as recommended by EPA (EPA 1992a). Information for identifying and selecting toxicity measures was obtained from the two sources recommended by EPA, IRIS, and Health Effects Assessment Summary Tables (HEAST), with priority given to IRIS. Toxicity measures used for all COCs and the toxicological information used to select those measures are provided in the BRA.

Unfortunately, EPA has no oral and inhalation RfDs for mercury (EPA 1992b). EPA is currently evaluating the potential noncarcinogenic effects of mercury and has, in the interim, published a tentative oral RfD of 0.0003 mg/kg (ppm) per day for inorganic mercury based on the effects of mercuric chloride in rats. Because mercury is the primary COC at EFPC, information on the physicochemical properties of mercury was considered crucial to estimating more accurately the intrinsic public health and environmental hazards posed by mercury

contamination. During the RI, chemical analysis of the soil samples collected from the floodplain indicated that mercury was predominantly present in an insoluble form, probably as mercuric sulfide (Revis et al. 1989). Because the toxicity of mercury closely parallels its solubility in the aqueous media and because the existing RfD for mercury is based on the toxicities of mercuric chloride, which is a highly soluble form of mercury, a detailed examination of the toxicity of inorganic mercurial species was considered necessary to evaluate the toxicities of mercury contamination at EFPC.

Science Applications International Corporation (SAIC) and ORNL worked together to review and evaluate the available toxicity information for mercury to determine whether sufficient data were available to reassess the inherent toxicity of inorganic mercury species and, ultimately, to derive alternate RfDs. Instead of a single RfD for all inorganic species of mercury, SAIC and ORNL derived an alternative RfD for mercuric chloride as a typical *soluble* inorganic species and for mercuric sulfide as a typical *insoluble* form of mercury. The resulting RfDs derived by SAIC and ORNL were 0.001 mg/kg (ppm) per day for a chronic oral RfD for soluble inorganic mercuric species and 0.04 mg/kg (ppm) per day for the insoluble mercuric sulfide. However, after discussion with EPA Region IV, SAIC agreed that no alternate RfDs would be used without the approval of EPA's Office of Research and Development. Thus, although the alternate RfDs are presented in this report for review, the RfD of 0.0003 mg/kg (ppm) per day currently found in HEAST was used for the EFPC BRA.

The use of toxicity values that are based on a number of variable studies, which differ greatly from realistic situations, introduces a major source of uncertainty in the risk assessment process. Derivation of the toxicity values must take into account such differences as using dose-response information from animal studies to predict effects in humans, using dose-response information from high doses to predict adverse health effects from low doses, using data from short-term studies to predict chronic effects, and extrapolating from specific to general populations.

ES.3.1.4 Risk characterization

Risk characterization integrates the results of the exposure and toxicity assessments by combining estimates of dose with appropriate toxicity measures to determine the likelihood of adverse effects in exposed populations. Risks are calculated for each chemical or radionuclide, for each pathway, for each receptor group (adults and children), each current land use scenario, and each future land use scenario. These individual risks are then summed over chemicals or radionuclides and pathways to obtain a total risk for each receptor group and for current and future land use scenarios. These total risks are calculated differently for each of three

contaminant types: (1) chemical carcinogens; (2) chemical noncarcinogens; and (3) radionuclide carcinogens. For each of these contaminant types there is a different equation for estimating risk, but all integrate the exposure and toxicity assessments. Table ES.4 identifies each of these measures of risk, their exposure and toxicity measures, and the equation for calculating risk for an individual contaminant and for the total risk. It also indicates EPA's target risk levels for each of the three risk measures. In this risk assessment, risks were summed across all plausible exposure routes for the receptor groups under evaluation. This may result in an overestimation of likely exposures, because it is unlikely that all possible exposures would converge on an individual receptor. The combined exposure risk estimates may be highly conservative because they are simple combinations of the risk estimates from all pathways to a single receptor.

A tiered approach to risk characterization was implemented, beginning early in the RI process. The first tier was a screening-level deterministic risk assessment using data from Phase Ia from the known areas of high mercury contamination. This was performed to estimate the magnitude of potential risks, assist in the identification of pathways of importance, and refine COCs. The second tier was a deterministic risk assessment using all valid data. The final tier was a probabilistic risk assessment and quantitative uncertainty analysis using Monte Carlo simulations. Because the first tier was only useful during the early stages of the RI and is essentially a subset of the Tier II analysis, it will not be discussed here.

Tier II. Results of the Tier II assessment are shown in Figs. ES.8 through ES.19. These maps show the total risk using both the MLE and the RME for all contaminants and pathways for each of the three measures of risk, for each receptor group (adult and child), for both current and future land use scenarios, within each of the nine EFPC segments. Based on these results several patterns are evident. For adults and children in both the current and future land use scenarios, the excess cancer risk due to radionuclides either is below or falls within the EPA target cancer risk range of 10^{-6} to 10^{-4}. For the other two risk measures, excess cancer risk from chemicals and the hazard index (HI) for chemical noncarcinogens, the risk outcome (within EPA targets) for the adult and child are similar, except that there is no risk estimate for children in commercial land use areas. Although the outcomes are the same for adults and children, the magnitude of the risk measures varies. From this summary, one can then focus on the risk results for the adult (with more scenarios), current and future land use, and the risk estimates for chemicals (Figs. ES.8 - ES.11) as opposed to radionuclides.

For the adult current land use scenario, the HI is below EPA targets for the majority of the 670 acres. There are four areas (shown in Fig. ES.8)—three residential areas in Segments 3, 6, and 8 and one agricultural land use area in Segment 7 where the HI is > 1. In all cases, the

Table ES.4. Risk measures and equations for risk

Contaminant type	Risk measure	Exposure measure	Toxicity measure	Individual contaminant risk equation	Total risk	EPA guidance on acceptable risk
Chemical carcinogens	Upper bound estimate of excess lifetime cancer risk to an individual	CDI - chronic daily dose averaged over a 70-year period (CDI = chronic daily intake)	CSF = 95% upper bound estimate of slope of dose-response relationship (CSF = cancer slope factor)	$Risk_i = CDI \times CSF$ i = chemical	$\sum_{i=1}^{n} \sum_{j=1}^{p} Risk_{ij}$ where i = chemical j = pathway	$Risk \leq 10^{-6}$ or $10^{-6} \leq Risk \leq 10^{-4}$
Chemical noncarcinogens	HQ = hazard quotient: potential for adverse noncarcinogenic effects	CDI = chronic daily dose averaged over the exposure period	RfD = acceptable daily intake for subchronic and chronic oral exposure or RfC = acceptable daily intake for subchronic and chronic inhalation exposure	HQ = CDI/RfD HQ = CDI/RfC	$HI = \sum_{i=1}^{n} HQ_i$ i = chemical (HI = hazard index)	HI < 1
Radionuclides (all carcinogens)	Excess lifetime cancer risk to an individual	IR = daily intake rate and EF = exposure days per year	SF = age- and sex-specific coefficients for individual organs receiving radiation doses combined with organ-specific dose conversion factor (SF = slope factor)	$Risk_i =$ C × IR × EF × SF where C= concentration i = radionuclide	$\sum_{i=1}^{n} \sum_{j=1}^{p} Risk_{ij}$ where i = radionuclide j = pathway	$Risk \leq 10^{-6}$ or $10^{-6} \leq Risk \leq 10^{-4}$

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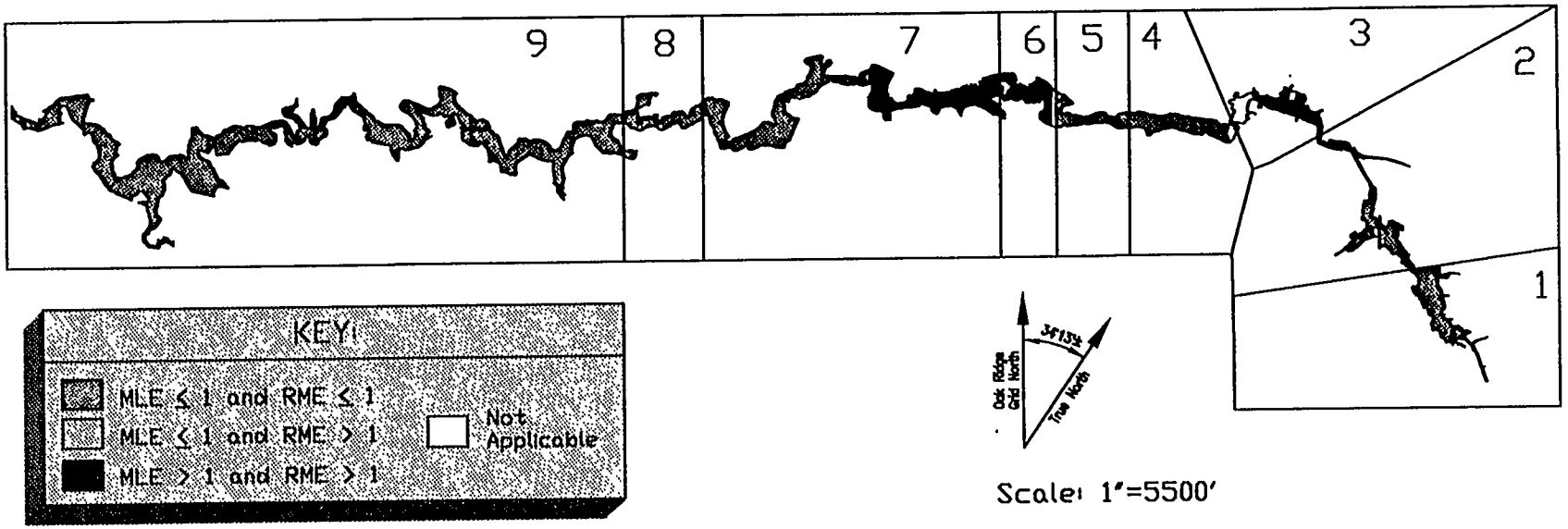

MLE = Most likely exposure estimate (mean)
RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

Fig. ES.8 Hazard index for noncarcinogens for adults under current land use scenario.

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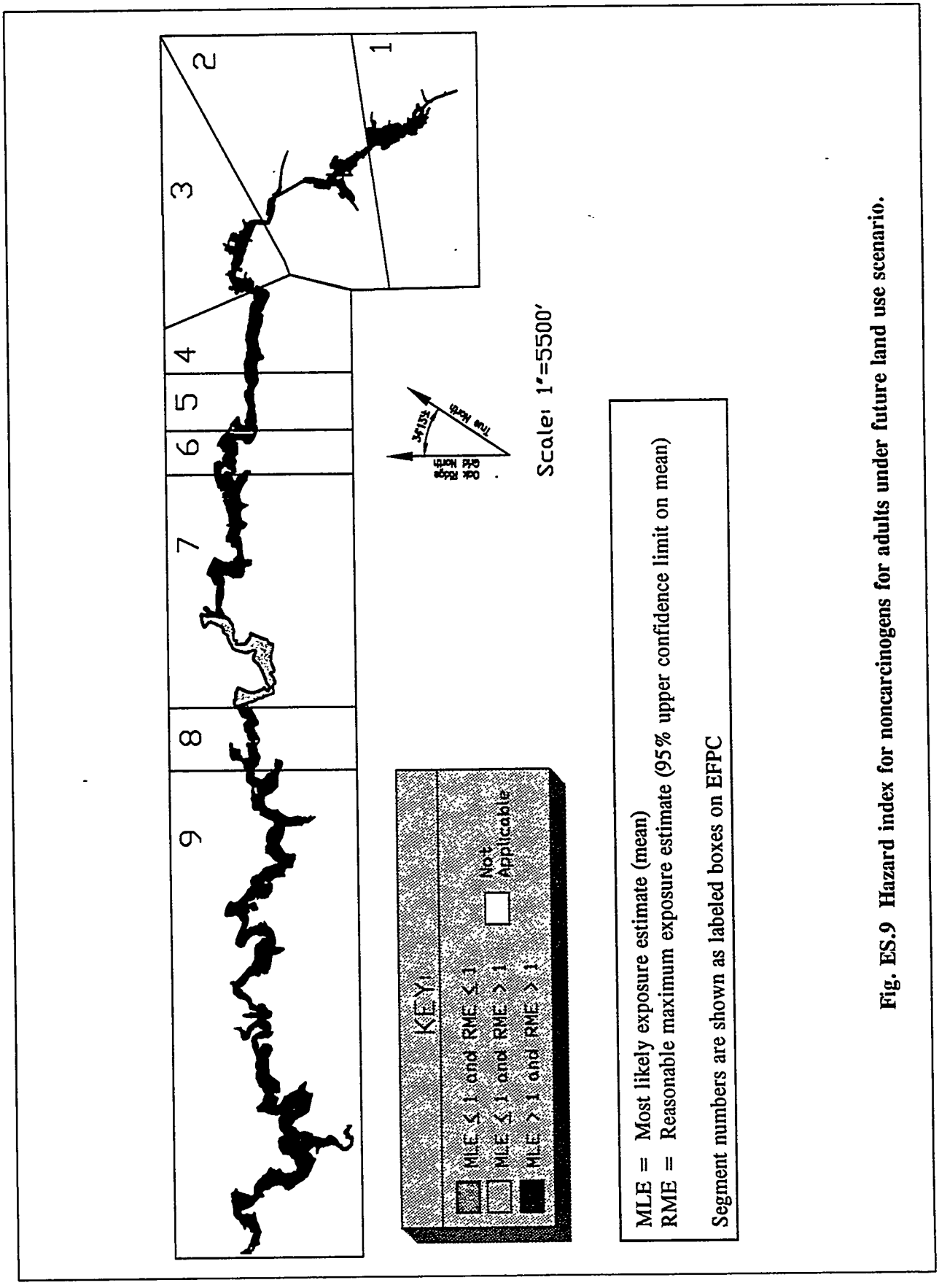

Fig. ES.9 Hazard index for noncarcinogens for adults under future land use scenario.

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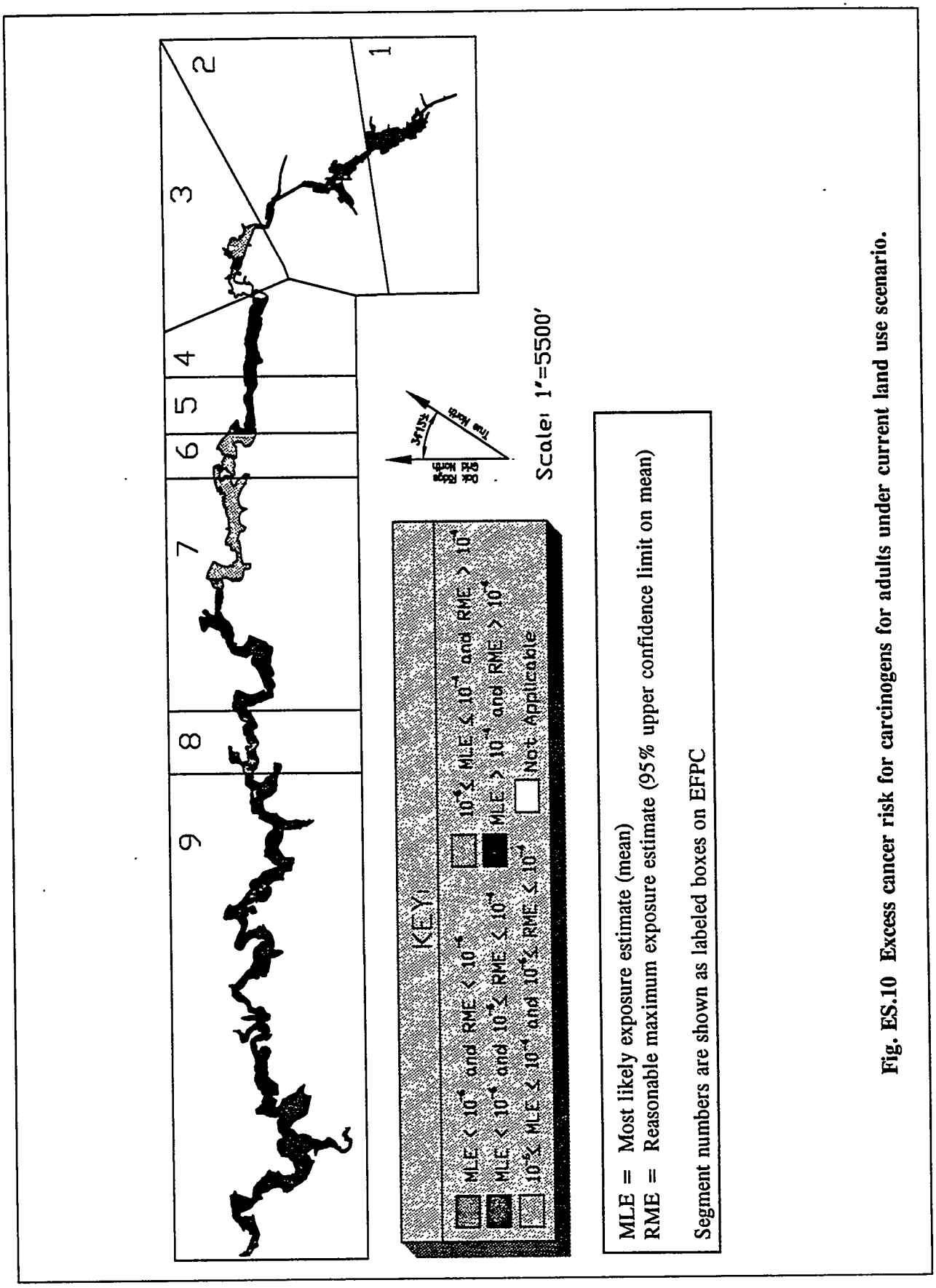

Fig. ES.10 Excess cancer risk for carcinogens for adults under current land use scenario.

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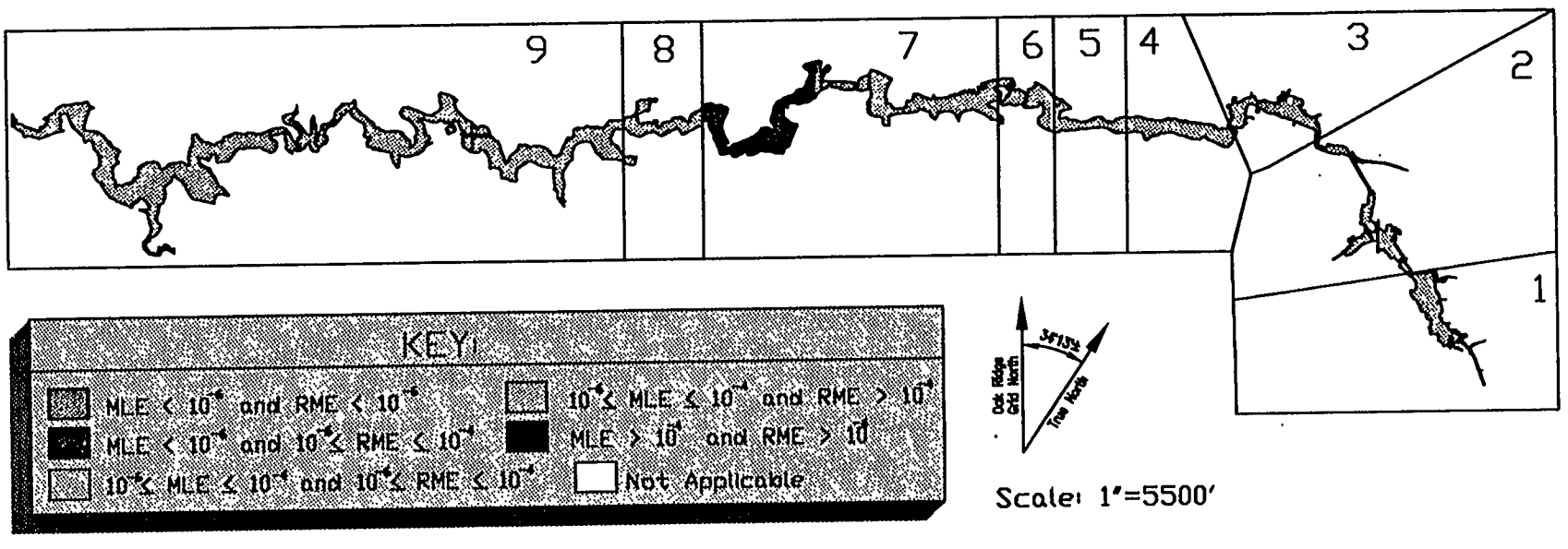

MLE = Most likely exposure estimate (mean)
RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

Fig. ES.11 Excess cancer risk for carcinogens for adults under future land use scenario.

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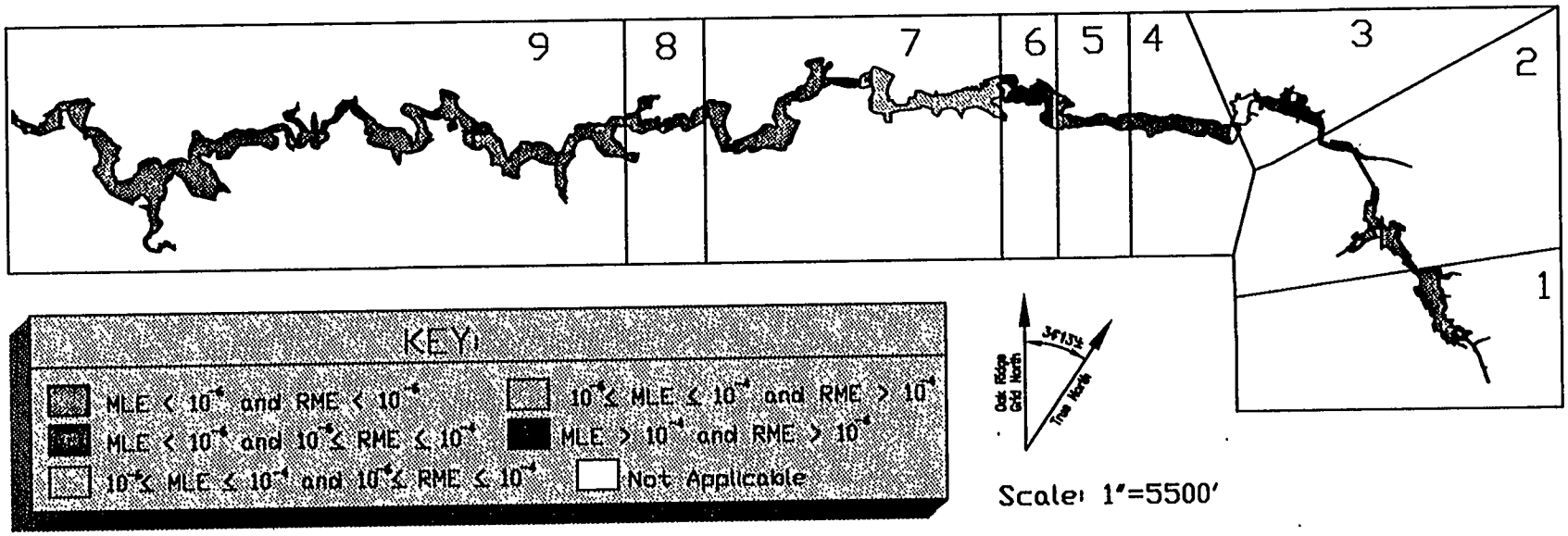

MLE = Most likely exposure estimate (mean)
RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

Fig. ES.12 Excess cancer risk for radionuclides for adults under current land use scenario.

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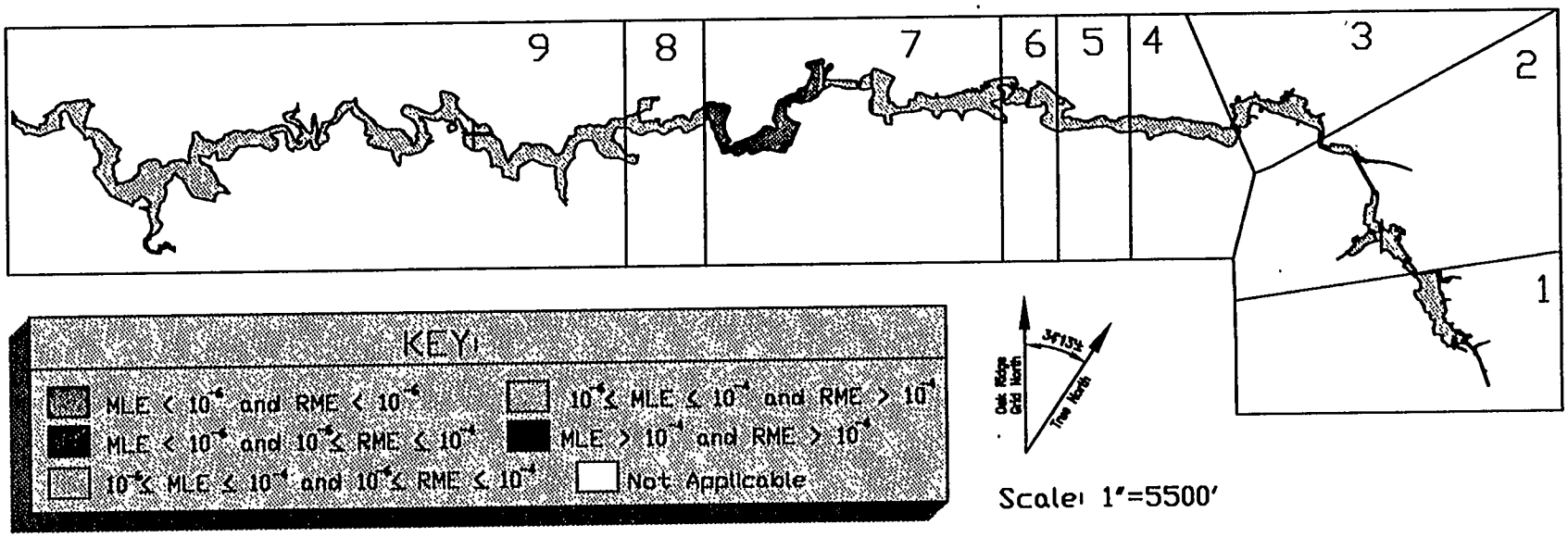

MLE = Most likely exposure estimate (mean)
RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

Fig. ES.13 Excess cancer risk for radionuclides for adults under future land use scenario.

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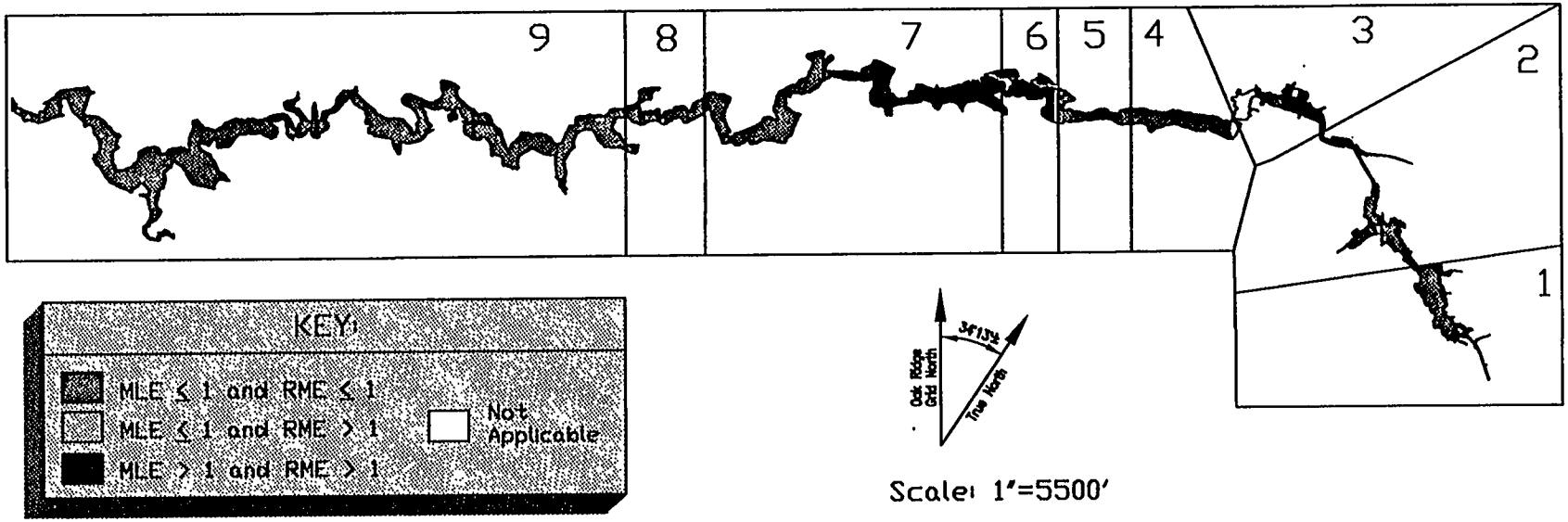

MLE = Most likely exposure estimate (mean)
RME = Reasonable maximum exposure estimate (95% upper confidence limit on mean)

Segment numbers are shown as labeled boxes on EFPC

Fig. ES.14 Hazard index for noncarcinogens for children under current land use scenario.

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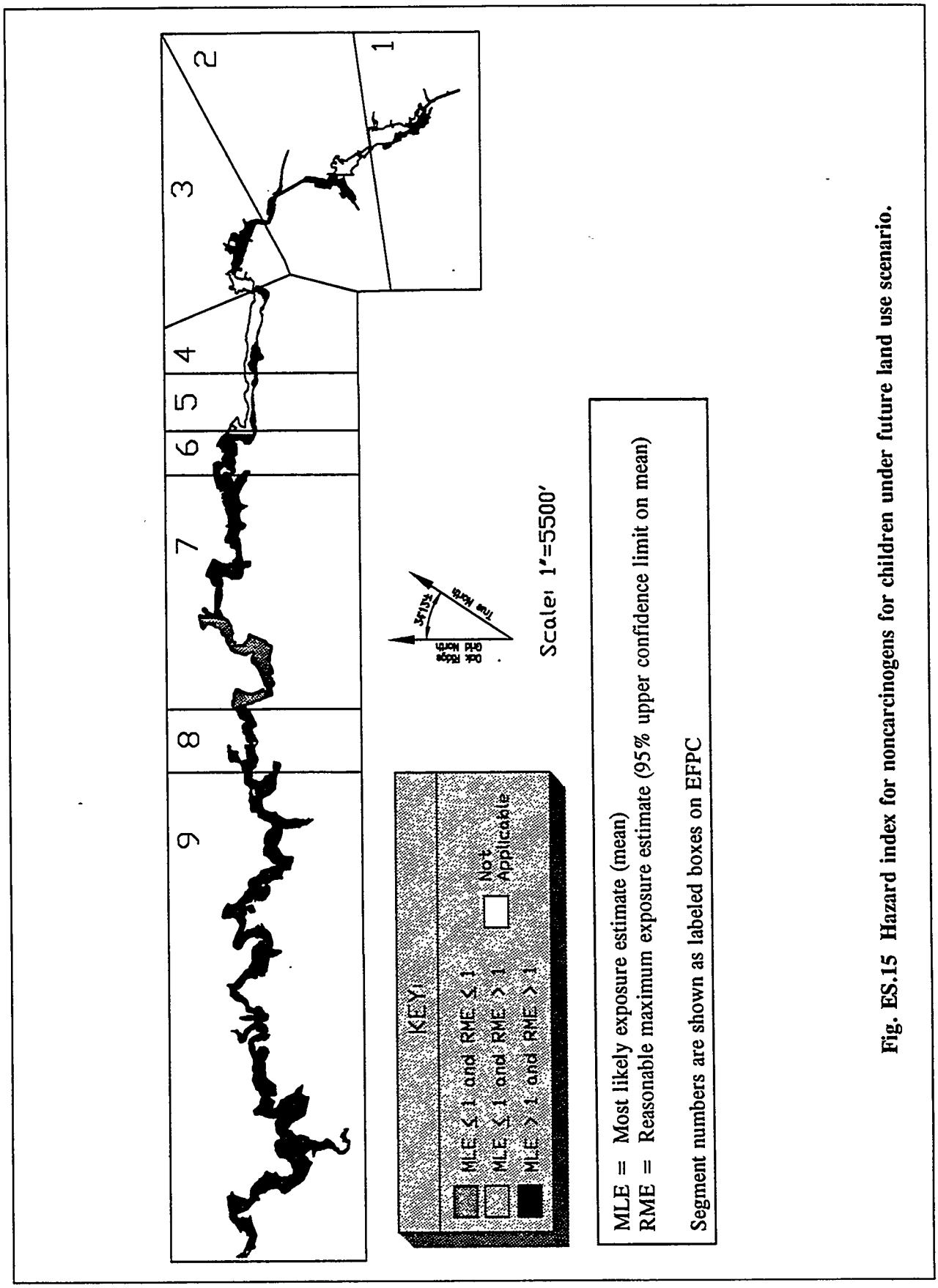

Fig. ES.15 Hazard index for noncarcinogens for children under future land use scenario.

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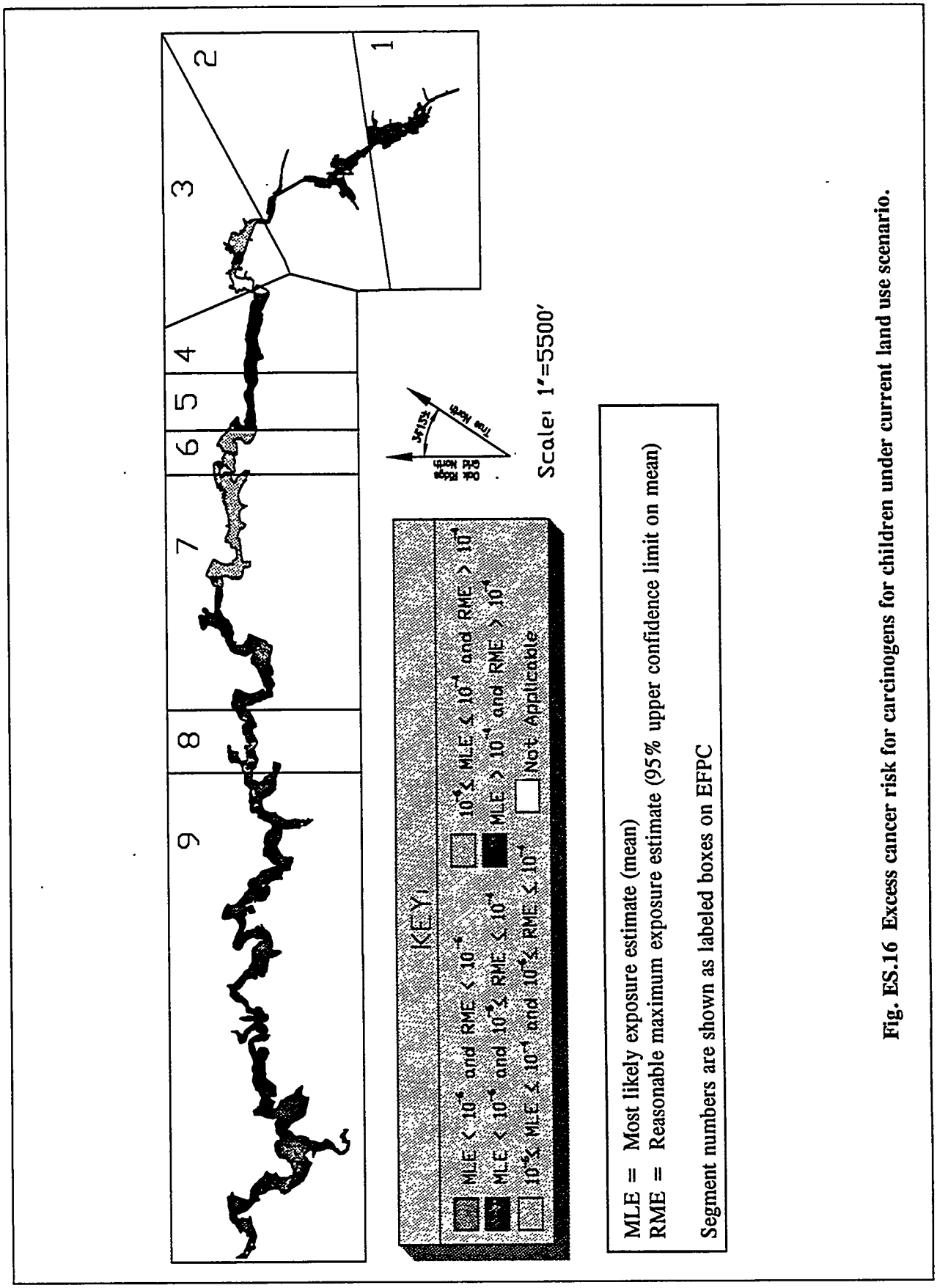

Fig. ES.16 Excess cancer risk for children under current land use scenario.

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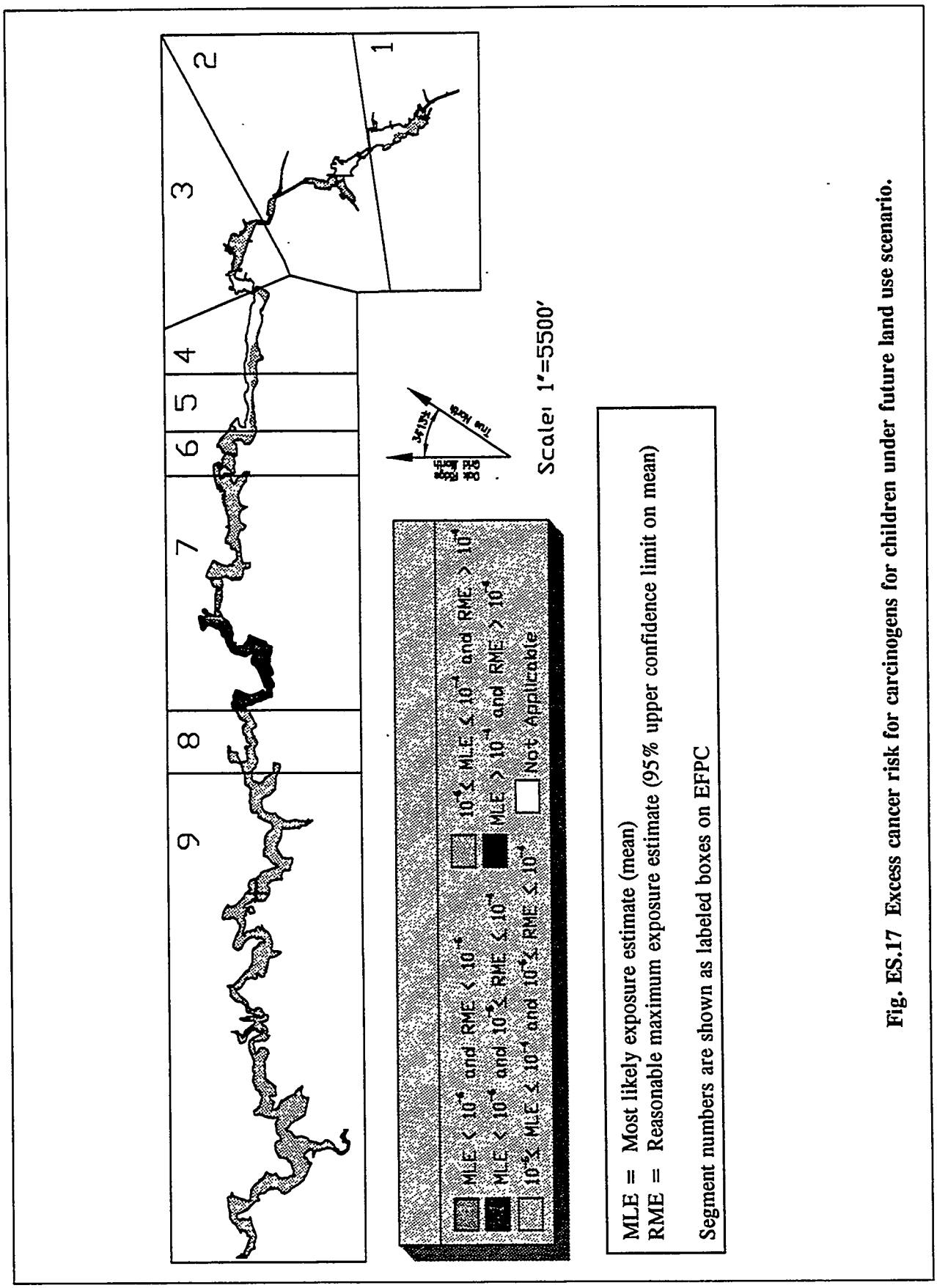

Fig. ES.17 Excess cancer risk for carcinogens for children under future land use scenario.

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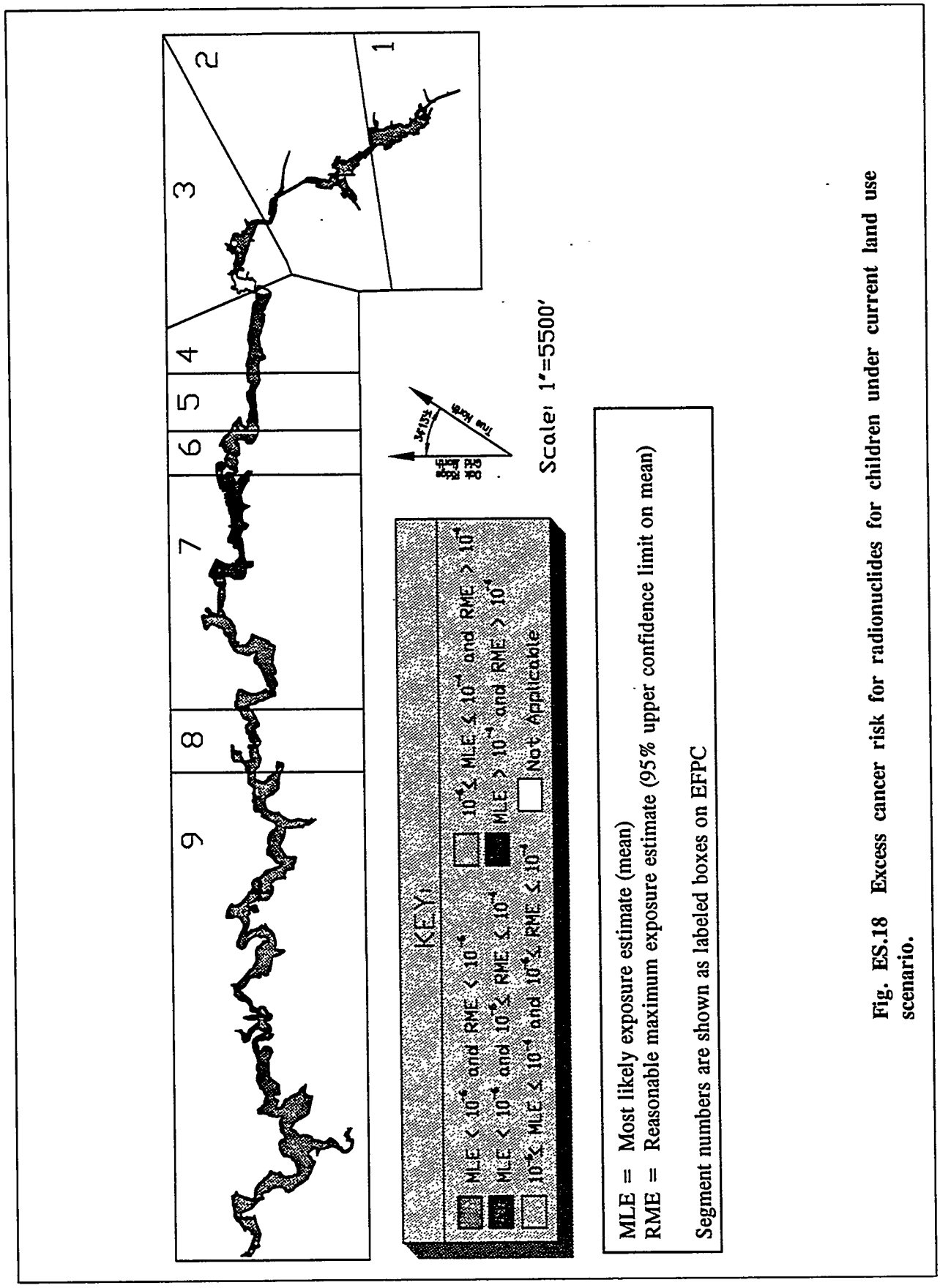

Fig. ES.18 Excess cancer risk for radionuclides for children under current land use scenario.

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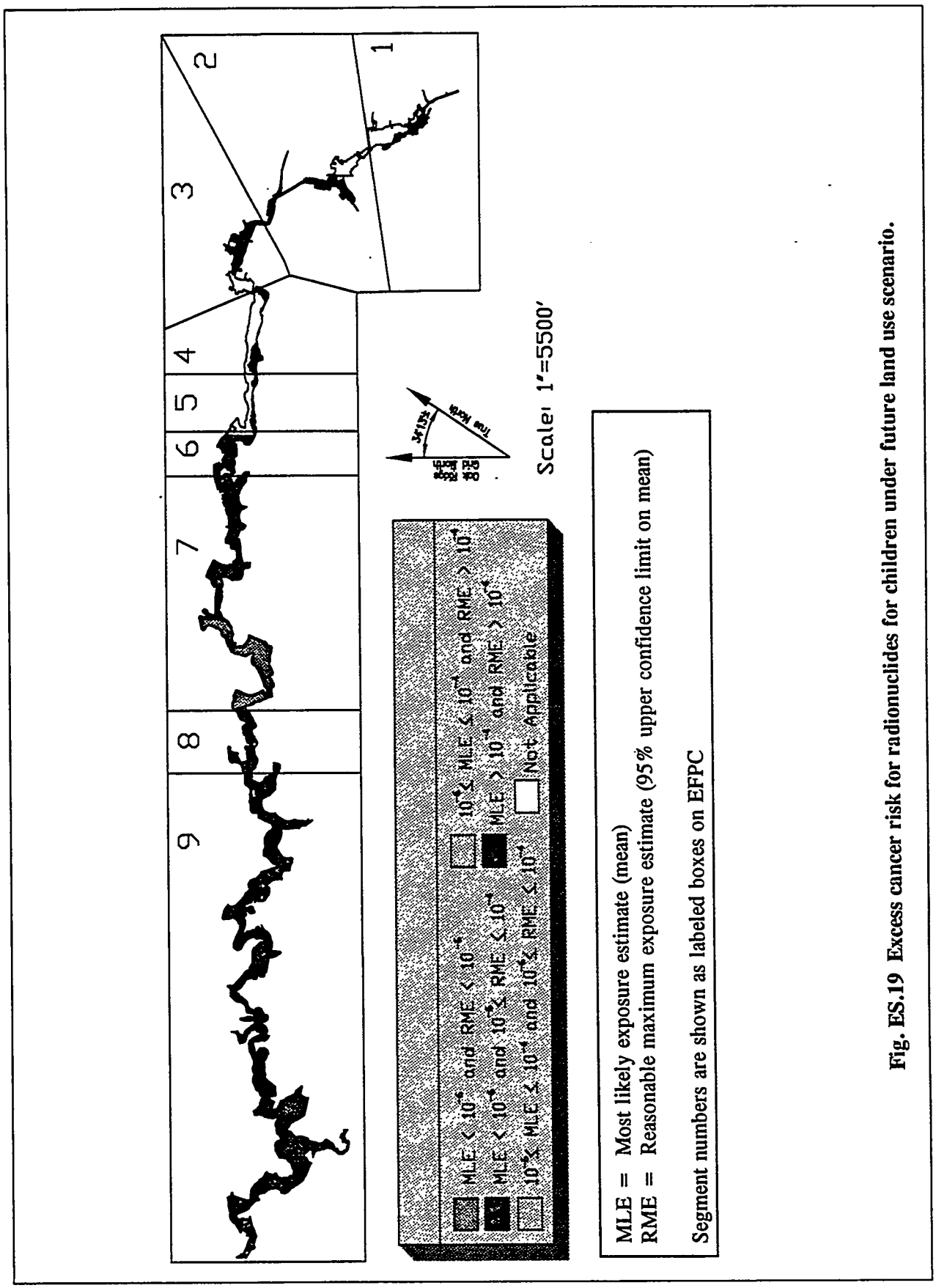

Fig. ES.19 Excess cancer risk for radionuclides for children under future land use scenario.

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pathway contributing the most to an HI >1 is produce ingestion for both children and adults. The contaminant contributing $>50\%$ to the risk estimate is mercury. In one case (Segment 7 - agricultural), ingestion of beef contributed >1 to the HI score.

To put the food chain pathway in perspective, risk estimates using the RME were calculated for the reference site at Hinds Creek using the agricultural exposure assumptions. Despite the absence of substantial mercury contamination in the reference soils, the produce, beef, and dairy ingestion pathways all had HI scores >1. For the produce and beef ingestion pathways, arsenic and manganese are responsible for $>90\%$ of the risk. For the dairy ingestion pathway, arsenic, barium, copper, manganese, and zinc are responsible for over 90% of the risk. This assessment indicates the conservatism built into the exposure and toxicity estimates.

In the future land use scenario for adults, all segments of the creek, except for a portion of Segment 7, result in risks below EPA targets if the MLE is used and risks above EPA targets if the RME is used (Fig. ES.9). This is due to the hypothetical use of groundwater as a future source of drinking water as well as a change in land use to a more conservative set of assumptions (from open to residential). The risk estimates for the groundwater pathway are aggregated over the entire creek and not by segment, and the same exposure assumptions were used for both the agricultural and residential scenarios; all segments thus have the same risk outcome. The groundwater pathway also results in commercial areas exceeding an HI of 1, even though their water use is lower than for residential and agricultural use. The principal COCs for the groundwater pathway were mercury and manganese. Using unfiltered concentrations, the levels of mercury and manganese result in HI scores exceeding EPA's targets. A comparative risk assessment was conducted using filtered groundwater samples. Overall, HI scores were lower, and the hazard quotient (HQ) score for mercury was lower by a factor of nearly 20. The HQ for manganese, however, remained >1.

In all segments with an HI >1, the largest contributor to the overall risk was produce ingestion. The soil ingestion pathway also resulted in HI scores >1 for children in Segments 1, 3, 5, and 8. In Segment 4, the HI for both children and adults exceeded 1 for the soil ingestion pathway. The portion of Segment 7 where the HI is <1 is an open land use area.

For the adult current land use scenario, the excess cancer risk from chemicals shows the same pattern as for the HI (Fig. ES.10). All segments have acceptable risk, except for the four areas within Segments 3, 6, 7, and 8 having HIs >1. Again the produce ingestion pathway was the predominant contributor to risk for all four segments. The groundwater pathway contributed about equally to the risk as the produce ingestion for those segments and land use areas where

it was applicable. However, the primary contaminant contributing to the cancer risk was arsenic in all four segments. Arsenic contributed 97%, 98%, and 98% of the cancer risk for Segments 3, 7, and 8, respectively. For Segment 6, arsenic and beryllium contributed 99% of the total cancer risk.

An additional analysis was included for three areas with elevated contamination along the SLB. This was limited to soil exposures only under the open land use exposure assumptions. Under open land use assumptions, exposures to groundwater, sediment, or additional media are not likely. Exposures at the SLB do not overlap those considered at EFPC and were limited to direct contact with soil. Commercial land use is not considered likely within the sampled portions of the SLB. Little or no change in land use is assumed for the SLB over time.

Risks associated with current and future land use at the three areas along the SLB are very similar. All of the noncarcinogenic or carcinogenic risk estimates were within or below EPA targets. All HIs are <1, and the greatest combined cancer risks are on the order of 10^{-6}. Arsenic was the only substance contributing significantly to the cancer risk estimate, accounting for nearly all of the cancer risk.

The excess cancer risk from chemicals for Hinds Creek exceeded EPA targets. The risks are greater than those for EFPC Segments 3, 6, and 8 because the EFPC segments are classified as residential, whereas Hinds Creek is agricultural. This indicates that even using background concentrations in the soil, the risk is unacceptable due to the exposure or toxicity estimates of the other variables in the food chain pathway. As with the noncarcinogens, the food chain pathways are responsible for the majority of the risk. Risks from ingestion of contaminated beef are in the 10^{-3} range, and the produce and dairy ingestion pathways are in the 10^{-4} range.

Similar to the HI for the future land use scenario, all segments of the creek had a cancer risk $< 10^{-4}$ using the MLE and $> 10^{-4}$ using the RME, except for the same open land use portion of Segment 7, where the cancer risks were all $< 10^{-4}$ (Fig. ES.11). For the same reasons, the hypothetical groundwater and the produce ingestion pathways were the cause of the excessive risk. Calculating the cancer risk based on filtered groundwater samples (that did not exceed federal MCLs) still resulted in risks $> 10^{-4}$.

These risk outcomes indicate that because the adult and child are essentially similar and because the HI and excess cancer risk have the same patterns, the driver for the risk assessment during Tier II is the conservatism built into the assumptions for the particular pathway.

Risk characterization for exposures to lead required an alternative approach in which lead uptake into children's blood is estimated. EPA has developed a computer program to evaluate blood lead uptake in children, the most sensitive receptors of lead exposures. Under current land use assumptions, only Segments 3, 6, 7, and 8 include exposures to children.

None of the blood lead levels associated with current exposure at any of these segments approach the EPA target for blood lead levels. When considering future exposures, blood lead levels are generally within EPA targets. For a child residing at Segments 3 and 4, the target was exceeded only when soil and groundwater exposures were combined. This is a marginal exceedance and includes soil, unfiltered groundwater, and built-in exposures from air and dietary sources of lead that are not site related. Soil exposures did not approach the target when considered independently of groundwater exposures. Only unfiltered groundwater exposures are associated with blood lead levels exceeding the EPA target, and the remaining exposures are well below the EPA target. As an additional point of comparison, the soil lead concentrations at each Segment fall substantially below soil cleanup guidelines for lead.

Tier III. The third tier, or probabilistic risk assessment, focused on exposure pathways that contributed the most to the overall risk, including inadvertent ingestion of soil, the produce ingestion pathway, and the hypothetical ingestion of groundwater. The outcomes of the Monte Carlo simulation include both receptor groups (adult and child), for each pathway, and for current and future land use. For the soil-related pathways (soil and produce ingestion), results are presented only for Segment 4. An uncertainty analysis for the soil pathways is presented only for one segment given that the exposure assumptions for the residential and agricultural scenarios are the same across land use segments. The only difference between segments is the exposure point concentrations. Therefore, an analysis of one segment will suffice for quantitatively characterizing the uncertainty in the risk estimates.

The RME point estimates are generally quite conservative and fall in the upper tail of the probability distributions. In some cases, the RME estimates exceed the 95th percentile values. Of particular concern are the conservative point estimates used for the food chain biotransfer factors (BTFs). These factors predict the biotransfer of each contaminant from soil to plant tissue. Based on these data and an experimental garden study, it is concluded that the BTF for mercury obtained from the literature and used in the BRA is likely one to two orders of magnitude too high.

The Tier II and III results, the results of the garden uptake study, and the risk assessment of Hinds Creek all indicate that there is a great deal of uncertainty in the risk estimates associated with the food chain pathways. Given this and the fact that very limited agricultural activity is occurring along EFPC (or is likely to occur in the future), it is concluded that the RME risk estimates for these pathways are not a useful decision-making tool. Without further confirmatory site-specific information, the food chain pathways should *not* be used as a basis for determining the need for site remediation.

Although risk estimates for the groundwater ingestion pathway exceed the acceptable range established by EPA, this pathway is concluded to have minimal impact on residents near EFPC. No one is currently using groundwater in the vicinity of EFPC as a source of drinking water or is likely to do so in the future because they are provided with city water. Even though contaminant concentrations were considerably reduced in filtered samples, the overall HI score for the pathway is still > 1 by a small margin. This is due to dissolved concentrations of arsenic and manganese. The presence of arsenic is responsible for the excess lifetime cancer risk estimate exceeding 10^{-4}. Manganese is present in background soils at levels comparable to that in EFPC soils and, therefore, occurs naturally in this geographic area. Although levels of arsenic in floodplain soils exceed those at the reference location, the presence of arsenic in groundwater cannot clearly be attributed to releases from DOE's Y-12 Plant. The results of the Tier III analysis of groundwater indicate a range of uncertainty of less than an order of magnitude. Taking into consideration the conservatism of the RME estimate and the uncertainty associated with the exposure pathway, groundwater should *not* be used as a basis for determining the need for site remediation.

The results from all three risk assessment tiers indicate that RME estimates of risks of adverse noncarcinogenic effects associated with inadvertent ingestion of soils exceed the target range established by EPA for the future land use scenario. The risk is due primarily to mercury concentrations in soil with cadmium, arsenic, and manganese contributing to a lesser degree. Concentrations of mercury, cadmium, and arsenic were significantly higher than those found at the reference location, but manganese was not. The Tier III assessment demonstrates that there is less than an order of magnitude uncertainty in the RME point estimates for soil ingestion. Based on these results, soil ingestion is the principal pathway of concern and the most appropriate basis for determining the need for site remediation.

The risk from the soil ingestion pathway was estimated using an RfD for mercury of 0.0003 mg/kg per day. This value was based on a very sensitive endpoint in laboratory test species and may be inappropriate as a basis for extrapolating toxicity from animal species to

humans. In addition, the RfD used was for soluble mercury species, not insoluble forms found in EFPC floodplain soils. If either of the alternate site-specific mercury RfDs derived by SAIC and ORNL are used (0.001 mg/kg per day—soluble inorganic mercury or 0.04 mg/kg per day—insoluble mercuric chloride), then the noncarcinogenic risk estimates will be acceptable for both current and future land use scenarios. These risk results could obviate the need for remediation in locations dominated by the soil ingestion pathways.

ES.3.2 Ecological Risk Assessment

The purpose of the ecological BRA is to determine baseline risk levels to various animal and plant populations and habitats in EFPC. Also, the purpose is to determine whether contaminants pose an imminent and substantial danger to the health of various ecological resources and whether and where site remediation may be needed. The ecological risk assessment (ERA) process differs from the human health risk assessment process in that it focuses on populations and communities rather than on individuals. Individuals are addressed only if they are protected under the Endangered Species Act, are unique, or have such public importance that individual consideration is merited. Rather than attempt to examine every species living in and around EFPC, a weight-of-evidence assessment was conducted to determine the effects of contaminants on indicator species (representative species from each major aquatic and terrestrial habitat) and to extrapolate from them to project the overall effects of other and unmeasured contaminants on the ecosystem.

The ERA, as described in *Framework for Ecological Risk Assessment* (EPA 1992c), involves four basic steps occurring in three primary phases (Fig. ES.20): (1) problem formulation, (2) exposure characterization, (3) effects characterization, and (4) risk characterization. These interrelated activities are defined as follows.

Problem formulation establishes the goals, breadth, and focus of the assessment and provides a preliminary characterization of chemical and physical stressors present in the ecosystem, the components and especially indicator organisms of the ecosystem likely to be at risk, and the potential ecological effects along with a selection of assessment and measurement endpoints as a basis for a conceptual model of stressors, components, and effects.

Exposure characterization evaluates the interactions of the stressors with the ecosystem attributes and describes the biotic and abiotic ecosystem attributes, along with the route, magnitude, frequency, duration, trend, and spatial pattern of exposure of each indicator population or habitat component in relation to a chemical or physical stressor.

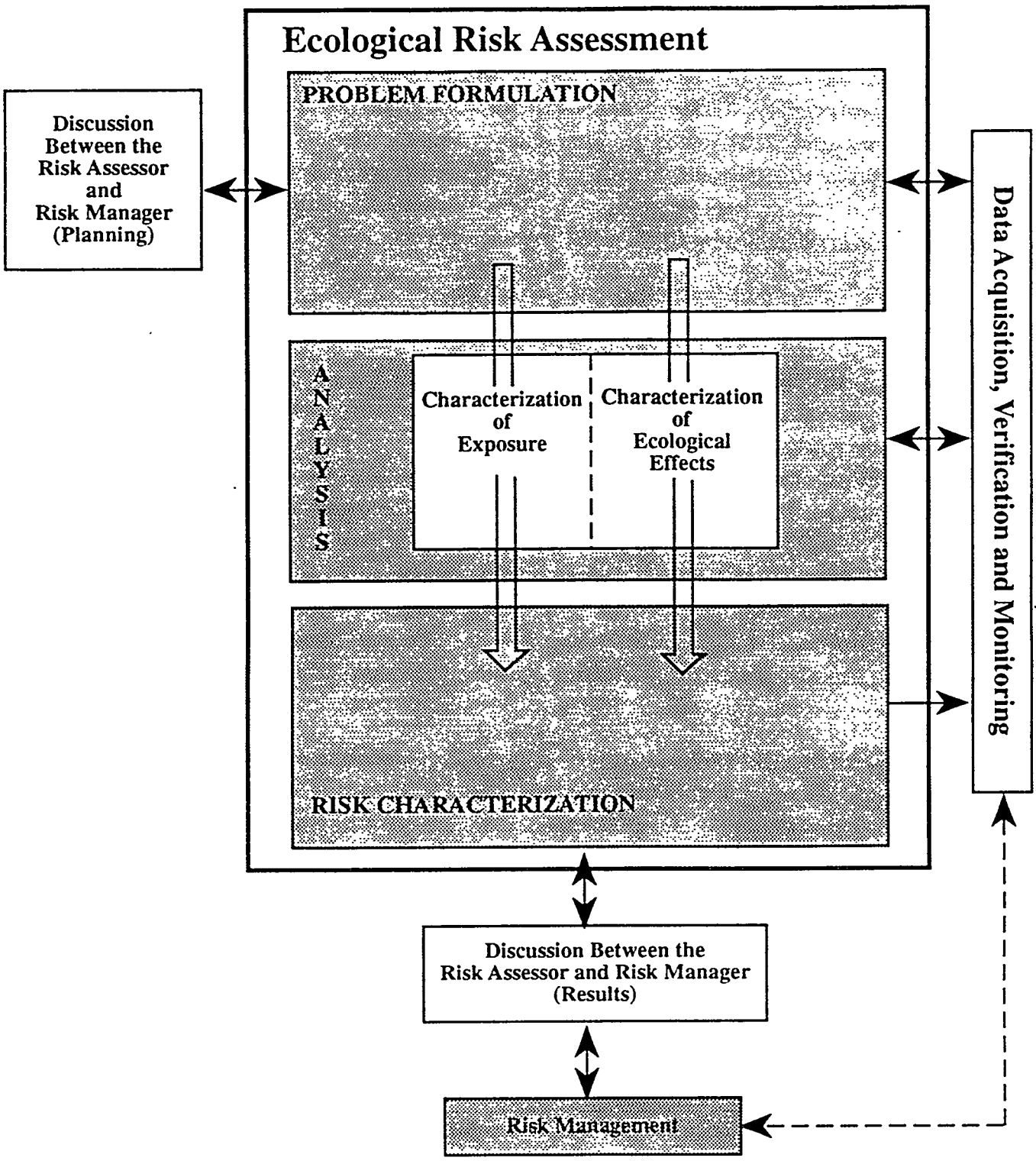

Fig. ES.20. Framework for ecological risk assessment (*Source:* EPA 1992c).

Effects characterization evaluates the ecological response to chemical and physical stressors in terms of the selected assessment and measurement endpoints and, depending on the parameters of exposure, results in a profile of response to stressors at concentrations or doses or other units of stress to which populations and habitats are exposed. Data from both field observations and controlled laboratory studies are used to evaluate ecological effects.

Risk characterization integrates the effects of exposure and stressor response on indicator populations or habitat components, using risk quotients (a ratio of exposure value to effect value); interprets these data according to the weight-of-evidence approach; and then further interprets the ecological significance, including the potential for ecosystem recovery.

ES.3.2.1 Problem formulation

Critical to the performance of such an ecological assessment is the early establishment of goals and objectives for the study. For the EFPC ERA, seven primary goals were developed, along with 11 associated assessment/measurement endpoints (Table ES.5). These goals reflect government policy goals, such as NEPA compliance or ARARs attainment, and important characteristics of the at-risk EFPC populations and habitats.

Also important to the initial formulation of the problem and development of conceptual models and sampling plans is a thorough understanding of the historical information on contaminant types, locations, and the respective ecological receptors of these contaminants. Contaminants within the EFPC environment have been described and characterized by several previous studies (Van Winkle et al. 1984; TVA 1985; Gist 1987; Carmichael 1989; Loar 1992; Hinzman 1992; Turner et al. 1992 and Appendix Q). The ORAU (Gist 1987) study, conducted between 1983 and 1987, included surveys for mercury in the surface soil along 100-m transects across the floodplain from the Y-12 Plant to the Oak Ridge city limits in Roane County, grid sampling for mercury within a highly contaminated floodplain property, sampling for mercury from vertical profiles at various sites, and sampling of selected lawns and gardens in Oak Ridge. Sampling of vegetation, sewage sludge, groundwater, and two road-killed deer was performed for radionuclides, mercury, and other metals. The TVA study, performed during 1984, sampled soils, sediments, surface water, fish, amphibians, crustaceans, and reptiles, which were then analyzed for mercury and other metals, radionuclides, organics, pesticides, and PCBs. The Y-12 Plant BMAP, begun in 1985, performs semiannual sampling of natural populations of fish, which are then analyzed for mercury, PCBs, and cesium (Loar 1992; Hinzman 1992). Bioaccumulation studies of PAHs and PCBs have been conducted annually using caged clams. The USGS conducted a survey of groundwater contamination by metals, radionuclides, and organics in 1987

Table ES.5. EFPC ERA endpoints

Goals	Assessment endpoint	Measurement endpoint
1. Conservation of threatened, endangered, and rare species and their critical habitats	1a. No harm to any threatened and endangered species and their critical habitat of the EFPC floodplain	1a. Surveys of presence/absence of species and their habitats on the EFPC floodplain
	1b. Maintenance of plant community composition and/or structure required for rare plant/animal and support species	1b. Abundance and distribution of plant/animal species that would support threatened, endangered, and rare species
2. Protection of migratory birds	2a. No killing or harming of migratory birds as a result of exposure to site-specific stressors	2a. Contaminant concentrations in selected migratory birds and weight-of-evidence data
3. Preservation of wetlands	3a. The presence and structure/function of wetlands in relation to contaminants	3a. Wetlands survey and their contaminant levels, if any, on the EFPC floodplain
4. Existence of a fish community indicative of undegraded conditions	4a. Fish community in which the proportion of species tolerant of degraded water quality is $<30\%$	4a. Proportion of tolerant species at the site
5. No adverse effects from contaminants to aquatic indicator organisms and/or predators that feed on them	5a. Ratio of contaminant concentrations in surface water to water quality criteria for protection of aquatic life ≤ 1	5a. Contaminants in surface water
	5b. Aquatic indicator organisms contaminant body burden ratio to toxicological effects levels ≤ 1	5b. COC concentrations in whole-body samples of aquatic indicator species
	5c. Fish contaminant body burden ratio to protective piscivorous biota levels ≤ 1	5c. COC concentrations in whole-body samples of aquatic indicator prey species
6. Existence of terrestrial animal community indicative of undegraded conditions	6a. Terrestrial animals with diversity, abundance, and distributions indicative of undegraded conditions resulting in ≥ 20 or more percent decrease compared to the reference.	6a. Population abundance and distribution by habitat
7. No adverse effects from contaminants to terrestrial indicator organisms and/or predators that feed on them	7a. Ratio of contaminant body burdens in terrestrial indicator species to toxicological effects levels ≤ 1	7a. COC concentrations in whole-body samples of terrestrial indicator species
	7b. Ratio of contaminant body burdens in terrestrial indicator species to levels protective of terrestrial predators ≤ 1	7b. COC concentrations in whole-body samples of prey terrestrial indicator species

(Carmichael 1989). This study sampled 14 shallow-aquifer wells at sites of known mercury contamination within the floodplain. Other one-time studies include the assessment of mercury and strontium in small mammals by Energy Systems and a 1982 rapid assessment survey of mercury contamination in multiple media, i.e., sediments, mosses and liverworts, grasses, and fish (Van Winkle et al. 1984).

Based on these early studies, two major exposure sources exist within EFPC and its floodplain. Water effluents from the Y-12 Plant continually expose aquatic organisms and can contribute to the exposure of terrestrial organisms during floods through direct contact or through deposition. The previously contaminated floodplain soil also contributes to the exposure of terrestrial organisms through dermal contact and ingestion and to exposure of aquatic organisms through erosion or scouring and redeposition. Direct exposure routes exist through the air, shallow groundwater, surface water, instream sediments, and soil. Indirect exposure occurs through ingestion of contaminated forage or prey.

ERA Sampling Locations and Sampling Design. The area in which organisms are exposed to contaminants is defined by both their home range in habitats and the distribution of contaminants. To facilitate evaluation of exposures in different EFPC habitats, the OU was divided into sections. The sections were arbitrarily based on the EFPC sampling grid; 17 sections were created, each comprising 1 km from west to east on the sampling map. The first section begins just below the confluence of EFPC with Poplar Creek, and section 17 is located at the beginning of the study area below Lake Reality. Within these 17 sections, a wide variety of surface water/sediment and soil/vegetation habitats was identified and mapped. For surface water, four distinct aquatic habitats were defined (runs, riffles, pools, and other); for the terrestrial habitats, 12 distinctions were made including 4 forest categories, 5 field or relatively cleared habitats, and 3 built-up/commercial settings. The majority of the terrestrial habitats were found to be bottomland hardwoods, while the most prevalent aquatic habitat was the stream runs. Seventeen wetlands were found to exist in the floodplain, and each appears to be functioning.

Locations of the ecological sampling sites were chosen to gain maximum information on EFPC biota and their physical environment and to allow comparison and contrast with historical data. The six aquatic sampling sites, as shown in Fig. ES.21, were selected to represent a gradient of biological and physical conditions. One site was located in Pine Ridge Gap near the outfall from Lake Reality, and two were located near areas previously identified as having high mercury concentrations in soils. Coordination with BMAP sampling personnel ensured that no adverse effects occurred to these sampling locations during the RI sampling and facilitates comparisons with the BMAP results. One of these sites also serves as an upstream reference for impacts of

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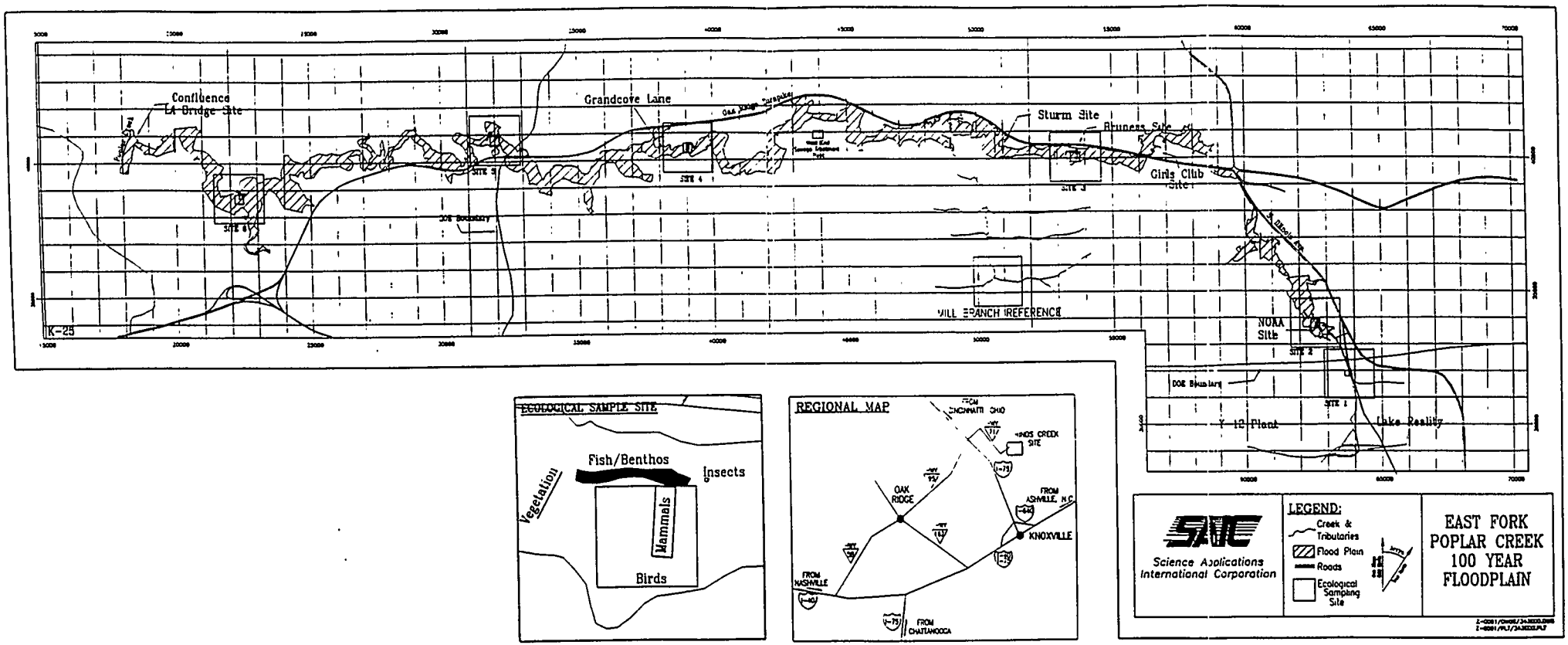

Fig. ES.21. Map of EFPC ecological sampling sit

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the Oak Ridge Sewage Treatment Plant. A fourth site was selected below the plant outfall to assess impacts of the treated municipal wastewater on the biota. The last two sites were located in the lower reaches of EFPC, one above and one below Bear Creek. Where possible, terrestrial biota were sampled at the same sites. Another selection criterion was access. Sites were selected to allow easy as opposed to difficult access for sampling gear and samplers.

The EFPC watershed is unusual in that there is no unaffected upstream location that can be used as a reference site. Hinds Creek, a relatively unaffected watershed in the Clinch River system, was chosen as the reference site most closely approximating the EFPC watershed and aquatic ecosystem. However, because the topography and land use surrounding Hinds Creek was atypical of patterns found along EFPC, it was not judged to be a good reference site for the species composition aspect of terrestrial biota. Although a site was selected on Mill Branch, which is a major tributary in the EFPC watershed, its use as a reference site for terrestrial biota is limited by the fact that it has a more upland community with an immature forest, unlike the bottomland hardwood sites on EFPC. Comparisons with areas similar to EFPC were hindered by the lack of a suitable reference site for the terrestrial biotic study from the species composition viewpoint. From the contaminant or chemical reference viewpoint, the reference sites were believed to be qualified because they were supposed to have experienced little anthropogenic chemical contamination.

In addition to the aquatic and terrestrial species sampling conducted at the EFPC and reference sites, grasses and browse were taken at three sites along the EFPC floodplain and at Hinds Creek, and beet roots, kale leaves, and tomato fruits were grown and sampled at a special vegetable plot located on the floodplain. These vegetation measurements supplemented the historical studies on woody species in EFPC. Also important to the ERA were the environmental sampling results for soils, sediments, surface water, groundwater, and air discussed earlier in this Executive Summary.

Indicator species were selected by a process, outlined in *Habitat Evaluation Procedures ESM 102* (FWS 1980), that relies on groups of organisms that occupy a common environmental resource (e.g., sediment, water column, vegetation). Factors included in the selection of indicator species included their presence in EFPC, ability to obtain measurable responses, adequate sample size, phenology, and small home range in EFPC so that exposure was assured. In addition, some species that did not necessarily meet these criteria, such as threatened or endangered species and other species of concern (e.g., migratory birds), were selected because they were important as assessment endpoints. Species of concern included those that are vital to ecosystem energy and biogeochemical cycling, are particularly susceptible or sensitive to

contaminants, and are specific bioaccumulators. Also, plants were selected to represent the lower trophic levels in the food chain to allow modeling up the food chain. Finally, indicator organisms need to be in harmony with natural resource trustee needs.

Aquatic indicator species included fish (stonerollers, redbreast sunfish, largemouth bass), sediment-dwelling invertebrates (benthic macroinvertebrates and crayfish), and periphyton (algae and heterotrophic microbes) attached to submerged surfaces in the substrate. Terrestrial indicator species included small mammals (shorttail shrew and white-footed mouse), birds (wrens and heron), invertebrates (earthworms and adult terrestrial insects) living in or on the soil, and plants (grasses and vegetables). These aquatic and terrestrial indicator species were targeted for population surveys and body burden analyses to represent the key exposure points in the EFPC ecosystem. A summary of the types of measurements and analyses conducted as part of the ERA is provided in Table ES.6.

The field investigations were conducted in the late summer of 1991 through the late summer of 1992. The aquatic ecosystem is considered to be representative under conditions of stable base flow. The late summer and early fall were selected for intensive field surveys based on the need for low rainfall conditions typically experienced during these seasons. Because of the present knowledge of the area, abundance of existing biological data on EFPC, and the schedule for the EFPC RI report, no initial field screening was performed. The schedule and funding level allowed the one-seasonal approach. Data from the BMAP—a many-season and multiyear study—were used to round out the temporal aspects of the characterization.

ES.3.2.2 Exposure characterization

Exposure environments in EFPC and its floodplain consist of a heterogeneous mixture of flow regimes, streambed conditions, and terrestrial habitats varying from commercial through agricultural to woodland. Surface water is the primary medium of exposure for aquatic organisms to contaminants currently being released to EFPC via surface water from the Y-12 Plant and to contaminants in floodplain soils that are transported via erosion, surface runoff, and shallow groundwater. Soil is the primary medium of exposure for terrestrial biota. Stream sediments are a second major exposure route for benthic invertebrates and for terrestrial consumers by way of flood deposits on soil and vegetation. In both aquatic and terrestrial communities, indirect exposure of organisms via the food web is important. Methylation/demethylation of mercury in sediments and stream water and biodegradation of organic contaminants are the most important chemical transformations. Methylmercury is assumed to be the predominant form of mercury in aquatic biota. In the absence of remediation,

Table ES.6. Measurements made for the EFPC ERA

Matrix sampled	Population measures			Contaminant concentration	Colonization rate	Growth rate
	Relative abundance	Biomass	Diversity			
Aquatic						
Fish	X	X	X	X		
Benthic macro-invertebrates	X	X	X	X		
Periphyton					X	X
Water				X		
Sediments				X		
Terrestrial						
Small mammals	X	X	X	X		
Birds	X		X	X		
Insects	X	X	X	X		
Earthworms	X		X	X		
Vegetation	X		X	X		
Soil				X		

the exposures of EFPC communities to contaminants are not expected to change dramatically from those levels identified through the Phase Ia and Ib sampling of the soils, sediments, surface, and groundwater along EFPC and the SLB. Based on the identified media of exposure and the respective indicator species, Table ES.7 summarizes the expected dominant mode of exposure to the EFPC ecosystem.

Characterization of the exposure conditions of the indicator species was accomplished through implementation of the ERA sampling plan and incorporation of historical data where appropriate to fill in data gaps. A summary of the ERA sampling results is provided in Table ES.8 for aquatic biota and in Table ES.9 for terrestrial biota.

Both historical and current studies of bioaccumulation show higher body burdens of mercury and/or PCBs and other pesticides in stonerollers, sunfish, crayfish, earthworms, and terrestrial insects at EFPC sites than at noncontaminated reference sites and generally decreasing body burdens with increasing distance downstream from the Y-12 Plant. Current body burdens are generally lower than those from the 1980s, possibly as a result of prior remediation activities at the Y-12 Plant. Thus, ecological recovery in the upper part of EFPC above and below Lake Reality has been documented by BMAP. Whole-body mercury concentrations found in redbreast sunfish during the BRA were 30 to 50% less than concentrations found in bluegill and redbreast sunfish taken from similarly located sites in studies conducted by ORNL in 1982 (Van Winkle et al. 1984) and by TVA in 1984 (TVA 1985). Other notable exceptions found during the EFPC ecological BRA to the general patterns indicated by historical studies were the high present body burdens of mercury in redbreast sunfish from a site located 6.4 km (3 miles) downstream from Lake Reality and increasing body burdens of PCBs in sunfish at this site and other sites downstream.

ES.3.2.3 Effects characterization

Data on the toxicity of inorganic and organic mercury compounds to fish demonstrate a positive relationship between dose and effect. Toxicity tests on a variety of aquatic and terrestrial organisms using EFPC surface water, soils, or sediments have shown deleterious effects, and in two cases, the effects were greatest at the sites nearest the Y-12 Plant. The results of surveys of indicator organisms at EFPC are also indicative of effects that most likely occurred from exposure to contaminants released from the Y-12 Plant. The number of indicator fish species, benthic macroinvertebrate families, and insect adult individuals at EFPC generally increased with increasing distance downstream from the Y-12 Plant. Compared with a reference site, EFPC had fewer species of fish, families of benthic macroinvertebrates, and mean numbers of individuals

Table ES.7. Dominant mode of exposure of indicator organisms to contaminated source media in EFPC

Indicator biota	Medium			
	Surface water	Instream sediment	Groundwater	Soil
Fish	D	D/I	*	*
Benthic invertebrates	D	D	*	*
Aquatic insects	D	D	*	*
Crayfish	D	D	*	*
Periphyton	D	I	*	*
Small mammals	D	*	I	D
Birds	D	I	I	I
Terrestrial insects	*	*	I	D
Earthworms	*	*	I	D
Plants	D	D	I	D

D = Direct exposure
* = Incomplete pathway or considered negligible
I = Indirect exposure

Table ES.8. Summary table of trends for whole-body concentrations of contaminants in aquatic biota collected from EFPC and Hinds Creek, October 7-29, 1991

Taxon	Mercury	Other inorganics	PCBs		Pesticides	PAHs
			Aroclor 1260	Other		
Redbreast sunfish	• In samples from all six sites in EFPC and Hinds Creek. • Maximum at Site 3. • Decreasing body burdens downstream from Sites 3 to 6. • All samples in EFPC exceeded concentrations in sample from Hinds Creek.	• Uranium was below sample detection at all sites.	• In samples from all six sites in EFPC and Hinds Creek. • Maximum level at Site 3. • Decreasing body burdens downstream from Sites 3 to 6. • All samples in EFPC exceeded concentrations in sample from Hinds Creek.	• All other mixtures were below sample detection limits.	• Most were less than sample detection limit. • Chlordane, dieldrin, and heptachlor were in samples from all sites including Hinds Creek. • Decreasing body burdens from Sites 1 to 2, then increasing to maximum at Sites 4 or 5. • Nearly all sites in EFPC exceeded Hinds Creek.	• All individual PAHs were below sample detection limits except for acenaphthene. • Acenaphthene body burden was greatest at Site 1, then nearly constant at remaining EFPC sites. • All samples in EFPC exceeded concentrations in samples from Hinds Creek.
Stoneroller	• In all six samples from EFPC and Hinds Creek. • Maximum at Site 2. • Decreasing body burdens downstream from Sites 2 to 6. • All samples in EFPC except Site 6 exceeded Hinds Creek sample.	• Uranium in samples from all sites. • Maximum body burdens at Site 1. • Decreasing body burdens downstream from Sites 1 to 6. • Sites 1 to 4 exceeded Hinds Creek sample.	• Sufficient sample at Sites 1 to 5 and Hinds Creek. • Maximum at Site 1. • Decreasing body burdens downstream from Sites 1 to 4. • All samples in EFPC exceeded concentrations in samples from Hinds Creek.	• All the mixtures were below sample detection limit.	• Same sites as for PCBs. • Maximum at Site 1. • General trend of decreasing body burdens Sites 1 to 4. • All samples in EFPC exceeded concentrations in samples from Hinds Creeks.	• Same sites as for PCBs. • Maximum at Site 1. • Same trend as for pesticides. • Nearly all sites in EFPC exceeded sample from Hinds Creek.

Table ES.8 (continued)

Taxon	Mercury	Other inorganics	PCBs		Pesticides	PAHs
			Aroclor 1260	Other		
Benthic macro-inverte-brates	• Sufficient sample only at 4 sites in EFPC and Hinds Creek. • Maximum at Site 2; other sites similar to each other. • All samples from EFPC exceeded sample from Hinds Creek.	• Same sites as for uranium and mercury. • Same trends as for mercury.	• Sufficient sample only at 2 sites in EFPC (sites 1 and 2). • Maximum at Site 1 (6-fold greater than at Site 2).	• All other mixtures below sample detection limit.	• Same sites as for PCBs. • Nearly all were below sample detection limits.	• Same sites as for PCBs. • Most individual PAHs were similar to concentrations in samples from the two sites. • Fluoranthene was maximum at Site 1. • Benzo(a)pyrene was maximum at Site 2.
Crayfish	• Sufficient sample at 4 sites in EFPC and Hinds Creek. • Maximum at Site 1. • Decreasing body burdens downstream. • All samples from EFPC exceeded concentrations in samples from Hinds Creek.	• Same sites as for mercury. • Uranium was below sample detection limit at most sites. • Selenium body burdens were greatest in samples for Site 3, and all EFPC samples exceeded concentrations in samples from Hinds Creek.	• Same sites as for mercury. • Same trends as for mercury.	• All other mixtures below sample detection limit.	• Same sites as for mercury. • Nearly all were below sample detection limits.	• Sufficient sample only at Sites 1 to 3, and Hinds Creek. • Maximum at Site 3. • Most individual PAHs increased downstream from Sites 1 to 3. • Most PAHs at the 3 Sites in EFPC exceeded concentrations in sample from Hinds Creek.

Table ES.9 Summary table of trends for whole-body contaminant concentrations in terrestrial biota collected from EFPC and reference site in late 1991

Taxon	Mercury	Other inorganics	PCBs		Pesticides	PAHs
			Aroclor 1260	Other		
Mice	• Levels below detection limit in 9 of 11 individuals. • Maximum value of 1105 μg/kg at Site 2.	• Antimony, chromium, and selenium measured above detection limit in >50% of individuals.	• Above detection limits in all samples except reference. • Range from 51 μg/kg to 480 μg/kg, with highest at Site 1.	• All others below detection limit.	• Nearly all were below detection limits. • One value for DDT and one for heptachlor oxide above detection limits.	• All levels below detection limits or twice reference levels.
Shrews	• Maximum of 7.9 mg/kg at Site 5.	• Uranium not detected. • Antimony, chromium, and selenium similar to mice.	• Maximum of 1400 μg/kg at Site 5.	• Not detected.	• Nearly all were below detection limits.	• Not analyzed.
Vole	• Less than detection limit.	• Chromium levels similar to mice. • Uranium not detected.	• Reported at 46 μg/kg.	• Aroclor 1016 at 73 μg/kg.	• All below detection limit.	• No unqualified levels above unqualified detection limits.

Table ES.9 (continued)

Taxon	Mercury	Other inorganics	PCBs		Pesticides	PAHs
			Aroclor 1260	Other		
Heron	• Breast feathers at 5.3 mg/kg • Liver sample at 9.0 mg/kg.	• Chromium, selenium, and zinc above detection limits in feathers. • Selenium and zinc above detection limits in liver.	• Liver sample at 1.4 mg/kg.	• All others below detection limit.	• Several reported but most below the detection limit.	• No unqualified levels above detection limit.
Wrens	• Levels at 3.5 mg/kg in both samples.	• Antimony, selenium, and EMC above levels in terrestrial insects.	• Average of 2100 μg/kg is 10 times average in terrestrial insects.	• No other detected.	• Only 4 detected.	• None above detection limit.
Flying insects	• Most samples below detection limit. • Maximum levels of 3189 μg/kg at Site 3. • No correlation between measure concentrations in insects and soils.	• Uranium and cadmium not detected. • Antimony, chromium, zinc, arsenic and selenium noted above detection limits at 2 sites.	• Range of 20-350 μg/kg. • Maximum at Site 2 and decreased steadily with distance from Y-12 Plant.	• All levels below detection or reference site levels.	• DDE reported at Site 3, chlordanes at Site 4. • Others not identified above twice reference site levels.	• Few detected; highest value at Site 3.

Table ES.9 (continued)

Taxon	Mercury	Other inorganics	PCBs		Pesticides	PAHs
			Aroclor 1260	Other		
Earthworms	• Range from 5-33 mg/kg. • Maximum observed at Site 2, with a steady decrease downstream. • No good correlation between earthworm composites and soil levels.	• Arsenic, cadmium, selenium, uranium, zinc, and chromium levels above reference site.	• Not sufficient sample for analysis.	• Not sufficient sample for analysis.	• Not sufficient sample for analysis.	• Not sufficient sample for analysis.
Grass/ vegetables	• Geometric mean grass/browse concentration of 0.34 mg/kg, with maximum of 17 mg/kg. • Grasses near creek showed higher levels. • Levels in vegetables ranged from <0.03 - 3.2 mg/kg.	• Data not available.	• Not measured.	• Not measured.	• Not measured.	• Not measured.

per sample of adult insects with terrestrial larval forms. The number of fish species classified as tolerant of degraded conditions decreased downstream in EFPC (Fig. ES.22). Taxonomic diversity (H') of fish, benthic macroinvertebrates, and adult insects increased downstream, except at Site 3, and was lowest at the three sites where surface water mercury concentrations were greatest (Fig. ES.23). Taxonomic diversity for fish, benthic macroinvertebrates, and adult insects with aquatic larval forms at EFPC sites was generally less than at the reference site. The richness of families from sensitive orders of arthropoda—Ephemeroptera, Plecoptera, and Trichoptera (EPT richness)—was lowest at the EFPC site nearest the Y-12 Plant and was lower at all EFPC sites than at the reference site (Fig. ES.24). In general, the results of the benthic macroinvertebrate sampling conducted to support the ERA parallel those of the fish sampling, suggesting that both communities (1) are dominated by large numbers of individuals from only a few of the total number of families present, (2) are dominated by tolerant organisms, (3) have less total species/taxa or EPT richness than the reference stream, and (4) have lower diversity indices than the reference stream. Taken together, these factors indicate that the benthic and fish communities in EFPC, especially in the upper part of the stream below Lake Reality, are experiencing environmental stress.

Studies of periphyton colonization and growth, populations of small mammals, earthworms, birds, and terrestrial vegetation showed less consistent patterns. A bird survey of EFPC in the fall of 1991, as well as other bird surveys, identified more than 30 species of migratory birds, which were likely ingesting contaminated worms and arthropods. White-footed mice were captured at all EFPC sites except Site 6. Shrews, a vole, and a chipmunk were captured at one or more of the sites furthest from the Y-12 Plant. A limited vegetation survey revealed few patterns associated with exposure to contaminants released from the Y-12 Plant. Earthworm contaminant body-burdens decrease as a function of distance from the Y-12 Plant. The threatened and endangered species survey, both literature and field, revealed no species requiring protection of their populations, nor their support habitats.

ES.3.2.4 Risk characterization

Risk characterization aggregates the effects of exposure and stressor response on indicator organisms, summarizes risk according to the weight-of-evidence approach, and interprets the ecological significance of these findings. This ERA takes two interrelated approaches to ecological risk characterization for EFPC and its floodplain. The first is the application of the quotient method (Barnthouse et al. 1986) to various criteria for protection of ecological resources. In this method, observations are compared to numerical criteria for protection of ecological resources, e.g., assessment endpoints. The ratio of the observed contaminant concentration to

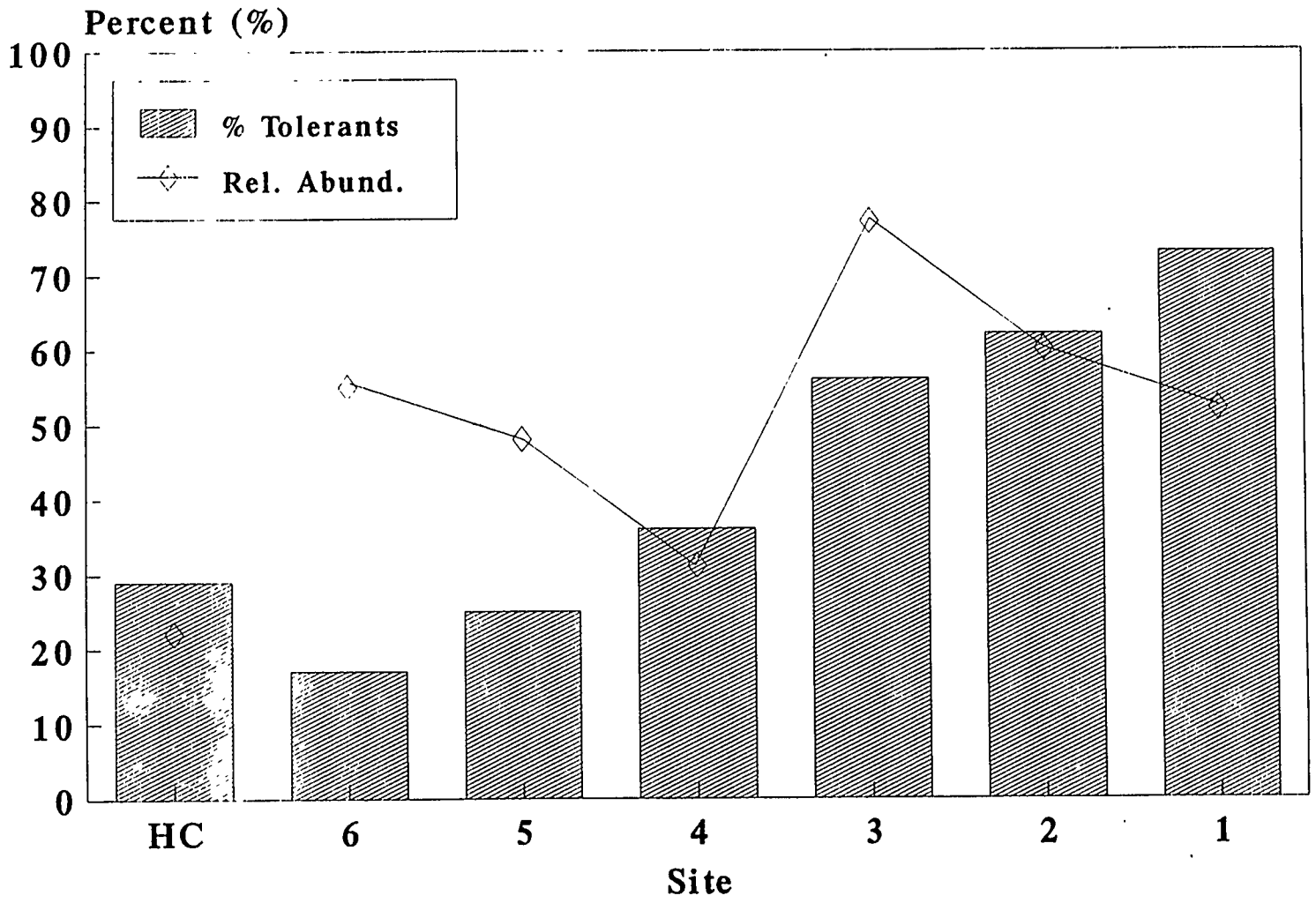

Fig. ES.22. Percentage of captured fish species from EFPC and Hinds Creek classified as tolerant of degraded water quality, October 7-12, 1991.

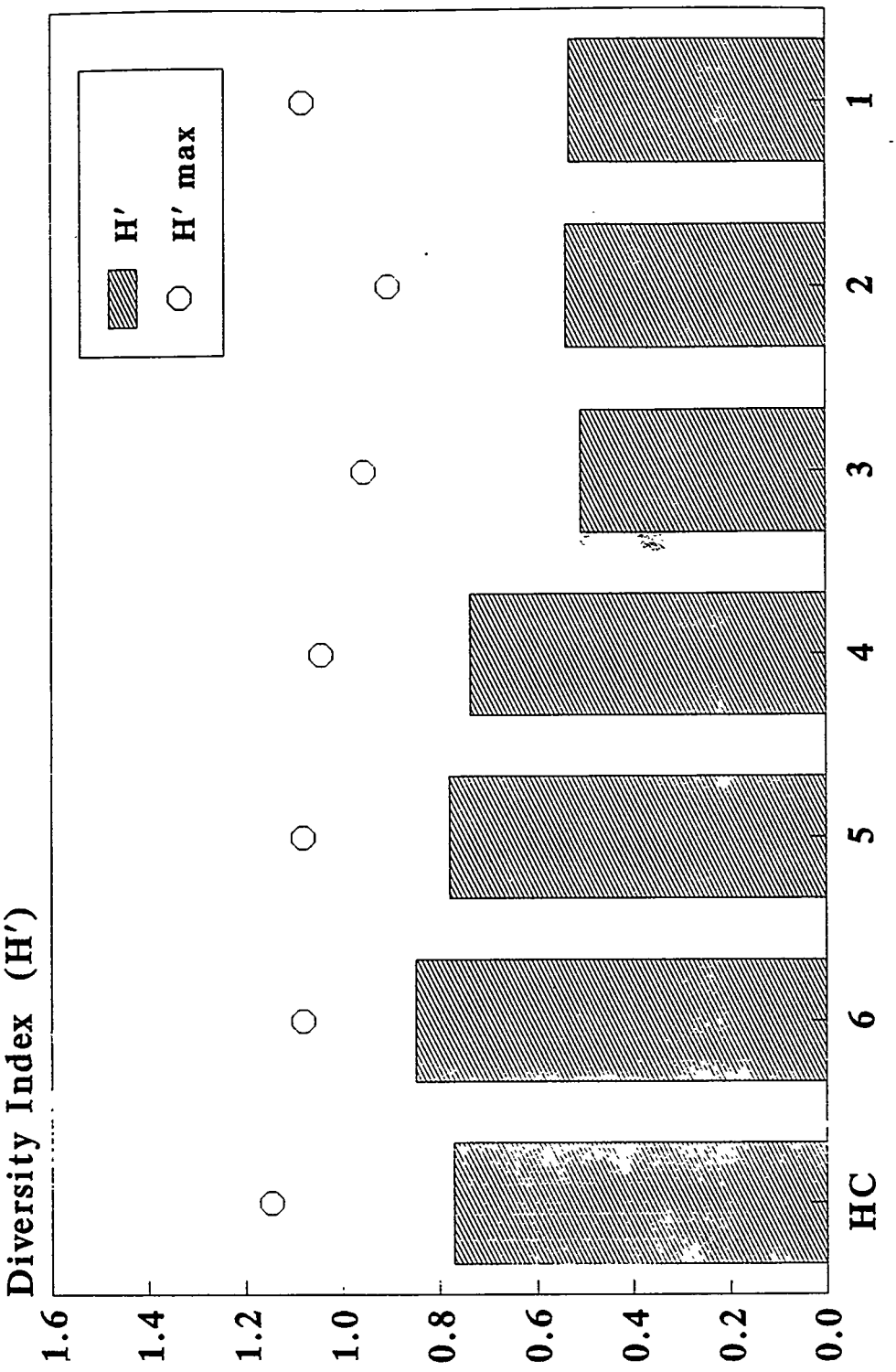

Fig. ES.23. Observed fish species diversity and maximum possible fish diversity at sites in EFPC and Hinds Creek, October 7-12, 1991

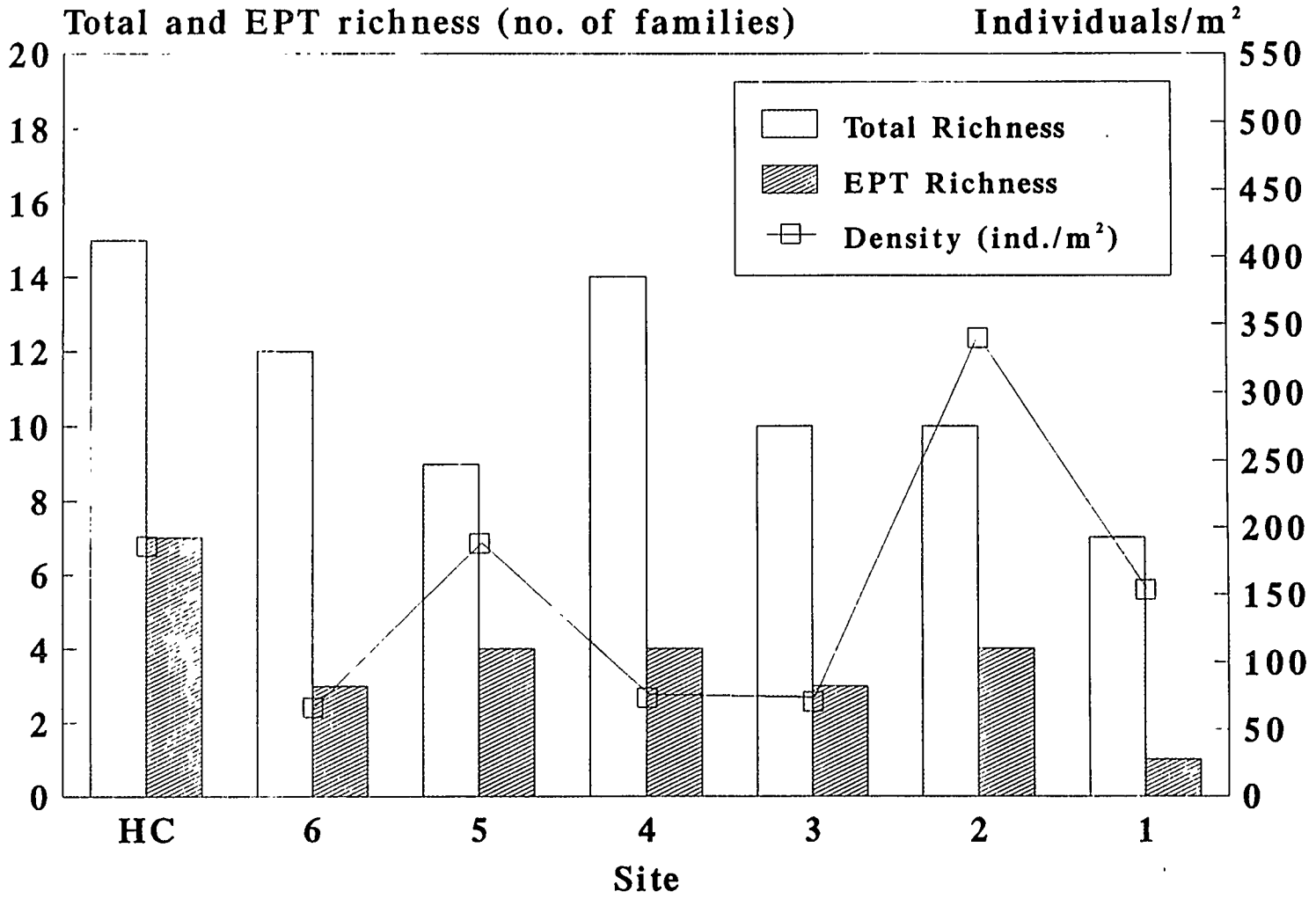

Fig. ES.24. Total family richness, EPT richness, and density (individuals per m^2) of benthic macroinvertebrates collected from EFPC and Hinds Creek, October 22-29, 1991.

the protection criterion indicates the severity of impact or risk, with larger quotients indicating larger potential impacts or risks. The second approach is to apply weight-of-evidence arguments to evaluate the strength of the relationship between stressors and observed effects on indicator species and the implications for assessment endpoints. This method helps to identify causes of observed ecological responses, using arguments derived from human epidemiology. In this approach, a causal relationship between a stressor and a response is proposed. Then, a series of questions or criteria is applied to the proposition. Not all criteria need be satisfied to demonstrate that the proposition is true, but weight is added to a conclusion by each criterion that is satisfied in the proposition(s). Ultimately, professional judgment is used to establish the strength of the causal relationship. The weight-of-evidence approach is especially useful when: (1) there are multiple lines of evidence to evaluate, (2) there are insufficient data for robust statistical analyses, (3) toxicity or other criteria are uncertain, or (4) exposure models are not sufficiently precise for statistical testing.

Quotient Methods Results. Risks to biota can be characterized by comparing exposure concentrations to specific criteria intended to be protective of the organism or its function in the ecosystem. Thus, criteria may be established to limit the concentrations of chemicals in surface water in order to protect aquatic biota (TDEC, Chap. 1200-4-3), or limits may be set on contaminant concentrations in tissues in order to protect organisms or their predators. Criteria may also be established by modeling the transfer of contaminants from exposure media through the food chain to the various biotic receptors, thereby taking into account bioaccumulation of contaminants. In the quotient method, if the ratio of exposure concentration to criterion concentration is < 1, risk is considered insignificant, whereas if the quotient is sufficiently > 1, risk is inferred (Barnthouse et al. 1986). Because of the uncertainty surrounding both sampling data and the criteria themselves, this approach requires careful interpretation of quotients near 1, but it provides a clear indication of high ($\geq$ 10) or low (< 0.1) risks. This method requires consideration of the uncertainty of estimating both the exposure concentration and the criterion values.

To address the assessment endpoints identified in Table ES.5 for the EFPC ERA, specific criteria were established for ambient water quality; for aquatic biota and predator body burdens; and for terrestrial mammals, birds, earthworms, insects, and predator body burdens. Threshold values for specific COCs (in particular, mercury, other heavy metals, PCBs, chlordane, and PAHs) were established for each of these criteria, and measured values in EFPC media and/or biota were compared to determine a quotient range. Tables ES.10 and ES.11 present the results of the quotient method results for aquatic and terrestrial exposures, respectively. As noted in the

Table ES.10. Classification of risk quotients for aquatic exposures by range and location[a]

Sample site	Quotient range[b]				
	Q>100	10≤Q<100	1≤Q<10	0.1≤Q<1	Q<0.1
1		WQC, Hg AI, pred. SR, PCB tox. SR, PCB pred.	CR, Hg tox. CR, PCB pred. RS, PCB tox. CR, PCB tox. RS, PCB pred.	WQC, Zn SR, Hg tox. RS, Hg tox.	
2		WQC, Hg SR, PCB tox. SR, PCB pred.	SR, Hg tox. CR, Hg tox. AI, pred. RS, PCB tox. RS, PCB pred.	WQC, Zn RS, Hg tox. CR, Hg tox. CR, PCB tox. CR, PCB pred.	
3		WQC, Hg	AI, pred. SR, PCB tox. RS, PCB tox. SR, PCB pred. RS, PCB pred.	WQC, Zn SR, Hg tox. RS, Hg tox. CR, Hg tox. CR, PCB tox. CR, PCB pred.	
4			AI, pred. SR, PCB tox. RS, PCB tox. SR, PCB pred. RS, PCB pred.	WQC, Zn SR, Hg tox. RS, Hg tox.	
5	HN, pred.	AI, pred.	HN, Hg tox. SR, PCB tox. RS, PCB tox. SR, PCB pred. RS, PCB pred.	WQC, Zn SR, Hg tox. RS, Hg tox. HN, PCB tox.	
6			SR, PCB tox. SR, PCB pred.	WQC, Zn CR, PCB tox. CR, PCB pred.	SR, Hg tox. RS, Hg tox. CR, Hg tox. CR, pred.

Table ES.10 (continued)

Sample site	Quotient range[b]				
	Q>100	10≤Q<100	1≤Q<10	0.1≤Q<1	Q<0.1
Reference				WQC, Zn SR, Hg pred. RS, Hg pred. CR, Hg pred. AI, Hg pred.	SR, Hg tox. RS, Hg tox. CR, Hg tox. SR, PCB tox. RS, PCB tox. CR, PCB tox. SR, PCB pred. RS, PCB pred. CR, PCB pred.

[a]Key:
WQC = Water quality criteria
SR = Stoneroller
RS = Redbreast sunfish
CR = Crayfish
AI = Aquatic insect
tox. = toxicity to indicator organism
pred. = toxicity to predators
HN = Heron
[b] Quotients based on concentrations below detection limits were not included.

Table ES.11. Classification of risk quotients for terrestrial exposures by range and location[a]

Sample site	Quotient range[b]				
	Q>100	10≤Q<100	1≤Q<10	0.1≤Q<1	Q<0.1
1	EW, pred.			TI, PCB pred. MS, PCB pred.	TI, PCB tox. MS, PCB tox.
2	EW, pred.	MS, pred. WR, pred.	WR, Hg tox. TI, pred.	MS, Hg tox. TI, PCB pred.	TI, PCB tox. MS, PCB tox. WR, PCB tox. MS, PCB pred. WR, PCB pred.
3	EW, pred.	TI, pred.		TI, PCB pred.	TI, PCB tox. MS, PCB tox. MS, PCB pred.
4	EW, pred.	SH, pred. WR, pred.	SH, Hg tox. WR, Hg tox.	WR, PCB tox. MS, PCB pred. SH, PCB pred. WP, PCB, pred.	TI, PCB tox. PCB tox. SH, PCB tox. PCB pred.
5	EW, pred. SH, pred.		SH, Hg tox.	SH, PCB pred. HN, PCB pred.	TI, PCB tox. MS, PCB tox. SH, PCB tox. TI, PCB pred. MS, PCB pred.
6		EW, pred.			TI, PCB tox. TI, PCB pred.
Reference			MS, Hg pred. EW, Hg pred.	MS, Hg tox.	TI, Hg tox. MS, HG tox. TI, PCB pred. MS, PCB pred.

[a] Key:
EW = Earthworm
TI = Terrestrial insect
MS = Mouse
SH = Shrew
WR = Wren
tox. = toxicity to indicator organism
pred. = toxicity to predators

[b] Quotients based on concentrations below detection limits were not included.

quotient ranges, measurable risks (≥ 10) are being observed for both aquatic and terrestrial biota, primarily through mercury toxicity to predators through the food chain. The higher quotients tended toward the upstream sample locations along EFPC, with small ecological risk noted for the reference sites. Several additional findings are highlighted below.

- **Toxicological effects.** Comparison of body burden concentrations with concentrations that have been proposed as protective against toxicological effects in the indicator organisms showed that 2 of 7 crayfish samples and 1 of 10 stoneroller composite samples had mercury concentrations exceeding toxicological limits. Body burdens of mercury in shrews were considerably above the toxicological limit, and the feathers and liver of a heron also exceeded toxicological limits.

- **FDA action limits.** A comparison of body burdens of contaminants in aquatic biota for human consumption with U.S. Food and Drug Administration (FDA) limits for these contaminants showed that redbreast sunfish and stonerollers sampled at the three sites closest to the Y-12 Plant exceeded the criterion for mercury. PCB levels in redbreast sunfish and stonerollers at Sites 1 and 2 and in sunfish at Site 3 also exceeded FDA limits. Mercury levels in crayfish sampled at Sites 1 and 2 exceeded FDA limits, but PCB levels in all crayfish were below the limits.

- **Protection of predators.** Comparison of body burdens of contaminants in aquatic biota with concentrations expected to protect their predators from toxicological effects showed that mercury concentrations in fish exceeded the criterion for mercury by ten-fold or more at all sites except the site farthest downstream. Concentrations in crayfish exceeded the criterion for mercury by at least ten-fold at the three sites closest to the Y-12 Plant, and mercury concentrations in aquatic insects exceeded the criterion by at least ten-fold at two sites. The same comparison applied to terrestrial mammals preying on contaminated organisms showed that earthworms at every site exceeded criteria for dietary mercury. If the mercury in the earthworms were bioavailable, exposure would be high, even if earthworms were only a small fraction of a predator's diet. Although terrestrial insect samples at Site 1 exceeded the criterion for mercury by a factor of 64, the mercury in insects is not likely to present a high risk to predators because predators of insects would not feed exclusively in the floodplain. Excessive levels of mercury in shrews and wrens likely result from their consumption of earthworms and insects, respectively, and, in turn, contribute to risk of those animals that prey on them.

Weight-of-evidence results. The weight-of-evidence analysis focused on risk to both aquatic and terrestrial ecological receptors. Three propositions were advanced for aquatic biota; these propositions were conclusions based on the results of the ERA field sampling, as well as historical studies on EFPC. The three propositions each began with the statement, "Continual releases of water-borne contaminants (including dissolved and particle-bound) such as mercury, uranium, other inorganics, pesticides, PAHs, and Aroclor 1260 from the Y-12 Plant," and are as follows:

> Proposition 1 — Continual release of water-borne contaminants . . . from the Y-12 Plant are the largest source of the elevated whole-body burdens of these contaminants in fish, benthic macroinvertebrates, and crayfish in EFPC, which results in risk from toxicological effects to indicator organisms and risks to piscivorous predators feeding on the organisms.
>
> Proposition 2 — Continual release of water-borne contaminants . . . from the Y-12 Plant impact fish community structure in EFPC, resulting in communities dominated by species tolerant of degraded water quality conditions.
>
> Proposition 3 — Continual release of water-borne contaminants . . . from the Y-12 Plant result in reduced taxonomic richness and diversity of the fish and benthic macroinvertebrate communities in EFPC compared to the same measurements in communities at the reference site.

The aquatic propositions were evaluated against five criteria (temporal association, spatial association, stressor-response, strength of association, and plausibility) and qualitatively ranked based on the level of available evidence. Major observations from the ERA field sampling and historical studies indicated that numerous COC body burdens in the aquatic indicator organisms (stonerollers, redbreast sunfish, crayfish, and benthic macroinvertebrates), as well as several measures of community structure (fish and benthic macroinvertebrates, taxonomic richness and diversity, and percentage of fish species classified as tolerants) showed the greatest impacts closest to the Y-12 Plant, then decreased downstream in EFPC. In addition, COC body burdens and community impacts in biota from all sites in EFPC usually were greater than equivalent impacts at a reference site.

The data for mercury and PCBs indicate a clear temporal association between the release of these two contaminants from the Y-12 Plant and their subsequent bioaccumulation in aquatic biota downstream in EFPC. Several variables (such as the percentage of captured fish species that are classified as tolerant of degraded water quality conditions, fish and benthic macroinvertebrate taxa richness, and species diversity) have consistently indicated that aquatic biota in EFPC are

adversely impacted in comparison to biota in a reference stream. Moreover, BMAP data show a recovering ecological system in the upper part of EFPC, below Lake Reality.

Spatial associations were strong for all three propositions based on current and historical evidence. Body burdens of many COCs were greatest in biota collected closest to the Y-12 Plant and decreased downstream. Also, the COC body burdens in biota from most sites in EFPC were greater than the body burdens in biota from the reference site. Similar trends were observed for the percentage of tolerant fish species (Proposition 2). Fish and benthic macroinvertebrate taxonomic richness and diversity (Proposition 3) generally increased downstream from the Y-12 Plant, indicating that the most severe impacts occurred closest to the plant.

Stressor-response associations were evaluated by determining linear correlation coefficients between estimated COC exposure concentrations (the stressor) and the magnitude of some response variable (e.g., percentage of fish classified as tolerants). In the absence of COC concentration data in surface water, COC body burden concentrations were used as an indicator of the stressor exposure level.

Mercury in surface water was significantly correlated with mercury body burdens in crayfish. Of the COCs that were below detection limits in surface water, ten were present in at least one of the aquatic indicator organisms at body burden concentrations that were maximum in samples collected closest to the Y-12 Plant, then decreased downstream. Mercury concentrations in surface water were correlated with the percentage of fish classified as tolerants, but zinc concentrations in surface water were not correlated (Proposition 2). Five contaminant body burdens in stonerollers were correlated with the percentage of fish classified as tolerants. Evidence of stressor-response associations between COC concentrations and taxonomic richness or diversity (Proposition 3) were practically absent. Thus, the data suggest a strong stressor-response association for Proposition 1, a moderate association for Proposition 2, and a weak association for Proposition 3.

Strength of association for all three propositions was strong. Likewise, plausibility for all three propositions was strong. The COCs from this study are known to bioaccumulate in most aquatic organisms. Although most COC concentrations in surface water were below detection limits, the large number of COC body burdens displaying longitudinal decreases in concentration downstream from the Y-12 Plant suggests that the Y-12 Plant is the source of the COCs in the biota (Proposition 1). Propositions 2 and 3 are plausible because the surface water mercury concentrations (0.54 to 0.32 μg/L) at the three sites closest to the Y-12 Plant exceed the

concentration known to cause toxic effects in fish (<0.1 μg/L). This alone could account for the observed impacts to the fish and benthic macroinvertebrate community structure and diversity.

The conclusions from the weight-of-evidence analysis have implications for the assessment endpoints associated with Policy Goals 4 (a fish community indicative of undegraded conditions) and 5 (no adverse effects from contaminants to aquatic organisms and/or predators that feed on them). For example, aqueous mercury concentrations in EFPC have been observed that exceeded levels known to produce toxicological impacts to sensitive (e.g., <0.1 μg/L in rainbow trout) as well as tolerant species (e.g., 0.23 μg/L in fathead minnows). This alone could affect community structure (Policy Goal 4 and its assessment endpoint), as demonstrated by increased proportion of tolerant fish species (Proposition 2) and impacts to taxonomic richness and diversity (Proposition 3). Elevated aqueous mercury concentrations that exceed ambient water quality criteria (AWQC) also place fish and benthic macroinvertebrate communities at risk, which links to Policy Goal 5 and assessment endpoint 5a. Elevated body burdens of mercury and other contaminants continue to place aquatic organisms and their predators at risk (Policy Goal 5, assessment endpoints 5b and 5c). The aquatic weight-of-evidence analysis indicates that Policy Goals 4 and 5 are not being met, most likely due to ongoing releases of contaminants from the Y-12 Plant.

The weight-of-evidence analysis for the terrestrial biota makes the following propositions concerning EFPC soil contaminants. Common to both propositions is the premise that EFPC soil contaminants were released from the Y-12 Plant and were transported by and deposited from EFPC surface water. The propositions are as follows:

(1) EFPC soil contaminants have resulted in elevated body burdens of these contaminants in terrestrial organisms residing on the floodplain, as indicated by field-observed measurements of earthworms, small mammals, and birds.

(2) EFPC soil contaminants have resulted in reduced abundance of terrestrial organisms residing on the floodplain, as indicated by field-observed measurements of terrestrial insects, especially 10 families of insects that live in or on surface soils or herbaceous vegetation.

The propositions explicitly address a subset of the EFPC terrestrial community—the animal indicator species. These species are generally ubiquitous and, for one or more of their life stages, relatively sessile inhabitants of the floodplain. The 10 families of insects considered in detail in the following analysis are inhabitants of soil, soil surface, or herbaceous vegetation, or are predators of other such inhabitants (Borros and DeLong 1964). The propositions link directly

to Policy Goal 7—the protection of terrestrial animals and their predators from the effects of contaminants. The propositions link indirectly to Policy Goal 2 because terrestrial organisms represent an essential resource for migratory birds passing through or residing seasonally on the floodplain.

The terrestrial weight-of-evidence analysis evaluated four criteria (spatial association, stressor-response, strength of association, and plausibility) and found that the weight of evidence supports these two propositions. It is concluded that increased body burdens of mercury and other contaminants in earthworms, mice, shrews, and wrens result from EFPC soil contaminants that originated at the Y-12 Plant and were transported by and deposited from EFPC surface water onto the floodplain. It is also concluded that the decreased abundances of 10 families of insects with terrestrial juveniles at EFPC biotic sample sites nearest the Y-12 Plant (especially Sites 1, 2, and 3) result from EFPC soil contaminants.

These conclusions have implications for the assessment endpoints. Elevated body burdens of EFPC contaminants in earthworms and their predators put still other unsampled and unanalyzed terrestrial predators on the EFPC floodplain at risk from exposure to these contaminants. Reductions in insect abundances may decrease the carrying capacity of EFPC for numerous species of insectivorous birds that raise their young on the floodplain in the summer. Combined with elevated body burdens of contaminants in insects, this represents an even more potentially serious risk to bird populations. Thus, Policy Goals 2 and 6, the protection of migratory birds and the maintenance of terrestrial animal communities indicative of undegraded conditions, are probably not being met as a result of EFPC soil contaminants that originated at the Y-12 Plant and were transported by and deposited from EFPC surface water onto the floodplain.

ES.3.2.5 Spatial distribution of ecological risk

The floodplain was organized into nine risk assessment segments (Fig. ES.25). These segments were developed based on the similarities of the distribution of contaminants and land use. A more descriptive explanation of the criteria for segment selection is found in Sect. 5 of the RI. Segments 1, 2, 3, and 4 are located in the upper part of the creek, below Lake Reality, whereas Segments 5, 6, 7, and 8 are located further downstream along the east-west axis of the stream. The longest segment (Segment 9) covers approximately the last 25 percent of the EFPC floodplain, and its western edge is located at the confluence with Poplar Creek. The same risk assessment segments are being used in both human health risk and ecological risk in this RI.

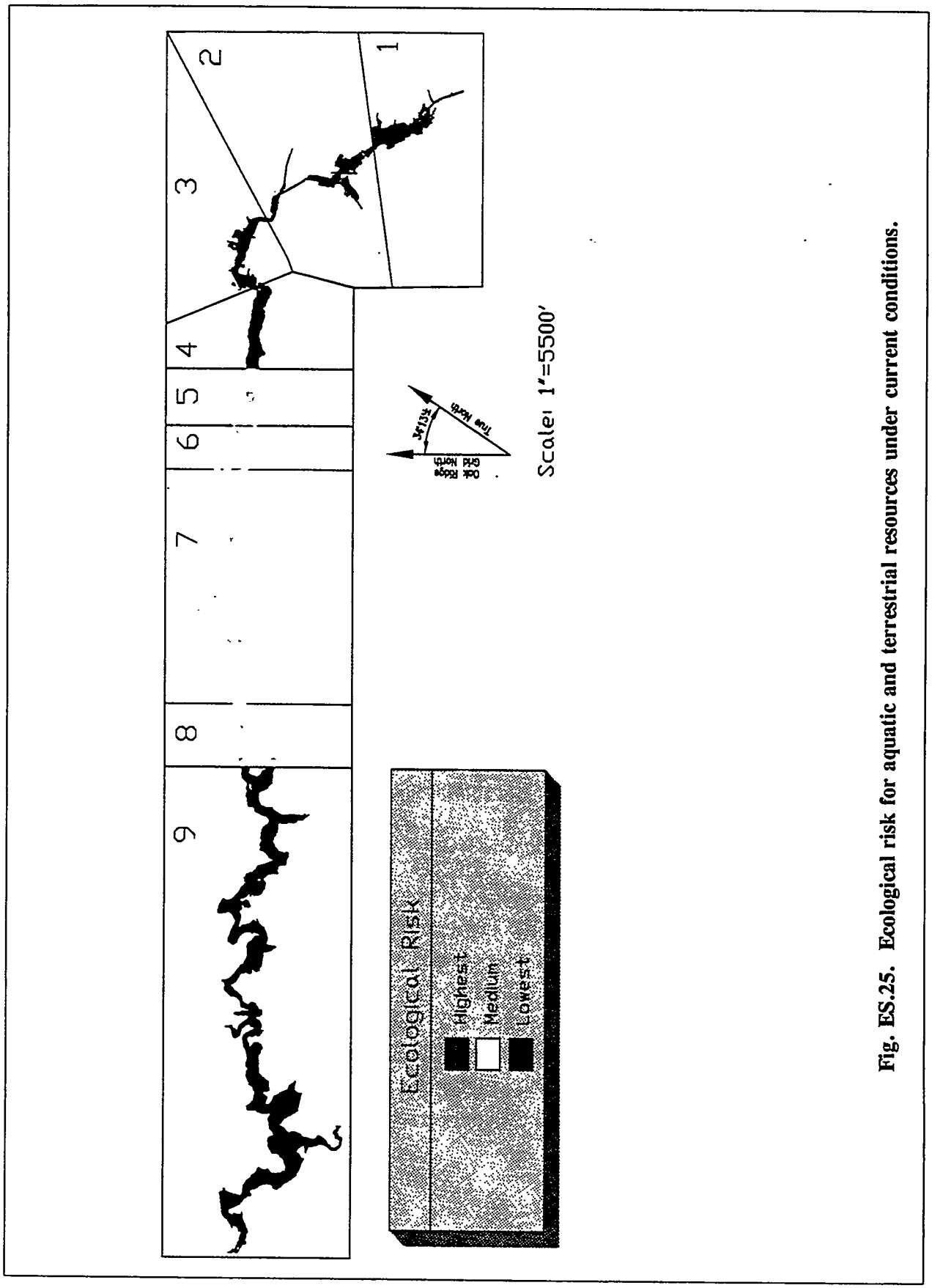

Fig. ES.25. Ecological risk for aquatic and terrestrial resources under current conditions.

Ecological risk differs from segment to segment along the ~23-km (14.2-mile) course of EFPC. Risk varies due to trends in exposure to contaminants and as measured by comparing contaminant body burdens relative to protective criteria (quotients) and weight-of-evidence discussions on spatial associations. Based on the trend that most contaminant body burdens, ecological community effects, and risk quotients decrease downstream from the Y-12 Plant, ecological risk is highest in Segments 1, 2, 3, and 4; these segments are closest to the source of the contamination. Also, there are several contaminated wetlands with resident invertebrates, amphibians, and other animals in these segments. Ecological risk is lowest in Segment 9, which is the segment farthest downstream from Y-12; contaminant body burdens and other assessment endpoint measures are also lowest in Segment 9. Ecological risk is intermediate in Segments 5, 6, 7, and 8, which are located in the midstream portion of EFPC.

Along this overall gradient of ecological risk and within each segment, two types of ecological resources are at risk: aquatic and terrestrial. Aquatic resources—fish, benthic macroinvertebrates, and primary producers—are at highest risk because they live in the water and are exposed continuously via body contact. The highest exposures occur in the highly contaminated aquatic area below Lake Reality. Risks to aquatic biota are greatest immediately downstream from the Y-12 Plant (EFK 20-23). Some locations in the creek provide contaminated prey to fish-eating predators. Exposures to aquatic and piscivorous biota decrease downstream. Aquatic ecological resources are subjected to a greater risk, segment by segment, than are the terrestrial resources in that particular segment.

As indicated above, terrestrial resources—birds, small mammals, worms, arthropods, and vegetation—exhibit less risk and less definitive trends than the aquatic resources for a particular segment. Exposures to terrestrial animals are primarily via contaminated animal food, in which contaminant levels are related to soil contaminant concentrations. Initial work shows that terrestrial areas of highest mercury concentrations are sometimes found in the bottomland hardwood forests, where flooding is most likely to have occurred. The systematic and rigorous associations among soil contamination patterns, habitats, and field-observed ecological effects will be developed for the FS/EIS activities. Yet, as explained in the risk quotient and terrestrial weight-of-evidence sections, available terrestrial measurements show trends. These trends consist of decreasing contaminant body burdens and more "normal" arthropod community structures as distance increases from the Y-12 Plant. Thus, both the aquatic and terrestrial organisms in the EFPC environment are at differing risks as a function of distance from the Y-12 Plant. In turn,

these ecological risks are in three large patterns: highest in Segments 1, 2, 3, and 4 (upper reach); intermediate in Segments 5, 6, 7, and 8 (middle reach); and lowest in Segment 9 (lower reach).

ES.3.2.6 Future exposures and risks

Many future exposure scenarios are possible. If there is no remediation at either the Y-12 Plant or the EFPC floodplain, exposures of the biota will not change significantly. Cessation of releases from routine Y-12 Plant operations would likely reduce chronic exposures in EFPC, but releases into EFPC by stormwater runoff from the Y-12 Plant into EFPC would likely continue. Revisions in Y-12 Plant operations that caused a reduction in the volume of water, but not in contaminants, flowing into EFPC could increase exposure concentrations to aquatic biota. Closure of the Y-12 Plant would alter the base flow of EFPC, causing disruption of many biotic communities, especially in the upper reaches of the creek. Because ongoing releases of contaminants from the Y-12 Plant into EFPC dominate the effects on aquatic biota in EFPC, it is not clear what baseline contaminant body burdens would be if the EFPC floodplain and sediments were the only source of contaminants to surface water.

The future (i.e., assuming no change from current conditions) would result in the continued exposure of: (1) aquatic biota via direct contact and ingestion of EFPC surface water, sediment, and food; (2) aquatic predators preying on other contaminated aquatic organisms or terrestrial insects; (3) terrestrial animals dwelling in or consuming contaminated soil; and (4) terrestrial predators preying on contaminated aquatic or terrestrial animals in the EFPC floodplain. The continued exposures of aquatic and terrestrial biota and their habitats to contaminants would result in continued elevated body burdens of contaminants in these biota and risk to their predators, along with impacts to community structure and taxa diversity.

Wetlands in contaminated areas of the floodplain would continue to receive contaminants transported by storm flow. Contaminated soils could act as a source of contamination to wetlands in the watershed. Contaminated soils could be eroded and transported as suspended load in the high flow of flood events. As flow velocity decreases and flood waters recede, contaminants transported as suspended solids drop out of suspension and are redeposited in wetlands in another part of the floodplain. Because wetlands in the EFPC floodplain have formed in low-lying areas of the floodplain subject to deposition, the wetlands could receive future contaminants. In this manner, contaminants could migrate, and relatively uncontaminated soils in the floodplain

downstream from the source area could become contaminated. In the future, contaminated soils in wetlands would remain a potential source of contamination to numerous other receptors, including soil, sediment, surface water, groundwater, plants, animals, and humans.

The floodplain contains trees, some of which have cavities and other hiding/brood places for bats. It is likely that these trees will remain and provide potential habitat to threatened and endangered bat species. However, the endangered Indiana bat has major population centers in Missouri and Kentucky and is not likely to reach eastern Tennessee. The endangered gray bat is also concentrated in cave regions; the species is mostly found in Arkansas, Missouri, Kentucky, Tennessee, and Alabama and forages primarily along rivers or lake shores. It is not likely that this bat will expand its range to the small stream area of EFPC.

ES.3.2.7 Comparison of ERA results with assessment endpoints

As documented in the Problem Formulation phase of this ERA (Table ES.5), 11 assessment endpoints were identified that would help to determine whether existing site conditions provided attainment of the ecological goals set for the EFPC watershed. Following the conclusion of the Exposure Characterization, Effect Characterization, and Risk Characterization phases, and within the limits of the uncertainties associated with this type of study, the risk assessment can be compared to these baseline assessment endpoints to get a clearer picture of the overall ERA results. Table ES.12 provides a listing of the defined endpoints along with the respective ERA results from direct surveys or risk characterization analyses (quotient or weight of evidence). A few of the key results of this comparison and conclusions from the ecological risk follow:

- Three assessment endpoints (assessment endpoints 2, 4, and 9 in Table ES.12) were achieved with the current EFPC contaminant conditions.
- Measurements or results obtained using risk characterization methods indicate that the rest of the assessment endpoints are not met with existing EFPC floodplain conditions, i.e., many body burdens exceed the protective concentrations.
- There is substantial ongoing risk to ecological resources, particularly aquatic organisms in the upper part of the creek, from exposure to contaminants in environmental and biological media of EFPC. The results of the ERA do not indicate a need for immediate short-term action to mitigate exposures or risks to ecological health. However, remediation will be necessary to reverse the existing negative impacts.

Table ES.12. Comparison of ERA results with assessment endpoints

Assessment endpoint	ERA result
1. No harm to any threatened and endangered species and their critical habitat of the EFPC floodplain	1. Literature and field surveys did not reveal threatened and endangered species living in EFPC floodplain. Habitat that could support an expansion of the range of a threatened and endangered species (e.g., Indiana and gray bats) was found. However, a range expansion of such species is not likely.
2. Maintenance of plant community composition and/or structure required for rare plant and animal and support species	2. Literature and field surveys did not find that potential habitat — plant community — for rare animal or support species was harmed by EFPC contaminants. Wetlands may be an exception depending on the preliminary remediation goal.
3. No killing or harming of migratory birds as a result of exposure to site-specific stressors	3. Field survey evidence provides names of more than 30 migrant bird species, which are likely ingesting contaminated worms and arthropods and, therefore, likely being affected by EFPC contaminants.
4. The presence and structure/function of wetlands in relation to contaminants	4. Seventeen wetlands exist in the floodplain, some with mercury contamination, but each appears to be functioning.
5. Fish communities in which the proportion of species tolerant of degraded water quality is <30%	5. Continual releases of water-borne contaminants are apparently sufficient to impact fish community structure, resulting in communities dominated by species tolerant of degraded water quality conditions at the 4 sites closest to the Y-12 Plant.
6. Ratio of contaminant concentration in surface water to water quality criteria for protection of aquatic life ≤1	6. The quotient method indicated significant exceedances by factors up to 45 from mercury concentrations above water quality criteria of EFPC below Lake Reality.
7. Aquatic indicator organisms contaminated body burden ratio to toxicological effects levels ≤1	7. Contaminant body burden measurements and quotients of 1 or less for mercury and up to 20 for PCBs were determined for stonerollers, redbreast sunfish, and crayfish.
8. Fish contaminant body burden ratio to protect piscivorous biota levels ≤1	8. The quotient method identified numerous exceedances by factors of 10 to >100 for mercury and up to 16 for PCBs for fish contaminant body burdens in a predator pathway.
9. Terrestrial animals with diversity, abundance, and distributions indicative of undegraded conditions resulting in ≥20 or more percent decrease compared to the reference	9. Some organisms missing from certain sampling sites may indicate large decreases in abundances. Other findings suggest that no 20% decreases occur.
10. Ratio of contaminant body burdens in terrestrial indicator species to toxicological effects levels ≤1	10. Body burdens of heron, wrens, and shrews were found to exhibit quotient ranges between about 2 and 8 for mercury in the ERA sampling.
11. Ratio of contaminant body burdens in terrestrial indicator species to levels protective of terrestrial predators ≤1	11. Contaminant body burden quotients in excess of 100 were determined for herons, earthworms, and shrews for predator pathways. Quotients for mercury were as high as 19 for mice and 70 for wren predators.

- Ecological risks come from two distinct sources. A preponderance of exposure to aquatic biota comes from water-borne contaminants being released from the Y-12 Plant during current operations. Additional contributions, albeit much smaller, to ecological risk come from the Oak Ridge Sewage Treatment Plant and other commercial and residential point and nonpoint sources along the creek. Experiments on methylmercury and other mercury uptake in fish held in tanks with various combinations of uncontaminated and contaminated water and with/without sediment indicate the minor role of the sediment as an exposure pathway to aquatic organisms. AT PRESENT

- The food chain is a primary exposure pathway for both aquatic and terrestrial fauna. Direct contact with the surface water is also an exposure pathway for aquatic biota. Direct contact with and ingestion of soil are significant to the health of terrestrial biota as points of entry for contaminants into the food chain.

- Methylmercury concentrations are very low (<0.01% of total mercury) in EFPC soils and sediments. However, methylmercury was assumed from BMAP and other evidence to be the predominant mercury species in aquatic biota, including flying aquatic insects. Consumption of contaminated aquatic biota may provide a high risk to terrestrial piscivores.

- Recovery of the aquatic ecological community has been occurring in the upper reaches of the creek above and below Lake Reality, as documented by BMAP and the present study. Dechlorination of process waters and other remedial activities at Y-12 have lowered the concentrations of some water-borne chemical stressors; thus, exposure has decreased, followed by partial ecological recovery. However, elevated contaminant body burdens and an excess of tolerant species are still present.

- Water-borne contamination (especially mercury and PCBs) must be controlled for protection of aquatic biota. In the FS/EIS, the implications of this and other findings will be rigorously and systematically examined.

ES.4 PRELIMINARY REMEDIATION GOALS

Results of the characterization of the nature and extent of EFPC contamination and of the BRA were used to develop *preliminary remediation goals* (PRGs) for the FS. PRGs are initial chemical-specific, numeric cleanup limits for each affected environmental medium that are protective of human health and the environment and that comply with ARARs. PRGs were developed for children and adults using results of the human health risk assessment.

The process of deriving a PRG consists of establishing an acceptable target risk value for exposure to a contaminant, and back-calculating the corresponding concentration in the environmental medium under evaluation. EPA requires the use of a 10^{-6} risk level as the point of departure for determining remediation goals for carcinogens and an HI score of 1 for noncarcinogens.

The listing of PRGs presented in this report includes all human health COCs that were evaluated in the Tier II risk assessment. However, this is a starting point, and remediation will *not* be required for all of these substances. For example, the presence of beryllium and manganese in EFPC floodplain soils was not significantly different from levels at the reference location. While the list will be refined during the FS, the PRGs for mercury in the agricultural setting (58 mg/kg for children and 198 mg/kg for adults) will be used for the FS alternatives screening. The soil pathway appears to be the most appropriate to determine the need for remediation.

Based on the results of the human health BRA, the primary pathways driving the risk assessment are the food chain pathway, the soil ingestion pathway, and the groundwater ingestion pathway. These results indicated that mercury (noncancer effects) and arsenic (carcinogenic effects) are the principal COCs for EFPC.

For the purposes of comparison, Fig. ES.26 shows the relative magnitude of the human health PRGs for mercury for all pathways related to soil and sediment. The PRGs are much lower for the ingestion pathway compared to direct soil contact. This directly reflects the conservative exposure assumptions adopted for the food chain pathways. The extremely high PRG for sediments reflects the limited exposure potential via this pathway.

The groundwater ingestion pathway is unlikely to adversely affect residents of EFPC. No one is currently using groundwater as a drinking water source nor are they likely to in the future. It is highly unlikely that the unfiltered water would be representative of the water ingested by homeowners, if there were a well installed. A more representative sample is the filtered groundwater. Although concentrations of COCs in the filtered groundwater are below federal MCLs, the risk assessment indicates that both the risk measures are outside the acceptable levels, primarily due to the presence of arsenic and manganese. Although it cannot be demonstrated that arsenic is not derived from DOE's Y-12 Plant, it is suspected as an area source. The PRGs for arsenic were calculated for groundwater ingestion and were significantly lower. Analytical

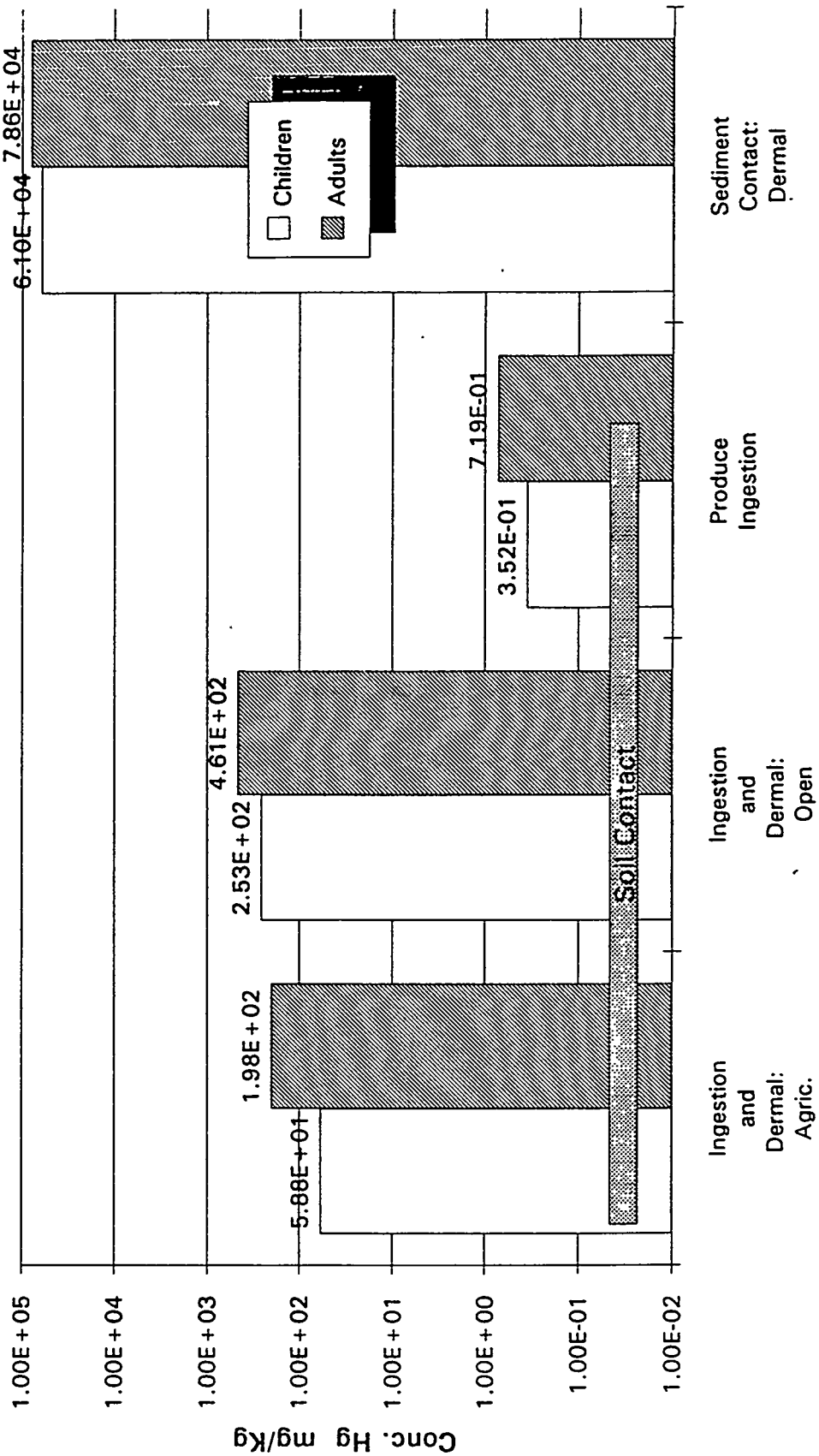

Fig. ES.26 Human health PRGs for mercury in soils and sediment of EFPC.

laboratories may be able to reach 3 μg/L as the instrument detection limit, but the uncertainty at this level is extremely high. It appears that it is physically impossible to reach the PRGs, given the current analytical methods.

The ecological PRGs are based on (1) analytical data obtained during sampling of biota, (2) physical media sampling carried out during Phase Ia and Phase Ib, (3) published information about the toxicity of mercury, cadmium, PCBs, chlordane, and PAHs, and (4) relationships among these findings. These relationships are expressed as formulae on a medium-by-medium basis. Emphasis is on sediments and soil.

For mercury in sediments, an equilibrium partitioning equation was used to calculate the PRG, which was set at 10 mg/kg.

For mercury in soils, four pathways were examined. Using equations for incidental ingestion, a lower limit of 3240 mg/kg was calculated. For inhalation of vapors from soil, the lower limit was 185 mg/kg. A lower limit of 230 mg/kg has been determined from food chain equations used to calculate levels for protection from toxicity and in discussions of the food chain, especially in relation to protection from predators that would feed on contaminated prey. The PRG for mercury in soil to protect ecological resources associated with soil was set at 200 mg/kg.

During the FS-EIS, these goals will be refined further to produce *final remediation goals.*

ES.5 RECOMMENDATIONS FOR FS-EIS DEVELOPMENT

Based on the results of the RI, BRA, and ERA, the following basic conclusions and recommendations are put forward for consideration in the development of the follow-on FS-EIS for EFPC. While many other important findings and results have been presented in earlier sections of this report, this summary is meant to reduce the large volume of information associated with this complex study into the principal guidance for remediation planning. This guidance has been summarized by EFPC/SLB environmental medium of concern for ease of incorporation into the follow-on studies.

ES.5.1 Surface Water

There is currently no excessive risk to human health associated with contaminants in surface water in EFPC, and in general the mercury concentrations are below drinking water standards (except on occasion in the upper reaches of the stream). Nonetheless, the preponderance of risk

to aquatic biota comes from water-borne contaminants currently being released from the Y-12 Plant (a facility not within the Lower EFPC OU). These releases appear to be affecting the fish community structure, resulting in communities dominated by species tolerant of degraded water quality conditions, and have caused reduced taxonomic richness and diversity in fish and benthic macroinvertebrate communities in EFPC compared to uncontaminated reference streams. This ongoing contaminant source will be addressed to ensure protection and long-term recovery of the EFPC ecological community.

ES.5.2 Groundwater

The groundwater ingestion pathway is unlikely to affect the human or ecological populations along EFPC. No one is currently using groundwater as a drinking water source, nor are they likely to in the future due to the availability of a municipal water supply. The results of the BRA demonstrate that the unfiltered levels of inorganic chemicals (primarily mercury and manganese) are primarily responsible for the elevated risk levels observed, a condition that would be substantially reduced by routine groundwater treatment for home or area use. To eliminate groundwater from further consideration, and to remove all doubt arising from the observed elevated risk levels, it is recommended that additional existing groundwater sampling data be obtained from applicable reference areas in the local vicinity of the ORR and that the resulting concentrations be used to calculate the overall risk to human health and to ecological receptors. These risks could then be compared to verify that the groundwater pathway should be eliminated from future remediation planning in the FS.

ES.5.3 Soils

Floodplain soils contain the highest levels of contaminants of all the EFPC environmental media. Potential COCs in the soils consist of inorganic trace metals, PCBs, PAHs, and radionuclides. Mercury was identified as the principal nonradiological contaminant through a concentration toxicity screening process, and uranium was identified as the primary radiological contaminant. Both of these contaminants are directly attributable to the past operations of the Y-12 Plant. Five million cubic feet of contaminated soil have been calculated to exist within the floodplain and SLB. The results of the BRA indicate that soil ingestion is the most appropriate basis for determining the need for site remediation. The ERA also identified the soil pathway as a concern to EFPC biota, primarily through terrestrial predator food pathways. PRGs have been derived for the observed chemical contaminants in soil for use in the initial screening of remediation alternatives in the FS-EIS. The ecological PRG for mercury in soil is 200 mg/kg. Final remediation goals will be determined as part of the CERCLA process leading to a Record

of Decision. Incorporation of quantified ecological goals and approved human health goals, in conjunction with the results of the soil contamination data, will identify locations where soil remediation may be required.

ES.5.4 Sediments

Creek sediments contain the same contaminants as floodplain soils, but at lower concentrations. Because of the transient nature of the sediments within the EFPC, however, the distribution of the contaminants is less predictable than in the soils. The same general patterns do exist, with the upper reaches of the creek showing somewhat elevated levels of the sediment contaminants (primarily mercury). Due to the nature of the sediments and their generally lower levels of contamination, the BRA identified little risk to human health via this environmental medium. The PRG established for mercury in sediments for children was 61,000 mg/kg, a value which essentially eliminates this medium from remediation concern for human health considerations. However, the ecological impact of the contaminated sediment pathway, while only partially understood at this point, may be significant but will be deferred in the future evaluations. Consequently, contaminant body burdens of mercury in aquatic biota, particularly from benthic invertebrates and aquatic predators, indicate a potential for significant bioaccumulation of contaminants in the food chain. The ecological PRG has been determined to be 10 mg/kg for sediments.

ES.5.5 Air Pathway

No COCs have been measured in air along the EFPC or within the vicinity of the ORR that are of human health or ecological concern. This pathway, therefore, should be eliminated from remediation consideration in the FS-EIS.

ES.5.6 Direct Radiation

Direct radiation measurements made along the EFPC floodplain documented the background levels of direct exposure resulting from natural and man-made radionuclides. No human health or ecological impacts from these background levels could be determined from the BRA or ERA studies, and the recommendation is that direct radiation pathways be eliminated from further consideration in the FS-EIS.

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1. INTRODUCTION

This Remedial Investigation (RI) report documents the results of investigation of the nature and extent of contamination of Lower East Fork Poplar Creek (LEFPC), its associated floodplain, and the city of Oak Ridge Sewer Line Beltway (SLB). This contamination is related to activities at the Department of Energy (DOE) Oak Ridge Y-12 Plant, which encompasses the headwaters of East Fork Poplar Creek (EFPC). The results of this investigation are used for the assessment and determination of current and future baseline human health and ecological risk.

Several key sections of this RI comprise the principal findings of this investigation. Section 1 presents the regulatory initiative for the EFPC RI within the context of the DOE Oak Ridge Reservation (ORR). The investigation of the environmental media to determine the nature and extent of contamination is presented in Sect. 3. The results of the baseline human health risk assessment are found in Sect. 5, and the findings of the baseline ecological risk assessment are located in Sect. 6. Because this investigation has produced a large volume of spatial data, reference to the maps presented in Volumes VII and VIII is essential to the understanding of these findings.

Investigation of the potential off-site transport of contaminants from the Y-12 Plant via EFPC was initiated in accordance with the requirements of the Resource Conservation and Recovery Act (RCRA) of 1980, as amended by the Hazardous and Solid Waste Amendments (HSWA) of 1984. Since that time, DOE has entered into a Federal Facility Agreement (FFA) with the appropriate state and federal regulators which defines the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) in 1986, as the lead regulatory driver. For this reason, the EFPC RI will fulfill the requirements of a RCRA facility investigation (RFI) as an applicable or relevant and appropriate requirement (ARAR).

The results of this EFPC investigation will be used to satisfy requirements of subtitle C of RCRA to provide for the safe management of hazardous waste. As such, the objective of this investigation conducted under the CERCLA process is to gather information sufficient to support an informed risk management decision regarding which remedy appears to be most appropriate for a given site. Requirements of the National Environmental Policy Act (NEPA) are being integrated into the CERCLA process and will be satisfied by the subsequent issuance of a combined Feasibility Study-Environmental Impact Statement (FS-EIS).

Potentially impacted environmental media along EFPC include surface water, creek sediment, groundwater, floodplain soils, and ambient air above the creek and floodplain. The media of concern along the SLB were limited to soil due to the absence of potential migrational pathways. Each of these media was assessed for the presence of contamination following an approved integrated sampling and analysis plan. Initial sampling, Phase Ia, characterized the nature of the contaminants through sampling for a broad range of analytes in areas of known contamination from previous investigations. Follow-on sampling, Phase Ib, was implemented to delineate the extent of contamination using a statistical modeling process to optimize sampling density and cost. The results of the sampling and analysis indicate that elevated levels of mercury and other metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and radionuclides (isotopic U and Th) are found in each medium (except ambient air), but are most significant in floodplain soils and creek sediments.

A baseline human health risk assessment has been conducted to determine if an imminent and substantial hazard to human health exists under current conditions in the absence of remedial actions. Identification of potential contaminants of concern (COCs), potential routes of exposure to human receptors, and the likelihood of adverse health effects resulting from exposure provides a basis for characterizing current and future risk associated with EFPC and the SLB. The results of the creek-wide assessment have been evaluated for each pathway, receptor group, and land use area for toxicity and carcinogenic effects under current and future uses. Current and future risk through ingestion of soil, water, and elements of the food chain in excess of established guidelines were identified for open and residential land uses.

Current and future risks through dermal absorption, inhalation, and ingestion of soil, water and elements of the food chain in excess of established guidelines were identified for particular land use patterns in nine discrete segments of the creek. Under the Reasonable Maximum Exposure (RME) scenario, residential and agricultural land uses (due to the food chain pathway) always result in unacceptable risks to human health for both current and future conditions. The commercial and open land uses never result in unacceptable risks to human health under either current or future scenarios. Unacceptable risks are always associated with exposure to chemical contaminants and never to the presence of radionuclides. Extremely high risks from the produce ingestion pathway are attributable to mercury, manganese, cadmium, and arsenic for noncarcinogenic effects, and primarily to arsenic for unacceptable cancer risks. However, uncertainty analysis shows that the RME is an extremely conservative scenario. In fact, a risk estimate of the "noncontaminated" reference site also exceeds the established acceptable range.

A baseline ecological risk assessment (ERA) was conducted to determine if an imminent and substantial hazard to ecological resources (animals, plants, and habitats) exists in the absence of remedial actions. The assessment used recent U.S. Environmental Protection Agency (EPA) and DOE guidance for problem formulation, exposure characterization, effects characterization, and risk characterization. The following groups of organisms were measured for their abundance and contaminant body burdens: fish, benthic macroinvertebrates, periphyton, mammals, birds, insects, annelids, and vegetation. These findings were compared to previous investigations on EFPC. Four aquatic and ten terrestrial habitat types were mapped and a geographical information system was utilized for data evaluation.

The food chain is a primary exposure pathway for both aquatic and terrestrial fauna. Direct contact with the surface water is also an exposure pathway for aquatic biota. Direct contact with and ingestion of soil are significant to the health of terrestrial biota only as points of entry into the food chain. Organisms higher in the food chain bioaccumulated contaminants and these observed concentrations exceeded a variety of protection criteria for predators. This and other abundant evidence show that aquatic populations such as fish in the upper reaches of EFPC are currently impacted negatively by water-borne contaminants, especially mercury and PCBs. These contaminants, as well as PAHs and pesticides, have resulted in elevated contaminant body burdens and changes in community structure, including the absence of species in habitats where they are expected to occur. This longitudinal trend decreases with distance from the Y-12 Plant.

The DOE Oak Ridge Field Office (DOE-OR) Document Content and Response Committee has developed an outline for RI/Baseline Risk Assessment (BRA) reports. This RI report has been developed in accordance with revision 1 of this outline, issued by DOE-OR on July 22, 1992. This report is organized as follows:

- Sect. 1 - Introduction and overview which presents the regulatory initiative, the Environmental Restoration Program (ERP), and the project scope, problems, objectives and schedule.

- Sect. 2 - Environmental setting, including the site geography, geology, hydrology, and ecology.

- Sect. 3 - Site history and current conditions which summarize the results of previous investigations and present the findings of the RI by each environmental medium.

- Sect. 4 - ARARs to be fulfilled during investigation and remediation of EFPC.

- Sect. 5 - Baseline human health risk assessment which identifies chemicals of potential concern, assesses exposure and toxicity, and characterizes the current and future risk.

- Sect. 6 - Baseline ecological risk assessment which identifies ecological hazards, assesses exposure and effects, and characterizes the current and future risk.

- Sect. 7 - Preliminary remedial action goals, describing the process of establishing these goals for each medium of concern and the current criteria for these values.

- Sect. 8 - Conclusions and recommendations which integrate and justify the findings and evaluations presented in the RI.

The purpose of the introductory section is to provide background information about the DOE-OR's ERP for the ORR generally and for EFPC specifically. Section 1.1 briefly describes the primary regulatory initiatives guiding the investigation and remediation of the ORR. Section 1.2 describes the general approach to remediation on the ORR. Section 1.3 summarizes remedial activities at the Y-12 Plant, which are being performed in accordance with the overall ORR approach to remediation. Section 1.4 summarizes the steps that have been performed and those still to be taken to complete the environmental restoration process at EFPC. Sections 1.5, 1.6, and 1.7 address objectives of the RI, special problems identified during the RI of EFPC, and the schedule for proceeding with preparation of the FS for EFPC.

1.1 REGULATORY INITIATIVES

On November 21, 1989, EPA placed the DOE's ORR and its environs on the National Priorities List (NPL) (Vol. 54 *FR* No. 233.48187). On January 1, 1992, an FFA between DOE-OR, EPA Region IV, and the Tennessee Department of Environment and Conservation (TDEC), formerly the Tennessee Department of Health and Environment, was implemented. This FFA establishes the procedural framework and schedule by which DOE-OR will develop, coordinate, implement, and monitor environmental restoration activities on the ORR in accordance with applicable federal and state environmental regulations.

The DOE-OR ERP for the ORR addresses the remediation of areas both within and outside the ORR boundaries, including Oak Ridge National Laboratory (ORNL), the former Oak Ridge Gaseous Diffusion Plant (K-25 Site), the Y-12 Plant, Oak Ridge Associated Universities (ORAU), the Clinch River, and EFPC, which is summarized in the ORR Site Management Plan for the ERP (DOE/OR-1001). The subject of this report is the portion of EFPC flowing from Lake Reality at the Y-12 Plant through the city of Oak Ridge to its confluence with Poplar Creek, and the surrounding 670 acres of floodplains. Both EFPC and its floodplains have been contaminated by hazardous, radioactive, and mixed waste releases from the Y-12 Plant since the mid-1950s. The primary COC is mercury.

Because EFPC is considered to be part of the ORR, it is included on the NPL, and its remediation must follow the specific procedures mandated by CERCLA of 1980, as amended by SARA in 1986. Because the contamination of EFPC is the result of the off-site release of contaminants from the Y-12 Plant, its remediation must also conform with the procedures of Sect. 3004(v) of RCRA, as amended by the HSWA. Actions taken to remediate EFPC may affect the environment, and the potential environmental impact of those actions must be publicly addressed in accordance with the National Environmental Policy Act (NEPA). As specified in the FFA for the ORR, the RI of EFPC, conducted from 1990 to 1992, integrated the requirements of these three primary federal regulations as well as those of other applicable federal and Tennessee state regulations.

1.1.1 FFA

The FFA between DOE, EPA Region IV, and TDEC for the environmental restoration of the ORR primarily addresses those activities necessary to meet the requirements of RCRA/HSWA, CERCLA/SARA, and NEPA, and establishes an agreed upon schedule for the attainment of those activities. Generally, CERCLA/SARA and RCRA/HSWA provide the principal legal stimuli for undertaking environmental restoration on the ORR and at EFPC. NEPA defines the process by which environmental restoration decisions about ORR sites are made and implemented. This section focuses on these three primary regulatory initiatives and their integration under the FFA.

1.1.1.1 RCRA

The primary objective of RCRA, as mandated by Subtitle C, is to treat, store, and dispose of hazardous wastes in such a way as to protect human health and the environment. The secondary objective is to conserve valuable material and energy resources by encouraging recycling and treatment of hazardous wastes, providing guidelines for solid waste management,

and promoting beneficial solid waste management, resource recovery, and resource conservation systems. To fulfill these objectives, RCRA requires that owners and operators of hazardous waste management facilities obtain operating or postclosure care permits for certain waste management activities.

RCRA regulates facilities that are currently operating or that have been closed since November 19, 1980, the effective date of RCRA; those disposal sites that were closed or abandoned before November 19, 1980, are regulated under CERCLA. RCRA emphasizes a health-based standard for the selection of corrective actions. It does not give response time schedules or cleanup goals, except in permits issued to allow continuing operation of a facility. The RCRA corrective action process involves the completion of an RFI and a corrective measures study (CMS).

The EFPC site falls under RCRA because it involves off-site contamination resulting from releases of hazardous wastes, primarily mercury, from DOE's Y-12 Plant, a currently operating facility. As amended by HSWA, Sect. 3004(u) of RCRA requires corrective actions for releases of hazardous constituents, such as those from the Y-12 Plant, and Sect. 3004(v) requires corrective actions for off-site areas of contamination, such as EFPC.

EPA has authorized the state of Tennessee to administer the RCRA program in lieu of the federal program, except for those RCRA provisions imposed by HSWA. Thus, the EFPC site is regulated by both EPA and TDEC. Region IV of EPA administers the federal RCRA program, including the HSWA provisions, and TDEC administers the Tennessee Hazardous Waste Management Act. TDEC also has RCRA authorization to regulate mixed hazardous and radioactive wastes, both of which occur on EFPC.

1.1.1.2 CERCLA

CERCLA, originally enacted on December 11, 1980, authorizes the federal government to cleanup releases of hazardous substances—primarily at closed or abandoned sites—by conducting site investigations, performing testing and monitoring activities, and implementing cleanup actions. These activities are conducted under the terms of the National Oil and Hazardous Substances Pollution Contingency Plan (40 *CFR* 300), otherwise referred to as the NCP, as mandated by Sect. 105 of CERCLA. The NCP details the cleanup procedures, including those for both immediate removal and long-term remedial action, and assigns regulatory authority to federal and state governments. CERCLA imposes strict liability on parties responsible, or potentially responsible, for hazardous waste sites and establishes funding (the "Superfund") that enables the federal government either to order the responsible parties to cleanup

the spill or to seek reimbursement from the responsible parties after the government has completed cleanup.

CERCLA focuses primarily on the cleanup of inactive disposal sites. Since May 1989, however, it has also given the federal government the authority to respond to current uncontrolled releases of hazardous and radioactive substances from all onshore and offshore facilities as well as from vessels, including over-the-road transportation vehicles.

SARA was enacted October 17, 1986. As amended by SARA, CERCLA authorizes EPA to maintain an NPL of sites requiring remedial action. Some of the most important sections of SARA discuss stricter cleanup standards, accelerated cleanup schedules, the Community Right-to-Know program, and the Leaking Underground Tank program. CERCLA/SARA emphasizes permanent on-site solutions rather than temporary treatment or transport-and-disposal alternatives, and it requires cleanups to be cost-effective and site-specific. The CERCLA/SARA remedial action process requires the completion of an RI and an FS for all NPL sites. 40 *CFR* 300.430(c) also requires the preparation of a Community Relations Plan (see PEER Consultants, P.C. 1991).

The EFPC falls under CERCLA because the entire ORR and its environs are listed on EPA's NPL. EFPC remediation planning was initially begun under RCRA corrective action authority; however, placement of the ORR on the NPL does not relieve DOE-OR from the obligation to implement RCRA Sect. 3004(v) corrective action requirements on the ORR. The CERCLA provisions for corrective actions on the ORR overlap, to some degree, the provisions of RCRA, thus creating the need for coordination of DOE-OR's efforts to respond to both sets of requirements. The FFA among DOE-OR, EPA Region IV, and TDEC establishes the procedural framework and schedule for cleaning up the ORR in compliance with CERCLA/SARA, RCRA/HSWA, and the Tennessee Hazardous Waste Management Act. Specifically, the FFA establishes procedures for integrating the requirements of CERCLA and RCRA by performing integrated RI-RFIs and FS-CMSs and identifies ORR operable units (OUs), one of which is the EFPC site. The FFA also recognizes DOE's responsibilities under NEPA and the impact that the NEPA process may have on meeting the established schedules.

1.1.1.3 NEPA

The purpose of NEPA (42 *USC* 4321-4347) is to establish a national policy to protect the environment and to promote a better understanding of the ecological systems and natural resources important to the nation by promoting efforts which will prevent or eliminate damage to the environment and the health and welfare of man. NEPA and the Council on Environmental

Quality regulations implementing NEPA (40 *CFR* 1500-1508) require that federal agencies consider and publicly address environmental concerns before making decisions on proposed action. These concerns are fully examined and presented in categorical exclusions, environmental assessments (EAs), or EISs, which are made available to the public and circulated to interested parties. The NEPA process assesses the environmental impacts of the proposed action and the project's alternatives, obtains public input through public scoping and issuance of the EA or EIS, and selects an appropriate alternative, notice of which is prepared and released to the public.

At ORR sites, the NEPA process is integrated with the CERCLA/SARA and RCRA/HSWA processes, as required by the FFA and by DOE Order 5400.4, culminating in issuance of an integrated FS-CMS-EIS and, subsequently, an integrated CERCLA record of decision (ROD) and NEPA decision document. In addition to analyzing the site-specific remedial actions in accordance with CERCLA and RCRA, socioeconomic and cumulative environmental impacts of remedial alternatives are analyzed in accordance with NEPA.

1.1.2 Other Regulatory Initiatives

In addition to the three primary regulatory initiatives imposed by the FFA as discussed in the previous section, the DOE-OR ERP for EFPC and the ORR must satisfy the requirements of several other federal and state regulations. Section 121(d)(2)(A) of CERCLA incorporates into law the CERCLA Compliance Policy, which specifies that Superfund remedial actions meet any federal standards, requirements, criteria, or limitations that are determined to be legally ARARs. Also included is the provision that state ARARs must be considered if they are more stringent than federal requirements. Federal statutes that are specifically cited in CERCLA include the Toxic Substances Control Act (TSCA), the Safe Drinking Water Act (SDWA), the Clean Air Act (CAA), and the Clean Water Act (CWA). These regulations are summarized in Table 1.1. The CAA, CWA, and SDWA, by establishing permissible pollution limits, primarily determine the degree of the response required to protect human health and the environment.

DOE-OR ERP activities conducted on the ORR and at EFPC must comply not only with the requirements of federal and state regulatory agencies but also with the guidelines established by DOE orders governing environmental restoration and hazardous and radioactive waste management on DOE sites. The primary DOE orders guiding the environmental restoration process on the ORR and at EFPC are highlighted in Table 1.2.

ERP activities on the ORR are also guided by several interagency agreements between DOE, EPA, and the state of Tennessee, as well as by several state orders. The primary regulators involved in these agreements and orders are the state of Tennessee, which administers

Table 1.1. Other federal regulations affecting the ORR ERP

TSCA
TSCA of 1976, which is administered by EPA, regulates existing chemicals that pose an unacceptable risk to human health or the environment. One chemical of concern at several ORR sites, including the Y-12 Plant and EFPC, is PCBs. TSCA regulates the use and disposal of materials containing more than 50 parts per million of PCBs. PCB-related projects may also be regulated by the CERCLA and RCRA.
CAA
CAA authorizes EPA to establish national standards for air quality that must be met by the states through compliance with EPA-approved State Implementation Plans. To ensure that national air quality standards are met and maintained, CAA requires that permits be obtained for specific air emissions. The new CAA, passed by Congress on November 15, 1990, contains sections that will revise the permitting program for operating sources and will impose regulations on 189 chemicals that are designated air toxins. The TDEC Division of Air Pollution Control has the primary responsibility for ensuring compliance with the CAA within the state of Tennessee and for protecting and maintaining Tennessee ambient air quality standards pursuant to the Tennessee Air Quality Control Act. TDEC's Division of Air Quality administers the air permits program. CAA requirements may become ARARs for CERCLA cleanups. DOE-OR has received approval of its compliance plan for meeting monitoring requirements of the National Emission Standards for Hazardous Air Pollutants (NESHAPs) for radionuclides, which are regulated under CAA.
CWA
CWA of 1977 sets standards for and regulates discharges into surface waters. Facilities that discharge wastewater directly into surface waters must obtain a National Pollution Discharge Elimination System (NPDES) permit. CWA regulations address technology-based effluent limitations, water-quality-based effluent limitations, new source performance standards (NSPSs), control strategies for toxic pollutants, and thermal discharges. Water pollution resulting from activities on the ORR is controlled through the Tennessee Water Quality Control Act and implementing regulations, and the NPDES permit program for the ORR is administered by TDEC's Division of Water Quality Control. Water quality criteria established under CWA may become ARARs for CERCLA cleanups.
SDWA
SDWA sets regulatory standards for levels of organic chemicals and other pollutants in drinking water and establishes programs to prevent contamination of groundwater sources. SDWA requires owners and operators to comply with all federal, state, and local requirements, to obtain applicable permits, and to satisfactorily complete required sample analyses and site inspections of public/industrial waste supplies and sources of drinking water. SDWA Primary Drinking Water Standards are frequently used to establish groundwater protection standards pursuant to RCRA and CERCLA.

Table 1.2. DOE orders governing environmental restoration activities on the ORR

DOE Order	Title	Purpose
5400.1	General Environmental Protection Program (11/9/88)	Establishes the environmental protection program for DOE operations.
5400.2A	Environmental Compliance Issue Coordination (1/31/89)	Establishes the process within DOE for resolving conflicting environmental compliance issues.
5400.3	Hazardous and Radioactive Mixed Waste Management (2/22/89)	Establishes DOE hazardous and radioactive mixed waste policies and requirements. The order clarifies DOE's interpretation of the definition of "byproduct material" (10 *CFR* 962) as it relates to RCRA regulation of mixed waste and establishes the lines of authority at DOE headquarters for RCRA implementation.
5400.4	CERCLA Requirements/NEPA Integration	Establishes DOE policy for integrating the NEPA (Sect. 7d) and CERCLA processes for DOE environmental restoration projects under Executive Order 12580.
5400.5	Radiation Protection of the Public and Environment	Establishes guidelines for controlling radioactivity in liquid wastewater effluents and other discharges. It also establishes criteria for residual levels of radioactivity in soils or on equipment that are being released back into the public domain.
5480.1B	Environment, Safety, and Health Program for DOE Operations (9/23/86)	Outlines (1) environmental protection safety and (2) health protection policies and responsibilities.
5820.2A	Radioactive Waste Management (9/26/88)	Establishes policies, guidelines, and minimum requirements for managing radioactive and mixed wastes. This order requires that DOE low-level waste be managed in such a way as to protect public health and safety and to preserve the environment. It calls for performance assessment of all radioactive waste management systems at DOE sites and facilities, including those for waste reduction, segregation, minimization, and characterization; development and implementation of waste acceptance criteria; waste treatment, storage, shipment, and disposal; and disposal site selection, design, operation, and closure/postclosure compliance. Chapter V of DOE Order 5820.2A sets forth requirements for decommissioning radioactively contaminated facilities.

the state RCRA program and regulates mixed waste; TDEC, which administers the Tennessee Hazardous Waste Management Act and its implementing regulations; and EPA Region IV, which administers a federal RCRA program focusing on HSWA provisions. Table 1.3 briefly discusses those site-specific agreements and orders that pertain to the EFPC, either directly or indirectly through requirements and schedules imposed on the Y-12 Plant or the ORR as a whole.

1.2 THE ORR ERP

The primary goals of the ORR ERP are to (1) reduce the risks to public health and the environment resulting from inactive disposal sites and (2) achieve regulatory compliance. Because the regulations have been designed to protect health and the environment, achievement of the second goal will simultaneously achieve the first. Section 1.2.1 describes DOE-OR's approach to remediation of the ORR to achieve these goals, and Sect. 1.2.2 presents the roles and responsibilities of the management and operating (M&O) contractor and other prime contractors responsible for implementing the ORR ERP.

1.2.1 Approach to Remediation on the ORR

DOE-OR, EPA Region IV, and TDEC all recognized the need to coordinate ORR assessment and remediation activities to comply with CERCLA, RCRA, and NEPA and agreed to develop a strategy to facilitate this coordination. In May 1991, DOE, EPA, and TDEC grouped the sites that were being assessed and remediated under RCRA into CERCLA OUs, and on January 1, 1992, the ORR FFA went into effect. The general purposes of the FFA are to:

- establish a procedural framework and schedule for developing, implementing, and monitoring appropriate response actions at the ORR in accordance with CERCLA, RCRA, NEPA, appropriate guidance and policy, and Tennessee state law;
- coordinate response actions under CERCLA with RFIs and CMSs now being conducted under RCRA with applicable state laws;
- minimize the duplication of investigative and analytical work and documentation and ensure the quality of data management; and
- expedite response actions with a minimum of delay.

The FFA provides a CERCLA framework for all future assessments and most remedial action activities planned for the ORR.

Table 1.3. Federal and state agreements and orders affecting EFPC

Memorandum of Understanding (MOU) Between DOE, EPA, and TDEC for the Y-12 Plant (5/26/83)
On April 8, 1983, DOE, EPA, and TDEC met to discuss the preliminary measures that must be taken by DOE at the Y-12 Plant to achieve full compliance with all federal and state pollution laws. This MOU, signed by DOE, EPA Region IV, and TDEC on May 26, 1983, outlines the actions that DOE-OR must take to achieve full compliance with all federal and state pollution laws. These actions include cleaning up (1) discharges to the Upper EFPC (UEFPC); (2) pollutants discharged from New Hope Pond (NHP), the New Hope sludge disposal area, S-3 Ponds, burial ground oil pond, isolation area, disposal pits, and oil land farm; and (3) contamination of EFPC and Bear Creek. The MOU also calls for a groundwater study of the Y-12 Plant site and development of a master monitoring plan for the plant.
Federal Facility Compliance Agreement (FFCA)/EPA Region IV, DOE (Y-12) (3/9/85)
This FFCA between DOE-OR and EPA Region IV outlines actions that must be taken at the Y-12 Plant to achieve compliance with the CWA and its implementing regulations. It establishes a compliance schedule and reporting requirements for the correction of deficiencies in wastewater treatment at the plant and contains plans for eliminating Category III discharges at the plant.
Agreement-in-Principle Between DOE and state of Tennessee (5/91)
DOE-OR agreed to provide grants to the state of Tennessee for independent oversight by the TDEC of ORR ERP activities, including review of FFA-required documents (RI, FS, remedial design, and ROD reports). The state will also conduct independent on-site and off-site monitoring and sampling.
TDEC Order (9/15/83)/Division of Water Quality Control, No. 83-228 (12/6/84)
On September 15, 1983, TDEC issued an order requiring DOE to submit a report of discharges at the Y-12 Plant, which would include a map of all discharge pipes from the Y-12 Plant into UEFPC, an effluent description of these discharges, and a determination of which discharge points will be eliminated. In addition, this order required DOE to provide an effluent sampling proposal; NPDES permit application for those effluents; plans for managing process waste streams; characterization of wastes deposited at the New Hope Sludge Disposal Area; report on the United Nuclear Corporation disposal site; report on the unclassified material in the classified burial ground; and characterization of waste in all other classified disposal sites in the UEFPC watershed area. The order also required DOE to cease any remaining process or area source discharges for which application for NPDES permits have not been made.
TDEC Order/Division of Water Quality Control, No. 83-228 (9/15/83)
This order, focusing on conditions at Bear Creek, requires DOE to stop disposing of or discharging all materials, except for treatment materials, into the Y-12 Plant S-3 Ponds. DOE-OR is required to submit to TDEC a plan and schedule for rehabilitating Bear Creek; a report characterizing wastewater discharged from the burial ground oil pond; an NPDES permit application for the discharge; a report inventorying waste deposited in the burial ground oil pond watershed; and a written proposal and schedule for remedial action for the Bear Creek watershed area.

Table 1.3. (continued)

TDEC Order for Correction/Division of Solid Waste Management, No. 84-374-11 (12/6/84)
On December 6, 1984, TDEC issued an order for correction requiring DOE-OR to submit RCRA Part A permit applications and closure and postclosure plans for the S-3 Ponds, NHP, Bear Creek Burial Grounds, and the oil land farm.
TDEC Order for Correction/Division of Solid Waste Management, No. 84-374, 84-2121AG (12/6/84)
This TDEC order of correction requires DOE-OR to comply with the interim status standards of Tennessee hazardous waste regulations for all mixed waste facilities until hazardous waste permits are issued by TDEC. It also requires DOE-OR to comply with the conditions of hazardous waste permits issued by TDEC and to submit to TDEC a schedule for submission of all RCRA Part B permit applications for mixed waste facilities.
TDEC Order/Division of Solid Waste Management, No. 87-3310 (3/17/88)
On March 17, 1988, TDEC issued an order requiring DOE to remove (and overpack, if necessary) all drums of hazardous waste from any standing water within the Y-12 Plant and to take all measures necessary to ensure that no releases of untreated runoff water contain hazardous waste constituents. The order also requires DOE to close the remaining active portion of the S020 container storage area in accordance with the order.

The CERCLA cleanup process involves a series of investigation, assessment, public involvement, and decision-making steps leading to publication of a ROD, which documents the preferred choice for a remedial, or cleanup, action. These steps are performed under three major phases: (1) a preliminary assessment/site investigation (PA/SI) to identify releases needing further investigation; (2) an RI to characterize the nature, extent, and rate of contaminant release; (3) an FS to evaluate remedial alternatives; and (4) a Proposed Plan to propose a remedy. Completion of the Proposed Plan sets the stage for preparation and signing of a ROD, followed by implementation of the remedial action selected in the ROD.

Not all sites on the ORR must enter the CERCLA process at the PA/SI stage. In some cases, knowledge of past releases may indicate that a site is contaminated without the need for SI sampling. Also, assessments previously performed at some sites can often be substituted for the PA/SI, allowing the investigation to start at the RI stage. In other cases, previous assessments may have shown certain sites to be uncontaminated or to present no threat to human health or to the environment. In such cases, the sites are designated as requiring no further investigation.

The primary steps included in an RI are to:

- collect data to characterize, or describe, site conditions;
- determine the nature and extent of contamination at the site; and
- assess risks to human health and the environment.

Before an RI can begin, a detailed RI work plan, including sampling and analysis, waste management, community relations, health and safety, and quality assurance (QA) plans, must be prepared and submitted to EPA Region IV and to TDEC for approval. After the work plan is approved, the RI is implemented according to plan, and the results of the investigative steps are published in an RI report, which is also submitted for regulatory approval.

RCRA calls for similar investigative activities to be conducted during an RFI. In some cases, RFI work plans had been prepared for ORR sites designated as RCRA sites before the ORR was placed on the NPL. Because all ORR sites are now categorized as CERCLA sites, requiring that an RI be conducted instead of an RFI, these RFI work plans were modified and submitted to regulatory authorities as RI, or integrated RI/RFI, work plans. All ORR sites designated as both RCRA and CERCLA sites will be investigated in such a way as to meet the

requirements of both regulations, and integrated RI/RFI reports will be prepared. For the purposes of this report, the integrated RI/RFI will be referred to as an RI.

After the RI is underway, work begins on the FS. The data collected during the RI are used to determine the extent of contamination and establish a baseline from which potential alternatives are developed for cleaning up the site being investigated. The FS involves a screening and evaluation of potential remedial technologies and an assembly of comprehensive cleanup alternatives followed by a detailed analysis of these alternatives to select the preferred remedial action for the site. Typical alternatives might include treatment of the waste in place, removal and permanent disposal of the contaminated media, removal and treatment of the contaminated media, or a combination of alternatives. The detailed analysis evaluates each comprehensive site-wide alternative independently against the nine criteria presented in Table 1.4. Finally, the alternatives are analyzed in a comparative manner, again using the nine CERCLA criteria.

The purpose of the FS is to provide decision-makers with sufficient information to adequately compare the alternatives, to select a remedy for the site, and to demonstrate compliance with CERCLA remedy selection requirements. Again, the objectives of the RCRA-required CMS are very similar to those of the CERCLA-required FS. NEPA, however, requires that adequate information on the environmental impacts, including cumulative impacts, of the alternatives be available to aid decision-making. In addition, the NEPA "no action" alternative is always considered as the baseline from which the effectiveness and feasibility of all other alternatives are judged. The integrated FS-CMS-EIS, which includes impacts not only on the site itself but also on surrounding communities, considers socioeconomic impacts and discusses interactive or cumulative impacts with other site activities.

The detailed analysis of the three or four recommended alternatives is documented in the integrated FS-CMS-EIS report. DOE-OR uses this report to select a preferred alternative and to develop a proposed plan for site cleanup, which is then submitted to EPA Region IV and TDEC for review and approval. The proposed plan and all supporting data and documents used to select the preferred alternative and to develop the proposed plan are entered into an Administrative Record for the site. The Administrative Record will be maintained in DOE-OR's Information Resource Center at 105 Broadway in Oak Ridge, where it will be available to the public.

After EPA and TDEC review and comment on the proposed plan, DOE-OR responds to the comments and then makes the report available for public comment. Notices announcing the

Table 1.4. Nine criteria by which alternatives are screened

The criteria, specified by law, are divided into (1) threshold, (2) balancing, and (3) modifying criteria.
Threshold criteria
These criteria **must** be met. The selected alternative must: 1) provide overall protection of human health and the environment and 2) bring the site into compliance with any other regulations that may apply.
Balancing criteria
These criteria are considered in determining which alternative best achieves or comes closest to achieving the threshold criteria. The balancing criteria evaluate the alternatives in terms of: 3) long-term effectiveness and permanence; 4) the degree to which a treatment reduces the toxicity, mobility, or volume of contamination; 5) short-term effectiveness; 6) implementability; and 7) cost. (Cost cannot be the sole determining factor in a remedial decision.)
Modifying criteria
These criteria allow for the influence of: 8) state acceptance of the proposed alternative and 9) community acceptance.

availability of the proposed plan, and specifying when and to whom comments should be made, are placed in the legal section of *The Oak Ridger* and other local newspapers. The notice either announces the date, time, and location of a public meeting to discuss planned activities at the site or gives instructions on how members of the public may request a meeting.

After the close of the comment period, DOE prepares a draft ROD and submits it to EPA Region IV. EPA, considering the input from TDEC and the public, makes the final remedial action decision, after which a legally binding ROD is signed by EPA Region IV, TDEC, and DOE. All comments that were received on the proposed plan are documented in a responsiveness summary, which becomes part of the ROD. A remedial design report is then filed with the regulators, detailing construction and work plans. The remedial action must begin no later than 15 months after the ROD is signed.

This integrated CERCLA-RCRA-NEPA process for achieving environmental compliance at contaminated and potentially contaminated ORR sites is a complex procedure requiring consensus on a wide variety of scientific and technical uncertainties among many diverse and competing interests. The objective of the process is to respond to all regulatory requirements in a way that minimizes duplication of effort and expedites response actions while helping decision-makers select the best remediation alternative for safeguarding human health and the environment at a particular site.

The schedule objective of the ORR ERP is to complete cleanup and compliance as soon as feasible, but no later than the year 2019. Characterization has begun at all facilities, but not at all suspected release sites. Some sites will be remediated in the near future using existing technologies while others will require scale-up of existing bench-scale technology before cleanup is feasible. Still others will require major development efforts before cleanup can be initiated. The schedule for each potential remediation site must be evaluated individually, and the aggregate of all schedules balanced against available technology and resources.

1.2.2 Roles and Responsibilities of M&O and Prime Contractors at ORR

The director of DOE-OR's Environmental Restoration Division, who reports to the assistant manager for Environmental Restoration and Waste Management, has overall responsibility and authority for planning and executing the ORR ERP. Working with the DOE-OR Environmental Restoration Division to accomplish ERP objectives on the ORR are four prime contractors. The roles and responsibilities of these contractors are described in the following subsections.

1.2.2.1 M&O contractor

As the M&O contractor for all DOE-owned facilities on the ORR, Martin Marietta Energy Systems, Inc. (Energy Systems) is assigned the role of integrating contractor for ERP activities at these facilities and for the Clinch River and EFPC actions. For other off-site and non-FFA actions, Radian Corporation is responsible for the integration activities. As the integrating contractor, Energy Systems leads the team of contractors in developing all upper-level planning documents, including schedules and budget packages, related to short- and long-term ERP activities on the ORR. It conducts meetings, collects information, and assembles packages of information about ERP activities for use by DOE-OR, including monthly reports of cost and schedule status. Energy Systems also ensures that technical consistency is achieved among all ERP participants in such areas as risk assessment and waste management.

In its dual role of the facility M&O contractor and integrating contractor, Energy Systems:

- evaluates other DOE prime contractor, subcontractor, and prospective subcontractor environmental restoration programs, procedures, systems, processes, and policies regarding health and safety, housekeeping, environmental requirements, radiation protection, security, QA, and related operations;

- provides coordination with plant operations for all field work, including RIs and remedial actions;

- evaluates the designs, strategies, and sequencing of work recommended by the remedial design architect-engineer in accordance with existing project management procedures established by DOE's assistant manager for construction and engineering; and

- participates in and operates the levels I and II Change/Configuration Control Board meetings chaired by DOE-OR, and processes and maintains all change requests and approvals for ERP projects on the ORR.

To fulfill its role as integrating contractor for the ORR ERP, Energy Systems created a centralized Environmental Restoration Division, which in turn established a dedicated ERP office for each major facility and off-site area under its authority and control. Site ERP managers are responsible for planning and implementing ERP activities at their respective sites.

1.2.2.2 RCRA-CERCLA-NEPA Technical Support Contractor (TSC)

The role of the TSC for the ORR ERP, Radian Corporation, is to provide technical support in the following areas through task orders issued by DOE-OR:

- development of FSs;
- preparation of integrated decision documents and the studies and assessments necessary to produce them (i.e., CMS-FS-EIS, proposed plan, and ROD);
- technical support for program management activities such as community relations, maintenance of the Administrative Record, public meetings, program-level planning, information management, quality assurance/quality control (QA/QC), or work plan development; and
- technical support for regulatory compliance and waste management, special studies, or remedial design or remedial action phases of the program.

In addition, although facility RIs will generally be conducted by the M&O contractor, DOE-OR may direct the TSC to conduct RIs (such as EFPC).

The performance of tasks in the activity areas identified above requires effective interface of the TSC with all other ERP participants, including DOE-OR and the M&O contractor, the remedial design contractor, and the construction management contractor. The specific requirements for interface vary with the nature of the activities being performed, but the general interface requirements with each ERP participant are as follows:

- **DOE-OR.** The TSC interfaces with DOE-OR for both contractual and technical needs. Contractual interface is facilitated by the TSC program manager and the DOE-OR Contracting Officer's Representative (COR) for task assignment, reporting, invoicing, and technical direction. The TSC also interfaces with the COR and other DOE-OR program managers for technical coordination of TSC activities in support of DOE-OR.
- **M&O contractor.** The TSC interfaces with the M&O contractor to (1) facilitate TSC involvement in RIs being conducted by the M&O contractor so that transition to the FS phase is effective and timely and (2) ensure consistency in areas such as modeling, risk assessment, ARARs, configuration management, data reporting, document control, and planning.

- **Remedial design contractor.** The TSC interfaces with the remedial design contractor to (1) obtain its input on implementability, constructability, or cost analysis during the FS phase; (2) facilitate timely and effective transition from the FS to the remedial design phase; and (3) ensure proper implementation of the ROD.

- **Construction management contractor.** During the remedial action phase, the TSC may be directed by DOE to provide technical support to ensure effective implementation of remedial design to comply with the intent of the ROD.

1.2.2.3 Remedial design contractor

Ebasco Services, Inc., the remedial design contractor for the ORR ERP, provides support as required during the FSs conducted by the TSC. After the TSC staff has recommended an alternative to DOE-OR, the remedial design contractor begins the design of the selected alternative sufficient for inclusion in the draft ROD and draft remedial design work plan. The remedial design contractor revises the design after the public comment period and supports the preparation of the proposed ROD and remedial action work plan for submittal to the regulators. After the ROD is signed, the remedial design contractor completes the remedial design work plan and the design details sufficient for issue for bidding and award by the DOE-OR construction management contractor and provides home office Title III support services as needed as well as Title III field services. The remedial design contractor ensures that the final design complies with both the ROD and the remedial action work plan.

1.2.2.4 Construction management contractor

All remedial actions on the ORR are performed by fixed-price or, if necessary, cost-plus-fixed-fee subcontractors. MK-Ferguson, the construction management contractor for the ORR ERP, manages these subcontracts.

1.3 FACILITY-SPECIFIC ERP

The Y-12 Plant was built in 1943 as part of the Manhattan Project to separate uranium isotopes using the electromagnetic process. When the process was discontinued after World War II, the Y-12 Plant's role was changed to manufacturing and developmental engineering. Since that time, the plant has been responsible for producing nuclear weapon components and subassemblies, developing and fabricating test hardware for the weapon design laboratories, and providing fabrication support to other Energy Systems plants and to federal agencies. The Y-12

Plant has recently discontinued the production of nuclear weapon components and is currently engaged in technology development and weapons disassembly.

Past operations have resulted in extensive on-site and off-site contamination. Contaminants at the 811-acre Y-12 Plant site include hazardous materials, low-level radioactive material (primarily uranium), and mixed wastes resulting primarily from the weapons production process. Those sites requiring environmental restoration include waste disposal sites, waste storage tanks, spill sites, and contaminated inactive facilities, all resulting from past operations. Additionally, mercury contamination has occurred not only onsite but also offsite in EFPC floodplain soils and sediments. *Mercury at the Y-12 Plant, A Summary of the 1983 UCC-ND Task Force Study* (Y/EX-23 November 1983) presents an historical perspective of mercury use at the plant.

The Y-12 Plant ERP for cleaning up these on-site and off-site areas of contamination is well documented and described in several publications, such as the *Oak Ridge Reservation Site Management Plan for the Environmental Restoration Program* (DOE/OR-1001), the *Environmental Restoration and Waste Management Site Specific Plan for the Oak Ridge Reservation* (DOE/OR-968 September 1991) and the *Y-12 Plant Long Range Environmental and Waste Management Plan* (Y/TS-83 Rev 7 May 1991). These and other ORR documents are available at the Information Resource Center at 105 Broadway in Oak Ridge, Tennessee. Many of these documents are updated and reissued annually. The following sections focus primarily on activities that affect EFPC.

1.3.1 UEFPC RIs

The previously existing RFI work plans for Bear Creek OUs 2 and 4, UEFPC OUs 1 and 2, and EFPC were revised and submitted to EPA and TDEC for approval in December 1991. Several of these RFI work plans were implemented and draft RFI reports were issued. These reports have been subsequently evaluated for CERCLA adequacy. The paragraphs below focus briefly on the status of the CERCLA process at the UEFPC OUs.

The flow of the UEFPC watershed, which encompasses most of the Y-12 Plant area, is completely derived from plant runoff, controlled NPDES discharge points, and groundwater seepage (Fig. 1.1). Because UEFPC is the source of contaminants in LEFPC, a decision must be made on the remediation of LEFPC prior to the control of all contaminant releases from the Y-12 Plant.

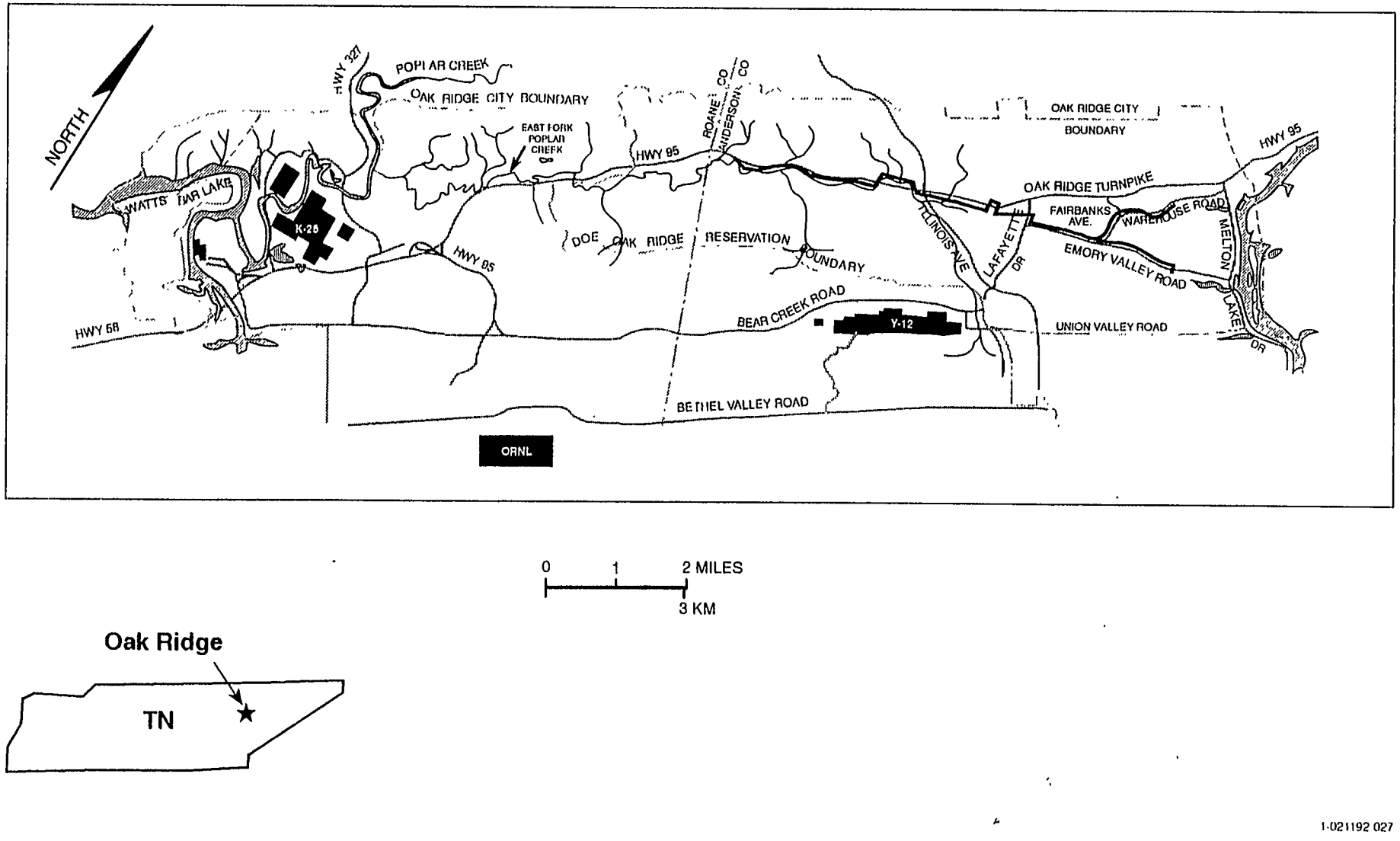

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Fig. 1.1. EFPC RI study area.

The Phase I sampling for UEFPC OU 1, which focuses on surface runoff from the storm sewer system and on contaminated soil, shallow groundwater, and surface water associated with Y-12 Plant mercury-use areas, is scheduled for completion in the out-years. It includes a comprehensive sampling and analysis of more than 200 outfalls into UEFPC. Evaluation of the data from four wet-weather and four dry-weather sampling events will be used to identify which outfalls are the primary contaminant sources into UEFPC. Mercury is the primary COC. If deemed necessary, sampling will continue upgradient into the storm sewer system and assessment of contaminated soil will be conducted in a second phase of sampling.

UEFPC OU 2 is a below-grade pipeline that for 30 years carried a waste stream composed of nitric acid and depleted uranium to a discharge point at the S-3 Ponds. Numerous leaks have occurred along the pipeline, potentially contaminating soil, groundwater, and surface water (from groundwater seeps). Phase I of the UEFPC OU 2 sampling, which focuses on shallow soil contamination along the length of the pipeline, is scheduled for completion during FY 1993.

1.3.2 Mercury Remediation Programs

A 1985 study by the Centers for Disease Control and TDEC (*A Pilot Survey of Mercury Levels in Oak Ridge, Tennessee*, October 1985) determined that mercury concentrations found in urine and hair samples were within background range and thus concluded that residents of Oak Ridge are not likely to be at increased risk from significantly higher mercury levels in the local environment. Nevertheless, due to the potential for health and safety risks at several solid waste management units (SWMUs), including EFPC, and the consequent public concern, there is an increased need for immediate action. Several programs addressing mercury contamination at the Y-12 Plant, in EFPC, and in the Clinch River and Watts Bar Reservoir have been implemented:

- **Decontamination and decommissioning (D&D).** Tons of mercury were used during operation of the column exchange (Colex) process for separating lithium isotopes, which was performed in Building 9201-4 (Alpha-4) and 9201-5 (Alpha-5) at the Y-12 Plant. Alpha-5 was shut down in 1959, and started up again in 1963 for a 6-month campaign. The equipment in this plant was dismantled and disposed of in 1965-66. Although Colex operations at Alpha-4 were discontinued in December 1962, an estimated 300,000 lb of mercury remain in the building and process equipment. Small amounts of mercury from these facilities continues to be released into EFPC through stormwater collection and discharge. The building is now being maintained and surveyed by Y-12 Plant personnel until it can be fully decontaminated and decommissioned. Phase I of the D&D, involving insulation removal, pipe abandonment and removal, and disassembly of equipment, will begin in 1993. Phase II, building demolition, is expected to begin in 1998, although these plans are subject to change.

- **Reduction of mercury in plant effluents (RMPE).** The RMPE program will selectively reroute stormwater systems, clean out building sumps, and remove some mercury-contaminated facilities from Building 9201-2 (Alpha-2) and other Y-12 Plant sites. These maintenance and source removal activities will reduce the daily contribution of mercury to UEFPC. Additionally, a small treatment facility for removal of mercury in plant effluents is being planned. The RMPE program will address the assessment and remediation of priority mercury discharge points to UEFPC.

- **Mercury-use areas remediation.** The remediation of various mercury-use areas, including Electrical Exchange (Elex) facilities (Buildings 9733-2, 9204-4); Organic Exchange (Orex) facilities (Buildings 9733-1, 9202) and Colex facilities (Buildings 9201-2, 9201-4, 9201-5) as well as the Mercury Recovery Furnace (Building 81-10) and the soils around these buildings, is being performed as part of the environmental restoration of UEFPC OUs 1 and 3.

These mercury remediation programs are particularly important to remediation decisions and efforts at EFPC because mercury is one of the primary contaminants in the creek and its floodplains.

1.4 SITE ENVIRONMENTAL PROGRAM

1.4.1 EFPC Site Definition

The RI reported in this document focuses on what is referred to as the EFPC OU, which covers that portion of EFPC known as LEFPC. LEFPC stretches over 14.5 mi from the outfall of Lake Reality through the city of Oak Ridge to its confluence with Poplar Creek, and includes the 670-acre floodplain, and the Oak Ridge SLB (see Fig. 1.1). The RI of UEFPC, from its point of origin at the Y-12 Plant to Lake Reality, is covered under three separate OU investigations, as described in Sect. 1.3.1. The RI documented here focuses on what is referred to as the EFPC OU, which includes the 14.5-mi LEFPC, its 670-acre floodplain, and the Oak Ridge SLB (see Fig. 1.1).

1.4.2 EFPC Site History

In the early 1970s, researchers discovered the first evidence of mercury contamination in EFPC. By May 1983, a memorandum of understanding was signed by DOE, the Tennessee Department of Health and Environment (now TDEC), and EPA for the purpose of investigating the environmental contamination of EFPC. An interagency task force, referred to as the Oak

Ridge Task Force (ORTF), was organized to investigate the extent of off-site environmental contamination of EFPC and other Oak Ridge-area streams related to the ORR, and to determine if any immediate public health impacts might result from such contamination. The ORTF requested that the Tennessee Valley Authority (TVA), ORNL, and ORAU participate in studies to evaluate soil and sediment contamination in the EFPC and its environs. Per the summary report (*Summary Report: Task 5, Instream Contaminant Study*, TVA, January 1985), analysis of soil and sediment samples from several locations in the floodplain and channel of EFPC indicated that about 16 million ft³ of sediments and soils are contaminated with an estimated 170,000 lb of mercury. The ORTF studies performed between 1985 and 1988 also found other heavy metals, radionuclides, and some organic compounds in EFPC and associated floodplain soils. These contaminants included arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, lithium, selenium, silver, thorium, uranium, zinc, PCBs, and other organic chemicals. Although this contamination did not pose an immediate threat to humans, consumption of fish, game, and vegetables raised in floodplain soils has been discouraged (Travis et al. 1986). The results of these early studies identified the gross magnitude of the contamination in EFPC and its floodplain and outlined the need for further detailed investigations.

Immediately prior to this time, Congress enacted the HSWA to RCRA (November 8, 1984) which provided EPA with broad authority to ensure corrective actions at facilities subject to RCRA, and mandated the RCRA corrective action program. The corrective action program consists of three phases: the RCRA Facility Assessment, the RFI, and the CMS. Based on the results of the facility assessment performed for the Y-12 Plant (Welch et. al. 1987), the DOE, in conjunction with the EPA and TDEC, decided that an RFI for NHP and the upper and lower reaches of EFPC would be prepared. Subsequently, DOE decided to close NHP under RCRA, and conduct separate RFIs for UEFPC and LEFPC. Detailed site characterization planning for EFPC was initiated in 1987 under RCRA 3004(v) permit requirements, and an RFI work plan was prepared to guide the field data collection (Y/TS-366R1). In 1988, DOE-OR published a notice of intent to prepare an EIS for EFPC to comply with the requirements of NEPA. At a public scoping meeting on December 6, 1988, DOE-OR invited the public to submit comments and suggestions to help DOE identify significant environmental issues and to define the appropriate scope of the EIS.

In 1989, however, before the RFI work plan was approved for implementation, the entire ORR, including EFPC, was placed on the NPL, qualifying it as a CERCLA site. As a result of its new status as a CERCLA site and in compliance with the subsequent draft FFA between DOE-OR, EPA Region IV, and TDEC, an integrated RCRA-CERCLA-NEPA strategy was

defined for the ORR that included the importance of evaluating cumulative impacts across all sites of the ORR.

An EIS Implementation Plan was prepared for EFPC providing detailed, annotated outlines for the three documents planned for the site: an integrated RI report, an integrated FS-CMS-EIS, and an integrated ROD-NEPA decision document. The existing RFI work plan was modified to incorporate ARARs under CERCLA and to produce a risk-based approach for conducting the integrated RI. The resulting RI work plan also included a site-specific QA plan, health and safety plan, community relations plan, sampling and analysis plans for Phases Ia and Ib of the RI, and a waste management plan for wastes generated during the RI.

1.4.3 EFPC RI

Radian Corporation and its subcontractor, Science Applications International Corporation, are responsible for conducting the integrated RI and FS-CMS-EIS and for preparing the related decision documents for EFPC. The EFPC team (Radian Corporation and Science Applications International Corporation) designed the sampling plan, performed the field work, and conducted the risk assessments necessary to support preparation of this RI report and the FS-CMS-EIS.

The RI of EFPC, initiated in 1990, has been conducted and is documented in this RI report to integrate the requirements of the three primary federal regulations, as outlined in the FFA between DOE-OR, EPA Region IV, and TDEC, as well as the requirements of other applicable federal and Tennessee state regulations, agreements, and orders.

Phase Ia of the RI was designed to establish the nature of contamination and to identify the COCs—primarily radionuclides, organic compounds, mercury and other metals, PCBs, and pesticides. Completion of this phase of the RI required the installation of groundwater monitoring wells and the quarterly sampling of these wells to characterize the groundwater quality and hydrogeology of the floodplain. Surface water samples, creek sediments, and surface and subsurface soil samples were taken along the floodplain and channel and at a noncontaminated reference site (Hinds Creek) for the determination of 182 inorganic, organic, and radionuclide analytes, as well as geotechnical parameters and soil chemistry parameters related to treatability studies.

Phase Ib, which began in the summer of 1991, was designed to determine the extent and level of contamination. More than 4000 field samples were collected and analyzed during this phase. Sample locations were surveyed on transects spaced 100 m apart along the length of the creek. Each transect spanned the width of the floodplain with sample locations 20 m apart.

Composite sediment samples were taken over a 600-m run of the creek. Additional sampling included surface water for seasonal contrast, X-ray diffraction, and speciation of mercury. The work conducted under Phases Ia and Ib of the RI was structured to enable the determination of the nature and extent of contamination and the definition of the potential for migration and the potential exposure pathways.

As part of the RI, baseline human health and ERAs have also been completed and are documented in this report. The ERA process differs from the human health risk assessment process in that the ERA focuses on populations and communities rather than individuals. In the ERA process, individuals are addressed only if they are protected under the Endangered Species Act, are unique, or have such public importance that individual consideration is merited. The ERA must also address the requirements for DOE, as a Natural Resource Trustee, as well as those for cooperating trustees as specified under 43 *CFR* 11, Natural Resource Damage Assessments (NRDAs), Final Rule (August 1, 1986). Requirements under NEPA must also be addressed including state and federal agency coordination, public involvement, and alternative evaluation. To address these requirements, federal, state, and local regulators and Natural Resource Trustees (DOE, Tennessee Wildlife Resource Agency, TDEC, U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, and TVA) were involved in the planning and approach development for the ERA, and the ORNL Central Risk Assessment Council has been involved throughout the development and implementation of the ERA plans.

The EFPC ERA has adopted an "ecosystem approach" that addresses contaminant effects to populations and communities within the area of influence of the waste site. Maps of habitats within the 100-year floodplain will be used extensively. Through the use of indicator species, a "weight-of-evidence" assessment is used to determine contaminant effect on those species, and then projections are made as to the overall effect on the ecosystem. Considering the numbers of potential ecological receptors, it would be virtually impossible to study all affected individuals or species. By evaluating population structure such as species abundance, diversity, and richness as well as body burden data, the risk assessor can compare these values to similar measurements taken at reference or uncontaminated sites to determine the effects of exposure to site contaminants on those species. The "risk" to the ecosystem is then evaluated based on the indicator's role in the ecosystem and the degree and extent of exposure. This process provides an overall picture of the ecosystem and provides the decision-maker with a comprehensive view of not only the existing risk but also the information needed to select those remediation alternatives that provide the best ecological protection.

A baseline human health risk assessment has been conducted in support of the EFPC RI process. The primary objectives of this assessment are to determine if there is an "imminent and substantial" endangerment to human health based on current and future exposure potential and to evaluate the need for site remediation. The risk assessment examines: (1) the presence of chemicals in EFPC attributable to release from the Y-12 Plant, (2) the potential routes of exposure to human receptors, and (3) the likelihood of adverse health effects following contact with contaminated environmental media.

A phased approach to human health risk assessment has been adopted using both deterministic and probabilistic methods. The EFPC risk assessment team has worked with EPA Region IV, TDEC, DOE, and the ORNL Central Risk Assessment Council throughout the process in an effort to establish consensus and to ensure consistency with existing regulatory guidance. The methods adopted will facilitate derivation of the most scientifically valid estimates of the potential for adverse effects. The goal has been to focus the evaluation on the receptors and exposure pathways of principal concern and to quantitatively characterize the uncertainty surrounding all assumptions and resultant risk estimates.

1.4.4 Post RI Activities and Reports

Following the RI report, an integrated FS-EIS will be prepared. The FS will complete the identification and screening of media-specific technologies that was begun in the "Initial Screening of Alternatives" (Radian 1991). The screening is conducted by using the CERCLA effectiveness, implementability, and cost criteria. Comprehensive site-wide alternatives are then developed in the FS-EIS for the remediation of the site to ensure the long-term protection of human health and the environment. A detailed analysis will then be performed on the comprehensive site-wide alternatives using the nine criteria established by CERCLA (see Table 1.4). Integrated into the FS, the EIS ensures that the NEPA criteria are adequately addressed and evaluated for potential environmental impacts resulting from the remedial action. Based on the analysis of all alternatives studied in the FS-EIS and the evaluation of the alternatives against the nine criteria specified by CERCLA, DOE will recommend preferred alternatives, as outlined in submission of a Proposed Plan for cleanup to the state and federal regulators. After review and comment by the regulators on the plan and after those comments are addressed and resolved, the Proposed Plan is made available for public comment. Comments are summarized and addressed by DOE and compiled into a Responsiveness Summary which becomes part of the ROD. After close of the comment period, DOE will prepare a draft ROD and submit it to EPA. EPA will consider input from the state and the public and then make the final remedial decision. At this point, the decision process is nearly complete except that a

legally binding ROD must be signed by the regulators and DOE. Remedial action is committed to begin no later than 15 months after the ROD is signed.

A remedial design report, detailing work plans and construction activities, will then be completed and filed with the regulators, detailing work plans and construction activities. This report will be prepared by Ebasco Services, Inc., the designated remedial design contractor for the ORR. MK-Ferguson will provide project oversight for the cleanup operations in its position as construction management contractor. Energy Systems has the role of integrating contractor for the various groups working on the design and construction phases of the EFPC remediation.

1.5 SPECIAL PROBLEMS

Several factors distinguish EFPC from most sites within the ORR and even from other CERCLA sites across the nation, thereby creating special problems for the RI-FS and, ultimately, for the ROD.

1.5.1 Size and Shape

From the outfall at Lake Reality to its confluence with Poplar Creek, EFPC is more than 14 mi long and the associated 100-year floodplain encompasses more than 885 acres. Any investigation, risk assessment, remedial action or decision is magnified due to the size of the EFPC site and the number of unique areas within EFPC. The number of samples required to properly characterize the site, documentation of the field tasks, the cost to perform the analyses, and the time needed to validate and evaluate the data are enormous. In summary, the level of effort required to satisfy the requirements of the CERCLA-NEPA process is multiplied manyfold.

1.5.2 Geographic Diversity

As discussed in Sect. 2, EFPC is contained within both the DOE ORR and the city of Oak Ridge. Proper characterization of the site must focus on multiple settings such as the commercial, residential, and undeveloped areas of the city and the woodlands and rural areas of the reservation. The length of the creek and size of the floodplain do not allow for a simple determination of the contaminant levels, exposure pathways, and affected populations (both human and ecological). Furthermore, future land use and exposure pathways are subject to change as the city grows, resulting in a degree of uncertainty intrinsic to the projections.

The protection of designated wetlands may be in conflict with the risk-based cleanup standards set for the creek. In at least one wetland area, referred to as the National Oceanic and

Atmospheric Administration (NOAA) site (as it is behind the NOAA building on Illinois Avenue), elevated contaminant levels occur. Should widespread contaminant removal be required, special provisions must be made to re-establish these wetlands or create replacement areas of equal size to achieve the dual goal of protecting habitat and removing contaminants.

1.5.3 Source Control

Source control of the contaminants from the Y-12 Plant site must be considered in the framework and schedule of the EFPC remediation efforts. Presently, it is estimated that ~25 g of mercury per day are being released to the EFPC systems from residual contaminants on site. These contaminants are contained within the soils, bedrock, and drainage system of the Y-12 Plant site and cannot easily be removed. Future remediation and D&D efforts at specific OUs within the Y-12 Plant can increase the contaminant load to the EFPC watershed. Any ongoing or accomplished cleanup efforts will be jeopardized unless source control is implemented.

1.5.4 Remedial Action Considerations

Remedial decisions concerning the creek will necessitate large expenditures and significant impacts to the community and ecosystem. Small decreases in risk-based remediation can result in exponential increases in the volume of soils and sediments to be remediated. Removal and treatment actions for soils or sediments will require large capacity processes and large storage or disposal areas. Significant impacts to the terrestrial and aquatic systems can result from disturbances to the creek or ecosystem within the floodplain unless rigorous source controls are established. Further migration of contaminant loads downstream is likely to occur during any remedial action.

Due to the proximity of the nearby community, special health and safety practices must be implemented to safeguard residents. Transport of waste and on-site processing will require additional safety measures.

1.5.5 Urban Contaminant Contributions

Specific urban contaminants may exceed risk-based levels for the creek. These contaminants are not only related to processes that occurred within the Y-12 Plant but also are common to an urban/municipal environment. They are by-products of incomplete combustion of fossil fuels such as oil or coal and commonly occur with flyash and asphalt. It is impossible to determine whether the contaminant source is urban/municipal or the Y-12 Plant. Furthermore,

establishing a source control at the Y-12 Plant boundary and remediating select areas of the creek will not eliminate continuing municipal contributions.

In addition, the city of Oak Ridge West End Sewage Treatment Plant has a measurable effect on the biota of the creek. Moreover, several contaminants are found in high concentrations immediately downstream of its confluence with EFPC, suggesting a municipal source at these locations. Y-12 exports sanitary sewage to this city treatment works, thus some of the high contaminant concentrations immediately downstream of the sewage treatment plant could have an origin at Y-12. DOE's responsibility toward these ongoing municipal contributions must be considered in the final decision for remedial actions.

1.5.6 ERA

Regarding the ERA, the site is essentially a long and sinuous corridor. The floodplain habitats are organized linearly, presenting a rather different array of ecological resources and access than if the site had a simple geometry. These biogeographic constraints preclude an indepth study of ecological contaminant distributions, population structure and dynamics, toxicity to biological media and biota body burden. The ERA must be based on a limited set of indicators that allow only a present-day snapshot with neither extensive coverage spatially nor temporally. Historical data and weight-of-evidence approaches must be assumed to compensate for this.

1.6 OBJECTIVES

1.6.1 RI Report

The objective for the EFPC RI report is to provide information on the physical characterization of the environment and the characterization of the nature and extent of contaminants within the environment for input into the human health risk assessment, ERA, and the FS-EIS. Figure 1.2 displays the objectives of the RI as they relate to the segments of the EFPC investigation and the end products of each segment of the RI Report. Combined with the FS-EIS, these reports will provide the documentation and technical support for the decisions placed within the ROD and subsequent remedial actions.

As part of the site characterization process, the RI must confirm or revise the site conceptual model, which specifies contaminant types, concentrations, and distributions, and that establishes exposure pathways and susceptible population. To accomplish the above, the EFPC RI Report seeks to:

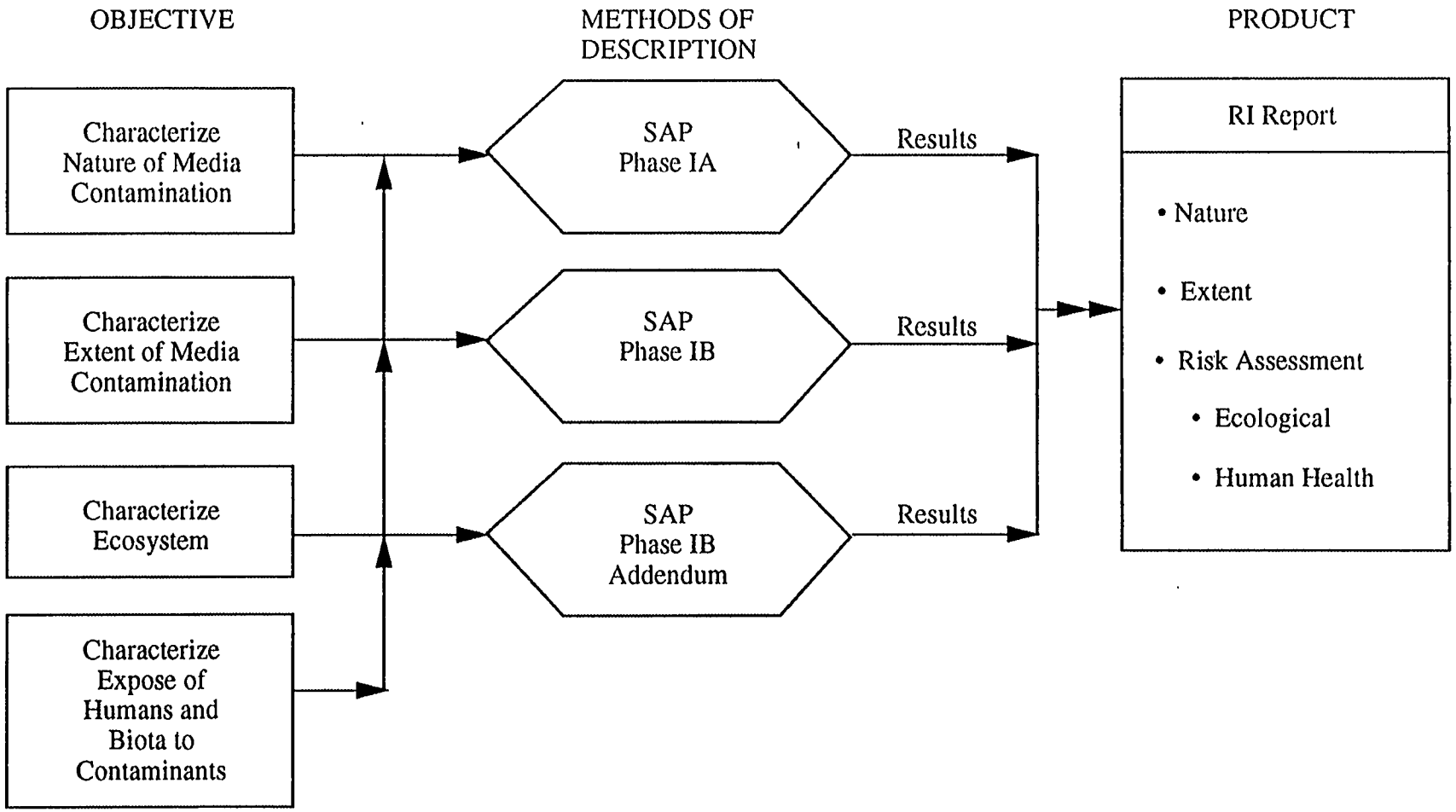


Fig. 1.2. EFPC RI process.

- supply an understanding of the physical nature of the site as a basis for identifying areas of concern;
- determine the affected media and establish the boundaries of contamination within the creek and its environs;
- determine the nature of the contaminants and understand their distribution, form, and associations;
- characterize primary contaminant transport into and out of the system and define contaminant migration within the system; and
- provide a comparison of contaminant levels against a noncontaminated, but similar site.

1.6.2 Human Health BRA

The human health BRA incorporates the results of the RI and determines if there is an imminent and substantial endangerment to human health based on current and future exposure and if the need for site remediation exists. Specific end results of the BRA are to:

- identify COCs;
- select ARARs; and
- derive preliminary remediation goals (PRGs) for COCs and establish cleanup criteria.

To accomplish the above, the risk assessment must complete its evaluation of four fundamental components: data evaluation, exposure assessment, toxicity assessment, and risk characterization. The data assessment evaluates all the available data on COCs present in the environment within the EFPC system; the exposure assessment identifies the receptors at risk of exposure, determines the exposure pathways of importance, and quantifies uptake for all COCs by pathway to establish ARARs; the toxicity assessment selects toxicological measures for use in evaluating the significance of exposure to identify PRGs; and the risk characterization integrates the exposure and toxicity assessments to identify areas needing cleanup.

1.6.3 ERA

The baseline ERA determines if and where adverse ecological effects to various animal and plant populations occur as a result of exposure to one or more stressors and if and where site remediation may be needed.

The ERA process consists of several steps, including population and habitat characterization; problem formulation (determining what contaminants are present in the various habitats of the floodplain ecosystem); analysis; which includes exposure characterization (determining the relevant exposures to the various indicator populations) and characterization of ecological effects (determining whether contaminants or other site-related stressors are toxic to these indicator biota or deleterious to their habitats at the concentrations to which various populations and habitats are exposed); and risk characterization (determining aggregate impacts of exposure and toxicity to indicator populations). In this process, exposure and especially ecological effects data are collected from a variety of sources and integrated by a weight-of-evidence approach into a final assessment of current and potential risks to the environment.

Specific objectives of the sampling and analysis of indicator populations and associated habitats and media are to:

- determine the population levels and structure of selected indicator species at various locations along EFPC and at nonimpacted reference sites;
- measure concentrations of COCs in aquatic indicator populations;
- measure concentrations of COCs in terrestrial indicator populations;
- measure concentrations of COCs in EFPC surface water and soils at the time of aquatic and terrestrial biota sampling;
- determine the presence in the EFPC floodplain of species designated as threatened and endangered or in need of management;
- develop the exposure parameters and relevant scenarios for realistic exposures to higher trophic levels through the ingestion of biota;
- display these findings using maps of habitats, contaminant patterns, and ecological responses; and
- integrate these findings using a weight-of-evidence approach.

When these objectives are met, the ERA will provide the organized data to help select remediation alternatives.

1.7 SCHEDULE

The schedule for the post RI report incorporates the document requirements of CERCLA and the procedural requirements of NEPA. Time spans are governed by the commitments in the FFA by DOE for submittals and by EPA-TDEC for document review times. Submittals of the draft documents are proposed annually by DOE and negotiated with EPA and TDEC and set as FFA milestones. Per the FFA, a time of 120 calendar days is allowed for regulatory review by EPA and TDEC. DOE has committed to providing responses to regulatory comments within 60 calendar days. DOE's time is extended if there is conflict between EPA's and TDEC's comments. The schedule of the major documents, both draft and final versions, is shown in Fig. 1.3. Concurrent with the development of the RI report, an integrated FS-EIS is being prepared to screen and identify remedial actions capable of meeting the cleanup criteria and ensuring that environmental impacts are acceptable. The draft FS-EIS is scheduled to be submitted to EPA and TDEC in October 1993. Concurrently with submittal to the regulators, the draft FS-EIS will be available for public review and interested governmental agencies and thus comply with the NEPA requirement for public comment. Following resolution of comments by regulators, agencies, and the public, the final FS-EIS is scheduled to be issued in April 1994, with regulatory approval in August 1994. The Proposed Plan (see Sect. 1.4.4.) is scheduled for submittal as a draft in April 1994, final in August 1994, and should be approved in August 1994. Review times are reduced for the proposed plan and the ROD, as it is a small document, and the content is likely to be similar to parts of the FS-EIS. The ROD is scheduled to be issued in draft in November 1994, final in February 1995, and should be approved in April 1995. It is followed by the Remedial Design Report before July 1996. Remedial action is scheduled to begin no later than July 1996. It must start a maximum of 15 months after the ROD is formally signed.

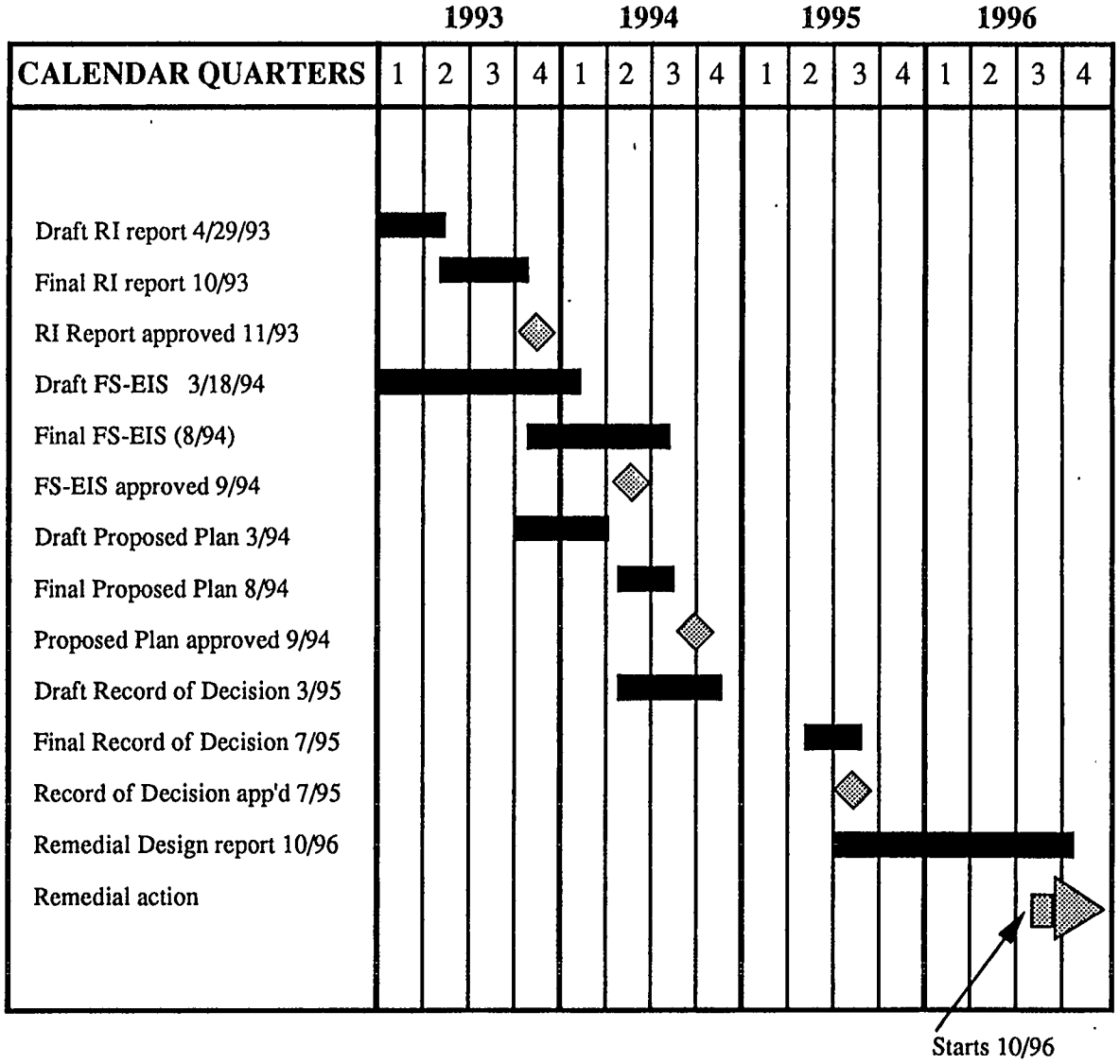


Fig. 1.3. Schedule of EFPC activities.

2. CHARACTERIZATION OF THE ENVIRONMENTAL SETTING

The environmental setting of EFPC and SLB encompasses both physical and cultural aspects of the sites, the ORR, and the city of Oak Ridge, Tennessee. Discussion of the geography of the sites includes the physiography of the area, the results of a wetlands inventory, and an archaeological survey. The demographics of the area are addressed using census tract data and by subdividing EFPC into nine segments based on land use. The climate of the site reflects its regional setting and is supported by NOAA monitoring in Oak Ridge. The general geology of the site is presented for the regional and site-specific bedrock types and structure. The soil is addressed by the soil types identified in previous studies and the results of geotechnical analysis. Groundwater in both the bedrock and shallow aquifers is presented in terms of the site conceptual model. Discussion of surface water and sediments is based on the watershed that contributes to EFPC and the observed distribution of creek sediments. The general ecology of EFPC is summarized for flora and fauna identified in this environmental setting.

EFPC originates within the Y-12 Plant and runs 23 km (14.5 mi) to its confluence with Poplar Creek (Sect. 2.1). The SLB consists of 16 km (10 mi) of sewer lines having a portion with two branches in the city of Oak Ridge and another portion primarily within the floodplain of EFPC. These sites lie within the Valley and Ridge physiographic province of east Tennessee and include several wetland areas and seven identified archaeological sites. Section 2.2 presents the demographics of the sites as derived from 1990 census data and the present land use patterns. Current and projected land use within and adjacent to the sites and the contaminant levels identified during this investigation have been evaluated. The EFPC floodplain has been divided into nine segments based on these findings. These segments form the basis for risk assessment under both current and future land use scenarios. The SLB has only one land use pattern in areas of elevated contamination, open land use, and has not been subdivided into segments for this reason. The climate of the sites reflects the regional moderate continental forest climate, which is temperate with mild winters and humid summers (Sect. 2.3). Section 2.4 presents the bedrock geology of the area, which consists of folded and faulted sequences of sedimentary rocks, predominantly limestone and shale at the sites, and the soil types encountered, which belong to the Newark, Newark variant, and Hamblen series characteristic of floodplains and low-lying areas. The groundwater model (Sect. 2.5) consists of a shallow unconfined aquifer found in residuum and floodplain deposits overlying a carbonate bedrock aquifer. EFPC is a perennial stream with both gaining and losing reaches and forms the principal drainage for a watershed of $\sim$77.2 km^2 (29.8 mi^2), and the creek has a typical distribution of bed and suspended sediment

loads over its length (Sect. 2.6). The ecology of the EFPC floodplain (Sect. 2.7) is characterized by mixed forests, herbaceous plants and shrubs in undeveloped portions, grasses in agricultural areas, and no natural edge in commercial areas. Both local and migratory species of birds and mammals have been observed within the floodplain.

2.1 GEOGRAPHY

2.1.1 General Geography

EFPC is a perennial stream located in Anderson and Roane counties in Oak Ridge, Tennessee, ~40 km (25 mi) west of Knoxville, Tennessee. This area is part of the Valley and Ridge Physiographic Province, which consists of thrust-fault-controlled ridges and valleys trending in a northeast-southwest direction. The EFPC watershed has a trellis drainage pattern and an area of ~77.2 km^2 (29.8 mi^2) above the confluence of EFPC and Poplar Creek (Fig. 2.1). The watershed lies within East Fork Valley and is bounded by Black Oak Ridge on the northwest and East Fork Ridge to the southeast. The EFPC headwaters are within the Y-12 Plant Site in Bear Creek Valley. The creek flows northward through a gap in Pine Ridge and enters Gamble Valley and the city of Oak Ridge. From there, the stream flows northwestward along Illinois Avenue through commercial and light industrial areas in Oak Ridge, then trends generally westward parallel to the Oak Ridge Turnpike in East Fork Valley through primarily residential, agricultural, and open areas until its confluence with Poplar Creek (Map 1).

From the outfall of Lake Reality to its confluence with Poplar Creek, EFPC's linear extent is ~23 km (14.5 mi). Stream depths range from several decimeters to 1 to 3 m depending on the morphology of the stream channel. The 100-year floodplain bounding the creek varies in width from several meters in its upper reaches to roughly 150 m (500 ft) in the flat-lying downstream areas (Map 1), and is ~2.71 km^2 (670 acres) in area. Major tributaries contributing to EFPC include Gamble Branch (Trib. TO) at N 36,800 ft; an unnamed tributary flowing past the Civic Center (Trib. CC) at N 39,150 ft; Mill Branch (Trib. TJ) at E 48,500 ft; Gum Hollow Branch (Trib. TF) at E 36,500 ft; Pinhook Branch (Trib. TE) at E 35,500 ft; and Bear Creek (Trib. BC), which drains into EFPC, at E 23,700 ft. (Coordinates are from the Oak Ridge Administrative Coordinate System, consisting of a northing and/or easting noted in feet. See Map 4.) Elevations in the area range from 222 m (740 ft) at the mouth of EFPC to 390 m (1300 ft) at Pine Ridge.

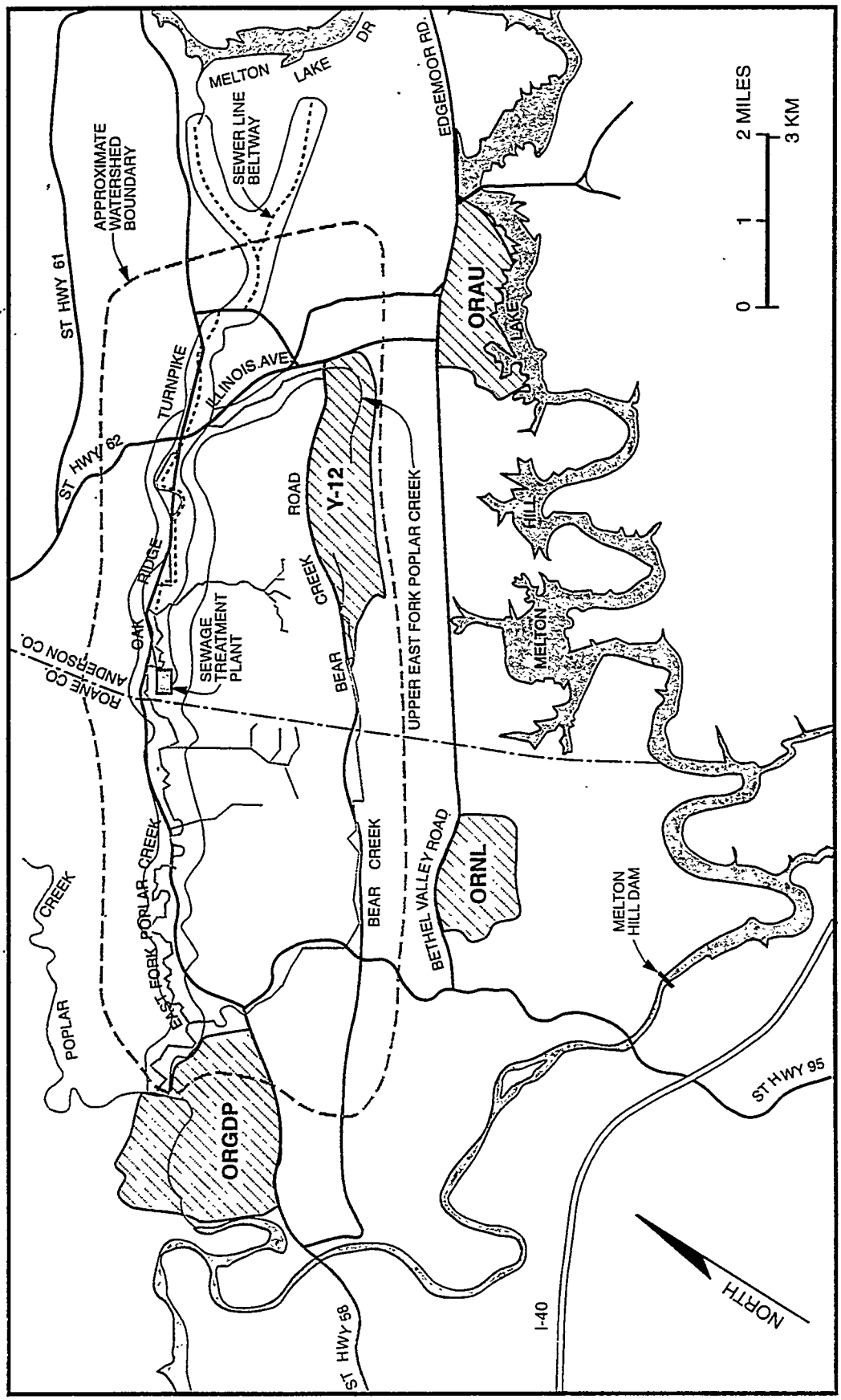


Fig. 2.1. Location map for EFPC and SLB.

Four major land use types were identified within and adjacent to the EFPC 100-year floodplain. These are commercial, residential, agricultural, and open. The commercial designation refers to offices, retail stores, restaurants, shopping centers, and other commercial establishments. Residential land use consists of single- and multi-family housing units and of public educational facilities. Agricultural land use includes farmland for crops and pastures for livestock grazing. The open land use category designates those areas on which recreational or incidental (e.g., trespassing) activities occur. It should be noted that, at present, there is no development within the floodway as defined by the Federal Emergency Management Agency. Any development between the floodway and the 100-year floodplain boundary must be done after the surface is raised above the 100-year flood level.

The SLB was constructed in 1982-1983 to serve as an interceptor sewer and contains more than 16 km (10 mi) of sanitary interceptor sewers and force mains (Fig. 2.1). The northern portion consists of two branches: a sanitary force main, beginning at E 79,000 ft and running west parallel to Emory Valley Road; and a gravity flow sanitary sewer, beginning at E 80,050 ft and running west parallel to Warehouse Road. The two branches converge near the Daniel Arthur Rehabilitation Center, at about E 70,200 ft, into a gravity flow system that parallels Oak Ridge Turnpike to the West End Sewage Treatment Plant (Welch 1987). Sediments and soils from EFPC and its floodplain were used as fill material for portions of the SLB. The southern portion of the SLB from the intersection of Illinois Avenue (E 59,800 ft) to the West End Sewage Treatment Plant (E 44,000 ft) runs within the floodplain, and the discussion of the floodplain along this stretch supersedes the SLB. The SLB discussion involves only that portion from Illinois Avenue eastward.

2.1.1.1 Wetlands

Wetlands are those areas inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal conditions do support, a prevalence of vegetation typically adapted for life in saturated soil conditions (40 *CFR* 230.3; 33 *CFR* 328.3). Wetlands generally include swamps, marshes, bogs, and similar areas. They possess three basic attributes—wetland hydrology, hydrophytic vegetation, and hydritic soils. All three criteria must be present for an area to be defined as a wetland.

To initiate the wetland inventory, National Wetland Inventory maps, Soil Conservation Service (SCS) surveys, U.S. Geological Survey (USGS) topographic maps, and other available pertinent information sources were studied to determine a preliminary indication of the locations of possible wetlands. Eventually the entire length of EFPC was inspected from the Y-12 Plant

boundary to the confluence with Poplar Creek. Within and around the EFPC floodplain, 17 wetlands were identified that exhibited all three wetland criteria (COE 1992). Wetlands ranged from 0.01 to 2.81 acres (Table 2.1); the majority of those wetlands were < 1 acre in area. In all, 11.83 acres of wetlands were identified (see Map 1). The U.S. Army Corps of Engineers (COE) report is included in Appendix A and further discussion of wetlands is included in Sect. 6.2.1.4.

2.1.1.2 Archeology

At the request of the Nashville, Tennessee, District COE, an archeological reconnaissance of the potential impact areas of the ERP along EFPC was conducted from December 16, 1991, to March 3, 1992 (Duvall 1992). The reconnaissance to assess adverse impacts to cultural resources located within the boundaries of federally licensed, permitted, funded, or assisted projects was conducted in compliance with the National Historic Preservation Act (NHPA) of 1966, NEPA, and DOE Executive Order 11593 (May 13, 1971).

Based upon the reconnaissance, a search of the site files at the Tennessee Division of Archeology and a search of the National Register of Historic Places, the proposed remedial action on the site will have no impact on any property included in or eligible for inclusion in the National Register of Historic Places pursuant to 36 *CFR* 60.4(d).

The reconnaissance of the floodplain and associated terraces of EFPC identified five historic period sites and two prehistoric sites. The reconnaissance also determined that the potential for archaeological sites on the floodplain is extremely low. Of the seven sites identified within the floodplain and associated terrace slopes, only two (a probable 19th-century mill site and a probable 19th-century house site) are eligible for inclusion in the National Register of Historic Places.

2.2 DEMOGRAPHICS

According to the 1990 U.S. Census figures, the population of Oak Ridge is 27,310 (U.S. Department of Commerce 1991). The census tract data are included in Appendix B and summarized in Tables 2.2 through 2.5. Of the total population within the region, the population potentially most affected by contamination within the EFPC floodplain are those whose households are within 500 ft of the creek. The total number of residences within this area is estimated to be 448 (see Table 2.2 for a count of residences by census tract). The total population living within 500 ft of EFPC is then estimated to be 1188. Table 2.3 gives the total

Table 2.1. Potential jurisdictional wetlands in the EFPC floodplain (see also Map 1)

Wetland location[a]	Area of wetland (acres)
Creek mile 14.1 right bank	0.39
Creek mile 14.0 left bank	0.01
N 33468 left bank	0.57
N 33806 left bank station W-12	0.56
N 34452 right bank	0.85
E 58069 right bank station N-16	0.09
E 54788 right bank station N-08	2.12
E 53804/E 53476 left bank	0.91
E 43306 right bank	2.81
E 42324 left bank	0.12
E 40024 right bank	0.21
E 30674 left bank	0.45
E 20339 right bank	0.61
E 20339 right bank, station N-14	0.86
E 20011 left bank	0.08
E 19682 left bank	0.39
E 19355 right bank	0.80
TOTAL	11.83

[a]Wetland locations are identified according to creek mile or soil sampling transects; right or left bank refers to direction when facing downstream. Station numbers refer to soil sampling locations along soil sampling transects.

Table 2.2. Number of residences by census tract within 500 ft of EFPC

Census tract number	County	Classification of residences	Total number of residences
201	Anderson	2 garden apts (23+23) 52 condos, 16 single family homes, 100 public housing units	168
202	Anderson	none within 500 ft of EFPC	0
203	Anderson	none within 500 ft of EFPC	0
204	Anderson	none within 500 ft of EFPC	0
205	Anderson	1 apt. bldg. (36), 2 4-plexes (8), 39 public housing units	83
206	Anderson	29 units	29
301	Roane	108 units, 3 apt. bldgs. (61 units)	169
TOTAL			448

Source: SAIC calculations combined with Center for Business Research, University of Tennessee, STFIA Table P12 by Census Tract and STFIA Table H2 by Census Tract, *1990 Census of Population and Housing*, Bureau of the Census, U.S. Department of Commerce 1991.

Table 2.3. Calculated distribution of population within 500 ft of EFPC (Numbers are derived from 1990 census data, estimated number of households within 500 ft of EFPC, and average estimated household size over all census tracts)

Anderson & Roane counties	Percentage of total (%)			Distribution of potentially affected population		
Age cohort	Male	Female	Total	Male	Female	Total
Under 1 year	0.34	0.42	0.76	4	5	9
1 and 2 years	1.01	1.01	2.02	12	12	24
3 and 4 years	1.09	1.09	2.18	13	13	26
5 years	0.59	0.67	1.26	7	8	15
6 years	0.59	0.59	1.18	7	7	14
7 to 9 years	1.94	1.85	3.79	23	22	45
10 and 11 years	1.26	1.18	2.44	15	14	29
12 and 13 years	1.35	3.03	4.38	16	36	52
14 years	0.59	0.76	1.35	7	9	16
15 years	0.59	0.93	1.52	7	11	18
16 years	0.84	0.76	1.60	10	9	19
17 years	0.59	0.59	1.18	7	7	14
18 years	0.59	0.59	1.18	7	7	14
19 years	0.51	0.59	1.10	6	7	13
20 years	0.42	0.42	0.84	5	5	10
21 years	0.42	0.51	0.93	5	6	11
22 to 24 years	1.35	1.43	2.78	16	17	33
25 to 29 years	2.27	2.36	4.63	27	28	55
30 to 34 years	3.03	3.37	6.40	36	40	76
35 to 39 years	3.45	3.70	7.15	41	44	85
40 to 44 years	3.37	3.87	7.24	40	46	86
45 to 49 years	3.62	4.12	7.74	43	49	92
50 to 54 years	3.45	3.37	6.82	41	40	81
55 to 59 years	3.11	3.37	6.48	37	40	77
60 and 61 years	1.18	1.26	2.44	14	15	29
62 to 64 years	1.68	2.02	3.70	20	24	44
65 to 69 years	2.69	6.90	9.59	32	82	114
70 to 74 years	1.26	1.85	3.11	15	22	37
75 to 79 years	1.09	1.43	2.52	13	17	30
80 to 84 years	0.34	0.76	1.10	4	9	13
85 years and over	0.08	0.51	0.59	1	6	7
TOTAL	44.69	55.31	100.00	531	657	1188

Number of residences in tract within 500 ft of EFPC: 448
Average household size in tracts: 2.65
Estimated population affected: 1188

Source: SAIC calculations combined with Center for Business Research, University of Tennessee, STFIA Table P12 by Census Tract and STFIA Table H2 by Census Tract, *1990 Census of Population and Housing*, Bureau of the Census, U.S. Department of Commerce, 1991.

Table 2.4. Number of residences by census tract within 500 ft of the SLB

Census tract number	County	Classification of residences	Total number of residences
201	Anderson	4 apts (35+24+72 Units) 8 single family residences	138
202	Anderson	150 single family residences, 29 duplexes (58), 1 retirement home (110)	318
203	Anderson	none within 500 ft of SLB	0
204	Anderson	none within 500 ft of SLB	0
205	Anderson	1 apt. building (36)	83
206	Anderson	35 single family residences	75
TOTAL			614

Source: SAIC calculations combined with Center for Business Research, University of Tennessee, STFIA Table P12 by Census Tract and STFIA Table H2 by Census Tract, *1990 Census of Population and Housing*, Bureau of the Census, U.S. Department of Commerce, 1991.

Table 2.5. Calculated distribution of population within 500 ft of the SLB (Numbers are derived from 1990 census data, estimated number of households within 500 ft of SLB, and average estimated household size over all census tracts)

Anderson & Roane counties	Percentage of total (%)			Distribution of potentially affected population		
Age cohort	Male	Female	Total	Male	Female	Total
Under 1 year	0.42	0.49	0.91	6	7	13
1 and 2 years	1.19	1.05	2.24	17	15	32
3 and 4 years	1.32	0.98	2.30	19	14	33
5 years	0.70	0.77	1.47	10	11	21
6 years	0.70	0.49	1.19	10	7	17
7 to 9 years	2.16	1.95	4.11	31	28	59
10 and 11 years	1.46	1.32	2.78	21	19	40
12 and 13 years	1.39	2.51	3.90	20	36	56
14 years	0.49	0.63	1.12	7	9	16
15 years	0.70	0.63	1.33	10	9	19
16 years	0.77	0.49	1.26	11	7	18
17 years	0.63	0.63	1.26	9	9	18
18 years	0.56	0.56	1.12	8	8	16
19 years	0.49	0.56	1.05	7	8	15
20 years	0.42	0.42	0.84	6	6	12
21 years	0.42	0.49	0.91	6	7	13
22 to 24 years	1.53	1.46	2.99	22	21	43
25 to 29 years	2.23	2.72	4.95	32	39	71
30 to 34 years	3.28	3.35	6.63	47	48	95
35 to 39 years	3.56	4.18	7.74	51	60	111
40 to 44 years	3.56	4.11	7.67	51	59	110
45 to 49 years	2.93	3.07	6.00	42	44	86
50 to 54 years	2.58	2.65	5.23	37	38	75
55 to 59 years	2.30	2.93	5.29	33	42	75
60 and 61 years	1.05	1.19	2.24	15	17	32
62 to 64 years	1.60	2.16	3.76	23	31	54
65 to 69 years	2.79	6.45	9.24	40	93	133
70 to 74 years	1.53	2.58	4.11	22	37	59
75 to 79 years	1.19	2.09	3.28	17	30	47
80 to 84 years	0.42	1.32	1.74	6	19	25
85 years and over	0.28	1.12	1.40	4	16	20
TOTAL	44.65	55.35	100.00	640	794	1434

Number of residences in tract within 500 ft of SLB: 614
Average household size in tracts: 2.34
Estimated population affected: 1434
Source: SAIC calculations combined with Center for Business Research, University of Tennessee, STFIA Table P12 by Census Tract and STFIA Table H2 by Census Tract, *1990 Census of Population and Housing*, Bureau of the Census, U.S. Department of Commerce, 1991.

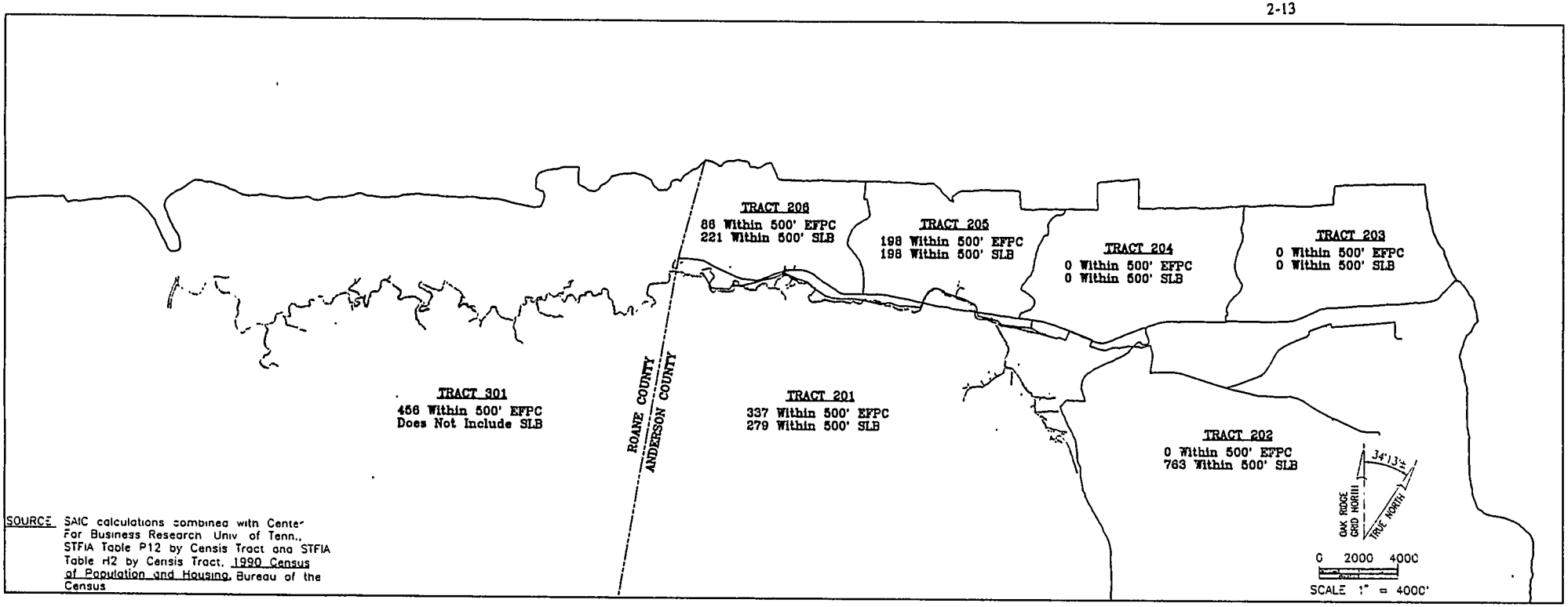
affected population distribution by age and sex, and Fig. 2.2 shows the population within 500 ft of EFPC by census tract. Census Tracts 201 and 301, on the south side of the creek, have the greatest number of potentially affected persons residing within 500 ft of the creek. The creek does not pass through Census Tracts 202, 203, and 204; or through Census Tract 206 proper, although there are residences on the southern edge of Census Tract 206 that are within 500 ft of the creek.

Residences within 500 ft of EFPC are primarily in clusters along several points of the creek. Near the intersection of Oak Ridge Turnpike and South Illinois Avenue, there are two public housing sites, Wilderness Trace Condominiums, three apartment buildings, and two quadplexes. As the stream flows westerly parallel to the Oak Ridge Turnpike, it passes through several farms and homes situated on large lots. The Grand Cove subdivision and Cedarbrook Condominiums are adjacent to the creek in west Oak Ridge.

The population living within 500 ft of the SLB was estimated in the same way as the population in the EFPC area. It is estimated that there are 614 residences within 500 ft of SLB. Table 2.4 details the classification of residences by census tract. The total population within this area is estimated to be 1434. Table 2.5 gives the population distribution by age and sex and Fig. 2.2 shows the population within 500 ft of the SLB by census tract. The SLB does not pass through Census Tracts 301, 204, or 203. Portions of Census Tract 204 are within 500 ft of the SLB, but no residences are within that portion.

The primary location of residences along the SLB are single-family homes along Emory Valley Road. The SLB also passes within 500 ft of Jefferson Junior High School, a retirement home, five apartment buildings, and 29 duplexes.

The most significant sensitive population was determined to be children between the ages of 3 and 12, for the RME scenario. The RME range was chosen because it was thought that children aged 3 to 12 years would spend the most time in the contaminated floodplain area. Children younger than 3 would more likely play in or immediately around the home and would generally be supervised by an adult. Children older than 12 would be more likely to spend time at other locations outside the residential setting. See Sect. 5.2 for a full discussion of exposure assessment.



SOURCE: SAIC calculations combined with Center For Business Research Univ. of Tenn., STFIA Table P12 by Census Tract and STFIA Table H2 by Census Tract, 1990 Census of Population and Housing, Bureau of the Census

EAST FORK POPLAR CREEK

Population is calculated from total number of residences and average household size data given in tables 2.2 and 2.4.

PLOTTING INFORMATION:		PEN CONFIGURATION
PROJECT NO. x-0001	XREFS x-0001b/	1 3 RED
DRAWING FILE. x-0001b/	barvtr	2
pcensus.drg		3
DATE. 12-23-92	PLOT FILES x-0001p/	4
PLOTTED BY. J Chisman	pcensus.plt	5 3 BLUE
SHEET 1 OF 1		6
		7 3 BLACK
		8 25 BLACK

LEGEND:

TRACT 301—CENSUS TRACT NO.

Total No. of People Residing Within 500 feet of East Fork Poplar Creek

Total No. of People Residing Within 500 feet of the Sewer Line Beltway

BASE FEATURES

—Creek & Tributaries

- - Sewer Line Beltway

— Census Tract Boundaries

TITLE: Fig. 2.2.
Estimated Population Within 500 Feet of East Fork Poplar Creek and the Sewer Line Beltway

Science Applications International Corporation

2.2.1 Current Land Use

EFPC and the SLB are predominantly within the city limits of Oak Ridge (Fig. 2.1). Each is located in both Anderson and Roane counties. Approximately 25% of the stream passes through property owned by DOE. The remainder of the stream and all the SLB pass through properties that are owned by private citizens or the local government.

This study investigated the EFPC floodplain as defined by 100-year flood boundaries (Map 1, Volume VII). Land use in this area is mostly undeveloped; developed areas within the floodplain are usually part of adjacent land use outside the floodplain. Land use around EFPC and the SLB was broken into four categories: residential, commercial, agricultural, and open. The residential land use category consists of single-family and multi-family housing units. Public educational facilities are also included in this category because children are considered in the residential exposure category. The commercial land use category includes offices, retail stores, restaurants, meeting places, and other commercial establishments. The agricultural areas are identified as areas with related land use: livestock, grazing, horse ranches, etc. No crops or family gardens are presently being grown within the floodway (as defined by the Federal Emergency Management Agency). The agricultural areas are similar to open areas with regard to exposure pathways, but take into account the ingestion of crops or livestock occupying the floodplain, and they represent a more conservative case for baseline risk assessment. Open land use areas are defined as those that may have only incidental use, e.g., recreation or trespass. An example would be the area along Illinois Avenue in the vicinity of the Y-12 Plant, where open land abuts commercial land use within the floodplain.

The EFPC floodplain was divided into the nine segments, numbered from 1 to 9 downstream, described below, based on uniform land use types and/or similar contamination levels (Map 2). An exception was made for Segment 7, which is comprised of two distinct land uses (agricultural and open) (see Map 2) but displays homogeneous contamination levels throughout. Specific locations and divisions between segments will be referenced to the Oak Ridge Administrative Grid Coordinate System.

Segment 1 begins at the Y-12 Plant and runs northward to ~N 35,500 ft, in the vicinity of Tulsa Road. This is a commercial district along Illinois Avenue, with the creek to the west. The actual 100-year floodplain is designated as open land because commercial development will not occur within a 100-year floodplain without alteration and protection to build within that area. Several wetland areas were identified in this segment (see Table 2.1). Segment 1 is characterized

by areas with elevated concentrations of mercury and other contaminants and includes the NOAA site, which from historical data was known to contain high contaminant concentrations within the floodplain. The NOAA site was one of three areas along the creek selected for detailed analysis in this study. Other detailed study areas are the Bruners Center site in Segment 4 and the Sturm site in Segment 5.

Segment 2 comprises the area along Illinois Avenue from Tulsa Road (N 35,500 ft) northward toward the intersection of Illinois Avenue and Oak Ridge Turnpike at the point where EFPC crosses Oak Ridge Turnpike in the vicinity of Robertsville Junior High School (~N 39,500 ft, E 58,800 ft). Segment 2 is similar to Segment 1 in that adjacent lands are primarily commercial, and areas within the floodplain proper have been designated as open land use because of the restriction on development within the 100-year floodplain. Because contaminant levels were significantly lower than in Segment 1, Segment 2 was established so that it could be considered separately. Part of this area has been rechannelized and was not sampled under this investigation.

Segment 3 extends westward from where the creek flows north under Oak Ridge Turnpike in the vicinity of Robertsville Junior High School (N 39,500 ft, E 58,800 ft) to where the creek flows south under Oak Ridge Turnpike at ~E 56,000 ft (Map 2). This area is characterized by residential, open, and commercial land use. The residential use category has been designated for the junior high school and several housing developments on the south side of the creek. The Jefferson Tennis Courts are located in the floodplain near E 56,000. Girls, Inc. of Oak Ridge plans to buy the tennis courts from the city of Oak Ridge and build a softball field and other facilities to accommodate their activities at the site, so it was designated residential land use. Open space consists of several undeveloped lots that are presently either wooded or open lands. Commercial designations consist of several small businesses, the National Guard armories, and miscellaneous facilities. This segment has moderate contamination levels much like Segment 2, but multiple land uses.

Segment 4 begins where EFPC crosses the Oak Ridge Turnpike from north to south (E 56,000 ft), and trends west to ~E 53,000 ft. The entire area is designated as open land use. It consists of woodlands and open pastures with no present use. The most elevated contaminant levels within the floodplain were detected at Bruners Center, which is one of the detailed study areas. This segment also contains several wetlands.

Segment 5 extends from E 53,000 ft to ~E 50,800 ft. Like Segment 4, it is designated open land with no present use, and although contaminant levels are higher than those generally

observed along the creek, levels are significantly lower than in Segment 4. Commercial and residential development is taking place along the Oak Ridge Turnpike adjacent to the floodplain; however, the floodway is still designated as open land use.

Segment 6 is a narrow zone extending from ~E 50,800 ft westward to E 49,000 ft. This area contains a subdivision (Wilshire Subdivision) and has been classified as residential land use adjacent to and within the floodplain. The 100-year floodplain actually encompasses some of the residential yards. It has lower contaminant levels than those observed in either Segments 4 or 5.

Segment 7 is a broad area that extends from E 49,000 ft westward to ~E 39,800 ft. Segment 7 is composed of two primary land use types: agricultural east of E 45,000 ft and open space west of E 45,000 ft. The agricultural area consists of two small farms where cattle and horses graze within the floodplain. No crops or individual gardens are known to be grown within the floodplain of this area. It is designated agricultural solely on the basis of the grazing livestock. The open land area to the west contains three facilities of note: Big Turtle Park, the Oak Ridge Sewage Treatment Plant, and the Oak Ridge Sportsman's Association property. Big Turtle Park is a recreational park, softball field, and playground adjacent to the floodplain on the north side of the creek. To the south of the creek is the sewage treatment plant, and to the west of that is the Sportsman's Association property. This property contains a rifle range and public access is restricted. However, an occasional trespass may occur within the floodplain; therefore, this section of Segment 7 was designated open land use. Because contaminant levels throughout the entire Segment 7 were relatively homogeneous, it was characterized as a single segment.

Segment 8, from E 39,800 ft to E 37,400 ft, has been designated as residential because of the Grand Cove Subdivision to the north of the creek. This area consists of single and attached housing. South of the creek is the golf course of the Oak Ridge Country Club. The area south of the creek has been designated as open land use under the current land use scenario because of the country club. The yards of individual and attached family dwellings adjacent to the creek frequently extend into the floodplain. Contaminant levels in Segment 8 are distinctly higher than those observed upstream in Segments 6 or 7.

Segment 9 consists of all the remaining floodplain west of ~E 37,500 ft. This includes undeveloped private properties within the city limits of Oak Ridge. These properties are currently being considered for residential development. Currently, no buildings exist on this land except a few barns and sheds; therefore, it is designated open land use. DOE ORR begins at ~E 32,500 ft and continues westward to the confluence of EFPC with Poplar Creek. The reservation is largely restricted from public access, but occasional trespass occurs, and DOE

allows hunters on the reservation during hunting season. Therefore, the area has been designated an open land use area. There are several wetlands identified in Segment 9. Contaminant levels in this area are low compared with other parts of the creek.

The SLB consists of two sewer branches that converge into a gravity flow system which parallels the Oak Ridge Turnpike to the Oak Ridge Sewage Treatment Plant (see Fig. 2.1). The section from Illinois Avenue (E 59,800 ft) to the treatment plant (E 44,000 ft) is within the EFPC floodplain, and the previous discussion of the floodplain—which includes this area—addresses this portion of the SLB. The northern branch originates at a staging facility near Warehouse Road in east Oak Ridge. This portion of the SLB is on the city of Oak Ridge right-of-way and runs parallel and adjacent to the CSX railroad until the junction with the southern branch. The SLB passes near several warehouses, two animal clinics, a retirement home, and Jefferson Junior High School until it meets the other branch. The southern branch is also located on the city of Oak Ridge right-of-way and originates at a pump station on Emory Valley Road. This branch passes near several single-family homes, a community swimming pool, a meeting hall, and a convenience store.

After the two branches converge, the SLB continues west along Emory Valley Road, still within the city of Oak Ridge right-of-way along Emory Valley Road. It passes near a branch community college, a vacant parcel, and an office park. The SLB remains on city right-of-way as it turns north and follows Lafayette Drive.

The SLB crosses private property at a Masonic Lodge. The city has a sewer easement for the remainder of the SLB. Beyond the lodge the SLB continues west by a church, through a residential area, and into a commercial portion of downtown Oak Ridge. Some of the businesses along the SLB include banks, retail stores, and restaurants. In addition there are churches and vacant parcels.

After traversing the commercial area, the SLB extends through the Oak Ridge Civic Center property and follows a small tributary between a shopping center and small commercial businesses. At this point it crosses South Illinois Avenue and follows EFPC to its terminus at the West End Sewage Treatment Facility.

The SLB contains backfill material taken from floodplain soils and sediments. Most of the SLB is situated on the city of Oak Ridge rights-of-way and sewer easements. There is only one portion of the SLB that passes through private property, in the vicinity of the Masonic Lodge. While many land use classifications can be imposed over the length of the SLB, only the open land use classification is applicable for areas displaying elevated levels of contaminants.

These areas include portions of the SLB along Emory Valley Road, Fairbanks Road, and the intersection of Tulane Avenue and Oak Ridge Turnpike.

2.2.2 Future Land Uses—Human Health Exposure Assessment

The designations for future land use are based on the map on p. 103 of the *Oak Ridge 1988 Comprehensive Plan* and observation of present day trends towards commercialization and residential development. If uncertainty exists, the most conservative assumptions (with respect to exposure pathways for risk assessment) for land use were chosen.

In general, most of the land use types within the floodplain of EFPC that are currently designated open are expected to convert to residential land use in the future (Map 3). Several exceptions will be noted. The shift from open to residential use is based on the fact that the city of Oak Ridge has relatively little land for residential development. The city is currently expanding in a westward direction, and any undeveloped land in that direction, either agricultural or open space, will probably undergo conversion into residential use.

As discussed previously, **Segment 1** is currently open space with adjacent commercial properties. For the future scenario, this open space, including the floodplain, is designated to be converted into residential use. **Segment 2** will also have a conversion of open space to residential use. No land use changes were made within **Segment 3** except for a few small undeveloped parcels presently designated open space. These will convert to residential use for the future scenario to expand established residential areas within the segment. **Segments 4 and 5** are grouped together because they are both currently designated as open land use areas and both are projected to convert for future land use to residential property south of the creek and commercial property north of the creek. This is based on the fact that commercial development is presently occurring within these segments adjacent to Oak Ridge Turnpike. **Segment 6** will remain residential for the future land use scenario. **Segment 7** has been assumed to remain open space and agricultural with a minor exception. The area adjacent to the Oak Ridge Sewage Treatment Plant and Big Turtle Park has been designated residential use for the future because this is the more conservative assumption. The shooting range on the Oak Ridge Sportsman's Association property, which has been in existence for many years, is assumed to continue to exist and will require buffer zones for safety; therefore, these lands will remain designated as open space rather than residential. In **Segment 8**, the area to the south of the creek has been converted from open land use to residential. This is the current site of the Oak Ridge Country Club golf course, and while a case may be made for maintaining this area as open land use based on the long-term future existence of the golf course, the more conservative residential designation was

chosen. As mentioned earlier, the undeveloped private property in the eastern third of Segment 9 is currently being considered for residential development north of the creek. For future considerations, the entire eastern third of Segment 9 has been designated residential. It is unclear at this time what future course the DOE property, which encompasses the western two-thirds of Segment 9, might take, so conservatively, the agricultural designation was chosen rather than the open land designation.

Present land use is indicated for each segment in Table 2.6. Using these data, an estimate of 7% residential, 2% commercial, 9% agricultural, and 74% open land areas was made for the EFPC 100-year floodplain area. Unclassified areas include EFPC and all roads and paved rights-of-way within the floodplain. Unclassified areas comprise 8% of the total floodplain acreage and will not be evaluated for exposure to floodplain soils. Projected future land use is estimated for each segment and shown in Table 2.7. Total future land use for the EFPC floodplain is estimated to be 29% residential, 12% commercial, 42% agricultural, and 8% open. The major shift in land use from present to future will be from open areas to residential use.

The Oak Ridge area transportation needs are met by a network of primary and secondary paved roads with easy access to the I-40/I-75 interstate system, and by the CSX Railroad System. The McGhee-Tyson Airport in south Knoxville is served by major and commuter airlines with service to major metropolitan areas across the country.

2.3 CLIMATE

Oak Ridge, Tennessee, is part of the southeast climatological region of the United States. This region is characterized by a moderate continental forest climate with mild winters [coldest month above 0°C (32°F) but below 18°C (64.4°F)]. The southeast region is consistently moist, with rainfall throughout the year (Espenshade 1980). The Oak Ridge area has a temperate climate with warm, humid summers and mild, cool winters. The Blue Ridge Mountains to the east and the Cumberland Plateau to the west have a protective and moderating influence on the area's climate (Fig. 2.3). As a result, the climate is milder than the more continental climate found just to the west on the Cumberland Plateau or on the eastern side of the Smoky Mountains. The Cumberland Plateau to the west and Smoky Mountains to the southeast also divert severe storms and tornados, consequently, high-velocity windstorms are rare. The mountains similarly divert hot, southerly winds that develop along the south Atlantic Coast. Slow-moving high pressure cells which may remain nearly stationary for days, suppress rain in the fall, and provide mild weather. The atmosphere can be considered to be in inversion status 36% of the time.

Table 2.6. Percentage and total area for current land use within the EFPC floodplain

SEGMENT	COMMERCIAL		RESIDENTIAL		AGRICULTURAL		OPEN		UNCLASSIFIED		TOTAL	
	Percentage	Acres	Percentage	Acres	Percentage	Acres	Percentage	Acres	Percentage	Acres	Percentage	Acres
1	1	0.16	0	0	0	0	91	12.81	8	1.11	100	14.08
2	4	0.53	3	0.38	0	0.0	81	11.73	12	1.79	100	14.43
3	29	3.87	47	6.13	3	0.45	11	1.42	10	1.31	100	13.18
4	1	0.04	5	0.82	0	0	87	12.70	7	1.05	100	14.61
5	3	0.03	2	0.18	0	0	92	7.71	5	0.46	100	8.38
6	0	0	83	9.34	0	0	11	1.26	6	0.67	100	11.27
7	0	0	0	0	43	23.71	50	28.01	7	4.01	100	55.73
8	0	0	15	1.75	0	0	75	8.69	10	1.17	100	11.61
9	0	0	0	0	0	0	91	117.76	9	12.13	100	129.89
TOTAL	2	4.63	7	18.60	9	24.16	74	202.09	8	23.7	100	273.18

Table 2.7. Percentage and total area for future land use within the EFPC floodplain

SEGMENT	COMMERCIAL		RESIDENTIAL		AGRICULTURAL		OPEN		UNCLASSIFIED		TOTAL	
	Percentage	Acres	Percentage	Acres	Percentage	Acres	Percentage	Acres	Percentage	Acres	Percentage	Acres
1	58	8.20	34	4.77	0	0	0	0	8	1.11	100	14.08
2	37	5.38	50	7.26	0	0	0	0	12	1.79	100	14.43
3	31	4.06	56	7.36	3	0.45	0	0	10	1.31	100	13.18
4	58	8.51	35	5.04	0	0	0	0	7	1.05	100	14.60
5	65	5.42	30	2.50	0	0	0	0	5	0.46	100	8.38
6	10	1.11	83	9.33	1	0.16	0	0	6	0.67	100	11.27
7	0	0	1	0.31	50	28.23	42	23.19	7	4.01	100	55.74
8	0	0	90	10.45	0	0	0	0	10	1.17	100	11.62
9	0	0	24	31.61	67	86.15	0	0	9	12.13	100	129.89
TOTAL	12	32.68	29	78.63	42	114.99	8	23.19	9	23.70	100	273.20

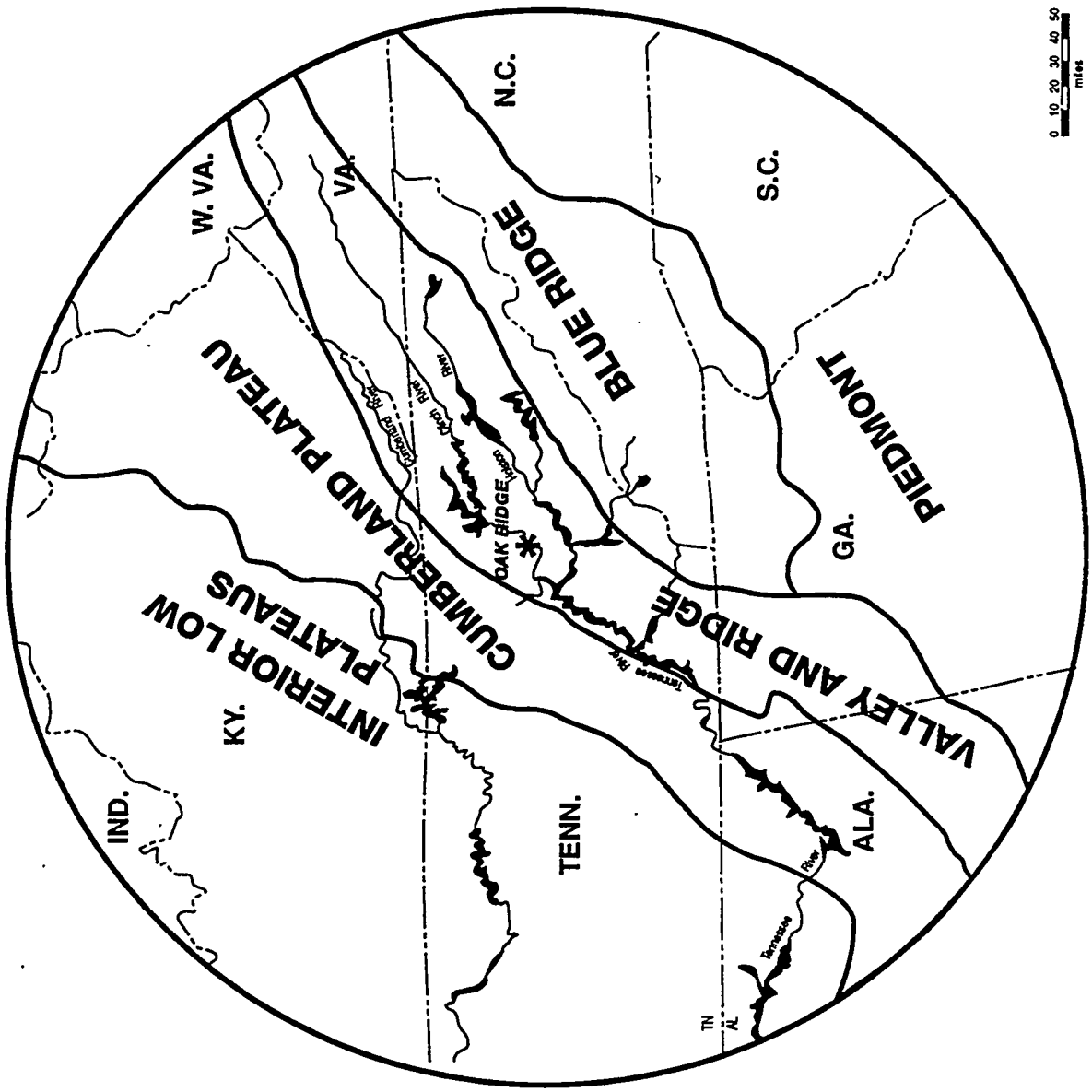


Fig. 2.3. Regional physiographic map.

3-070992-160

Precipitation in this portion of the Tennessee Valley is seasonally distributed (McMaster 1967). Winter storms are generally of low intensity and long duration; brief, heavy rains associated with thunderstorms are common in the summer. Peaks in precipitation usually occur in late winter and early spring and in mid-late summer (Fig. 2.4). The annual minimum precipitation usually occurs in the fall. According to the local climatological data published by NOAA, for Oak Ridge, Tennessee (1991), the 30-year mean annual precipitation in the Oak Ridge area is 54.16 in. (138 cm). The 30-year mean annual snowfall is 9.8 in. (25 cm). In 1991, there were 81 sunny days, 127 partly cloudy days, and 157 days with full cloud cover.

An isohyetal map of the Oak Ridge area (Fig. 2.5) shows that mean annual precipitation ranges from more than 150 cm in the west to about 115 cm in the east. Rainfall is at a maximum near the Cumberland Plateau and decreases from northwest to southeast, reaching a minimum at the foot of the Blue Ridge Mountains.

Loss of water to the atmosphere by evapotranspiration is about 76 cm annually in the Oak Ridge area, or about 55% of the total annual precipitation. Evapotranspiration is at a maximum from July to September during the vegetative growing season. Runoff is greatest in the winter when evapotranspiration is low and precipitation is high. Precipitation not lost as evapotranspiration or as quick surface and shallow-groundwater runoff percolates through the soil and eventually recharges the deep groundwater system.

Year-round mean temperatures are about 58°F (15°C) with a January mean of about 38°F (3.5°C) and a July mean of about 77°F (25°C). The prevailing winds in the Oak Ridge area follow the general topography of the surrounding ridges: up-valley winds come from the southwest during the daytime, and down-valley winds come from the northeast during the night-time (Fig. 2.6). The average wind speed recorded for 1991 was 4.5 mph with a predominant southwest wind direction. A maximum velocity of 59 mph was recorded at NOAA in January 1959.

2.4 GEOLOGY AND SOILS

2.4.1 Geology

Oak Ridge is located in East Tennessee within the Valley and Ridge Physiographic Province of the southern Appalachian Mountains (see Fig. 2.3). This area is a portion of the foreland fold and thrust belt of the Appalachian Mountain range in eastern North America.

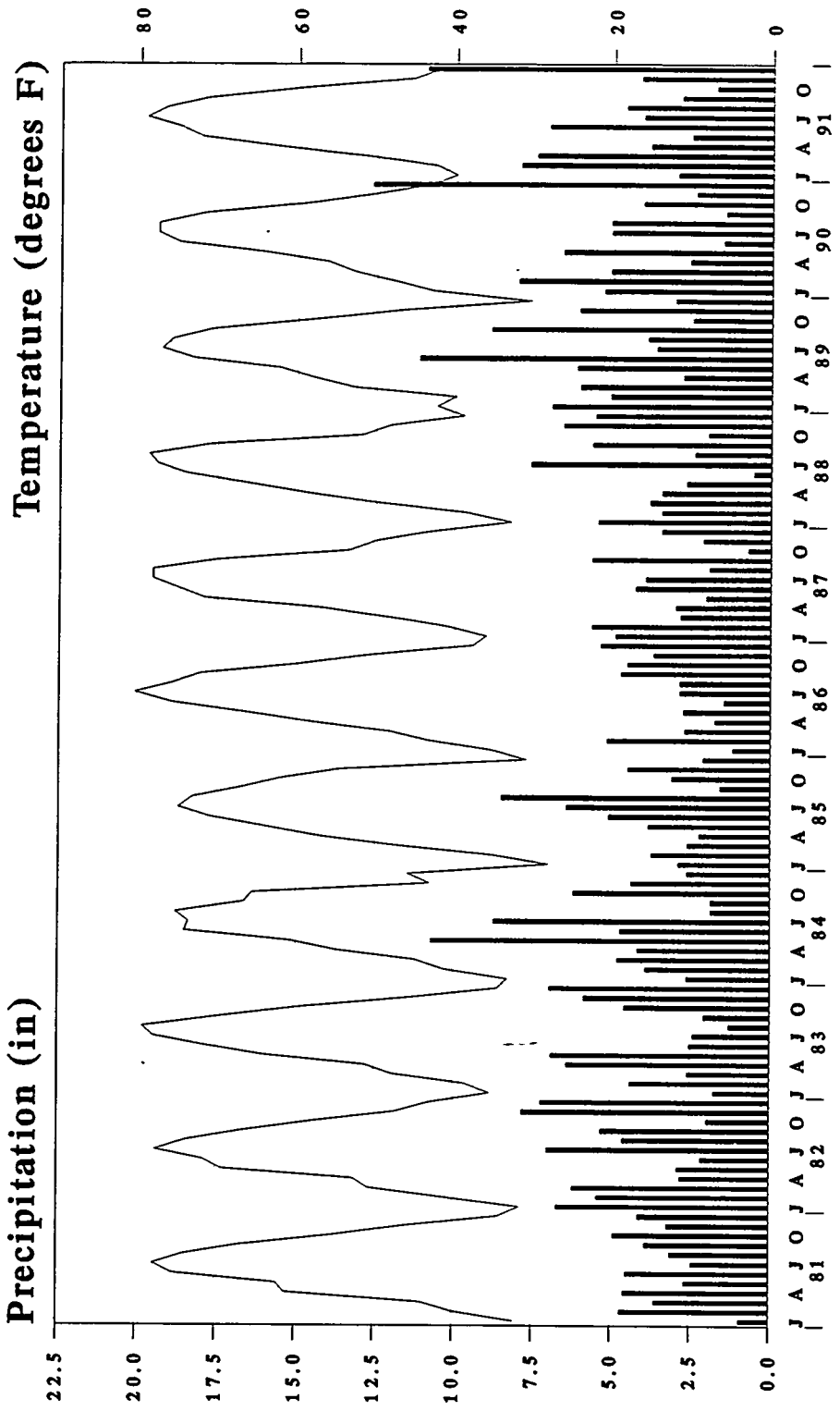


Fig. 2.4. Climatological data for EFPC and vicinity January 1981 - December 1991 (*Source:* NOAA 1991).

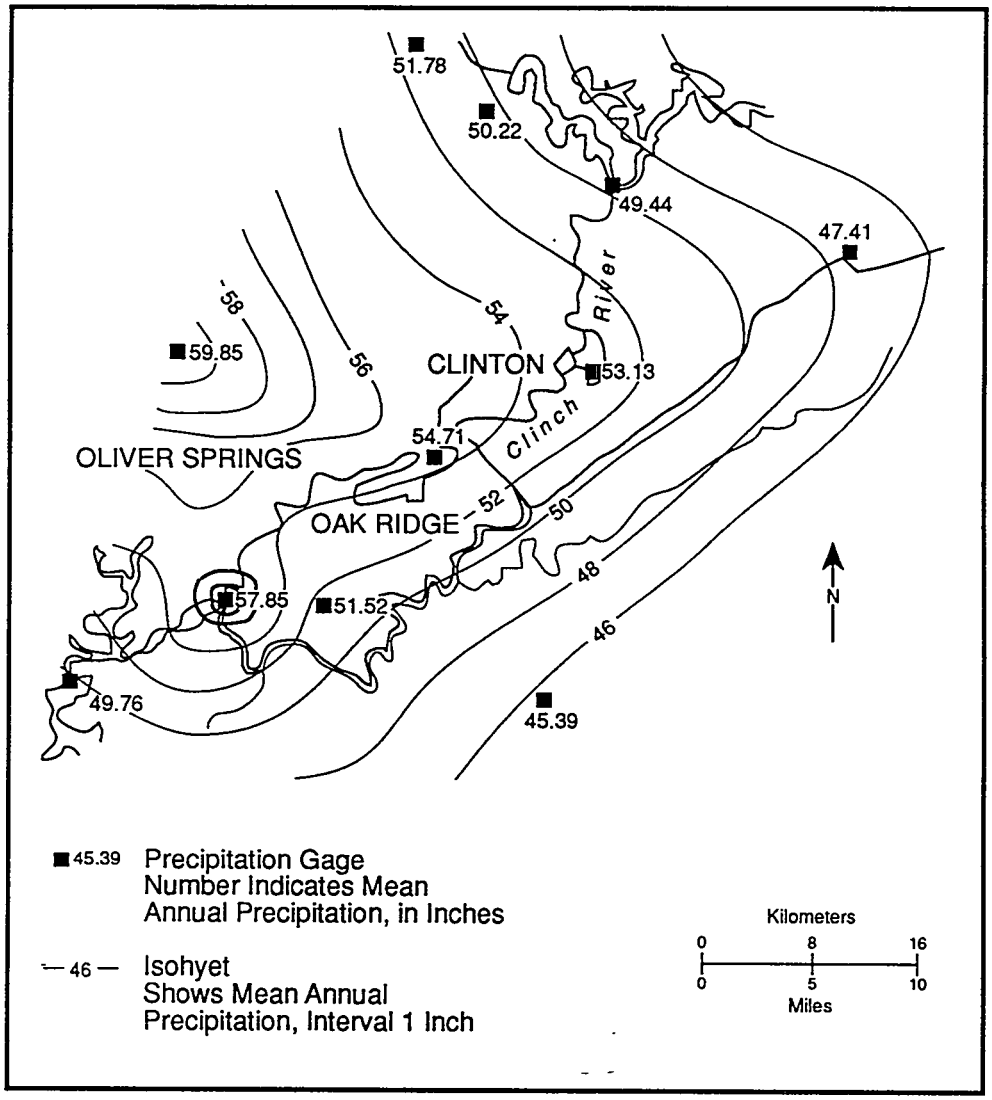


Fig. 2.5. Isohyetal map of the Oak Ridge, Tennessee area showing a northwest-to-southeast decline in average precipitation. Map based on mean annual precipitation data for 1936-1960 (McMaster 1967).

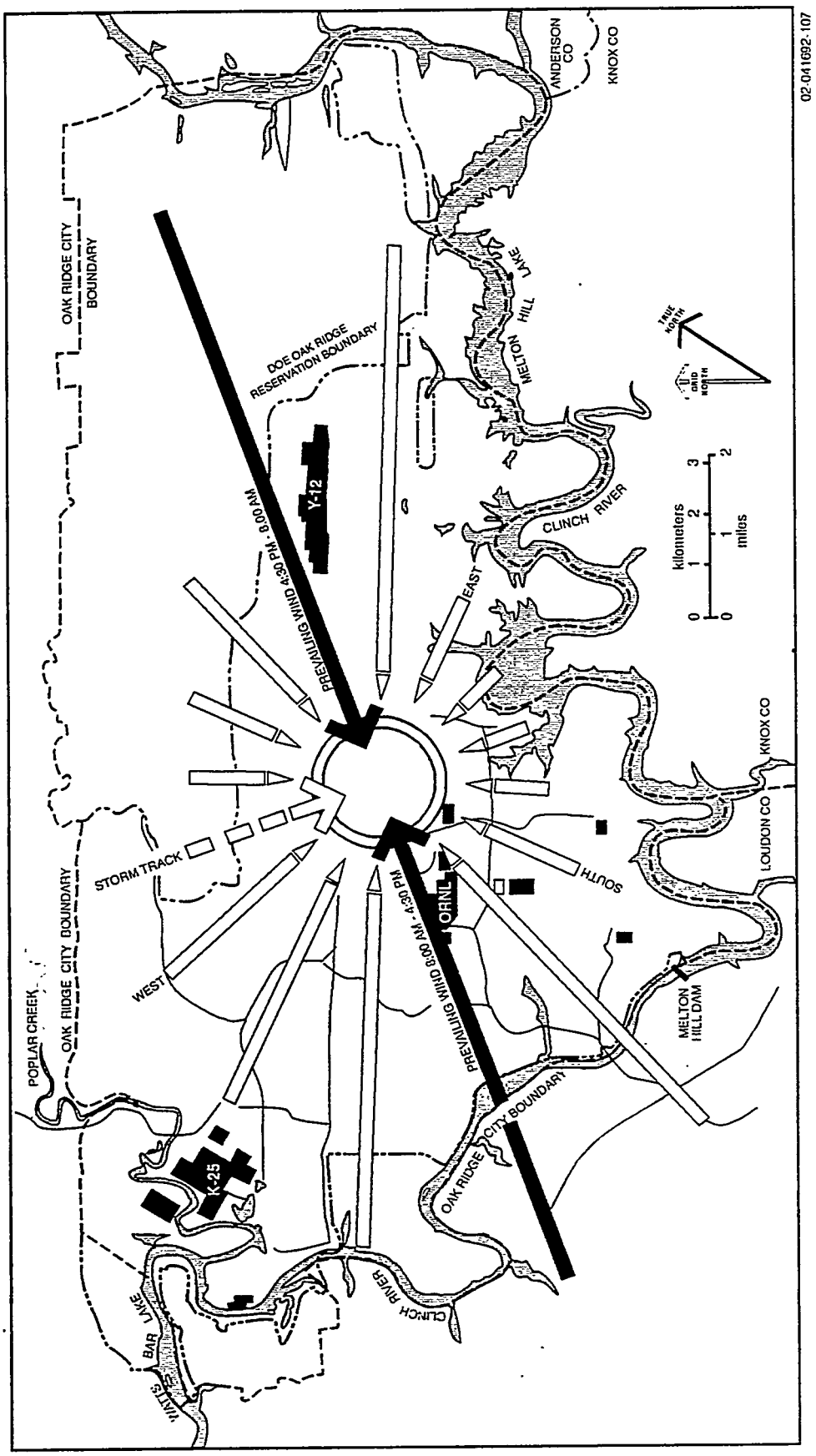


Fig. 2.6. Average wind frequency and direction for the DOE ORR and vicinity.

2.4.1.1 Valley and Ridge Province

The Valley and Ridge Province in Tennessee consists primarily of Cambrian to Ordovician age sedimentary rocks that occur as *en echelon*, northeast/southwest-trending thrust sheets above a basal detachment. Late Paleozoic northwest-directed thrust faulting is responsible for the emplacement of older rocks over younger rocks at the footwall of each thrust sheet (Fig. 2.7). Northwest verging low-to moderate-amplitude folds are associated with this thrust translation and are expressed in large-scale structures and as small-scale folding internal to the thrust sheets.

The stratigraphy of the Valley and Ridge Province in Tennessee includes units of the Cambrian Rome Formation and Conasauga Group, the Cambrian-Ordovician Knox Group, the Ordovician Chickamauga Group, and less extensive units of Silurian through Mississippian age (Fig. 2.8). The Rome Formation consists of interbedded sandstones, siltstones, and shales. The Conasauga Group includes formations of limestone or shale. The Knox Group is a massive sequence of limestones and dolostones with lesser intervals of shale. The Chickamauga Group is composed primarily of limestones and shales. Silurian through Mississippian units in the Valley and Ridge Province include sandstone, shale, and limestone units.

2.4.1.2 Oak Ridge area

Physiography. The Oak Ridge area is located in the western portion of the Valley and Ridge Physiographic Province of the southern Appalachians (see Fig. 2.3). These rocks were folded and faulted during northwest-directed thrusting events, and the resulting landscape has been differentially eroded to produce a topography dominated by narrow elongate ridges and valleys, which trend to the northeast/southwest (Thornbury 1965). The prominent valleys and ridges that are traversed by EFPC and the beltway drainage system are from north to south: East Fork Valley, East Fork Ridge, Gamble Valley, Emory Valley, Pine Ridge, and Bear Creek Valley. Elevations within the study area range from 222 to 390 m (740 to 1300 ft) above mean sea level (MSL), or a maximum relief of 168 m (560 ft).

Structure. The Oak Ridge area is underlaid by two major northeast/southwest trending, southeast-dipping thrust faults that define thrust sheets (Hatcher et al. 1989). The White Oak Mountain and Copper Creek faults are exposed in the Oak Ridge area and are projected into the southern Appalachian Master Decollement. The thrust sheet that forms the northern portion of the Oak Ridge area is bounded to the north by the Kingston fault and to the south by the White Oak Mountain fault zone. The White Oak Mountain thrust sheet is bounded on the north by the

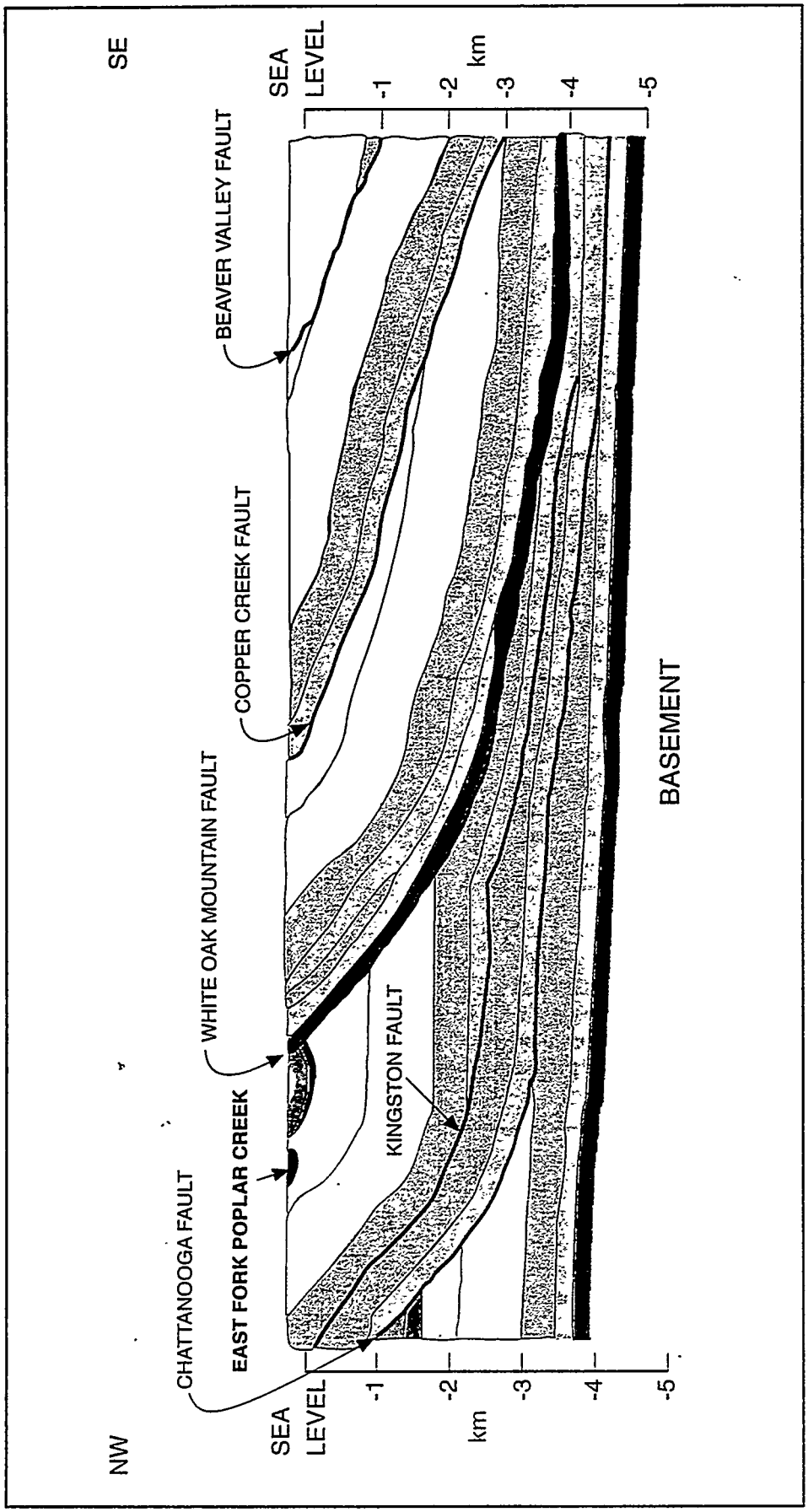


Fig. 2.7. Northwest-southeast structural cross section showing EFPC in relation to regional thrust faulting (*Source:* ORNL-DWG 85M-L0908R).

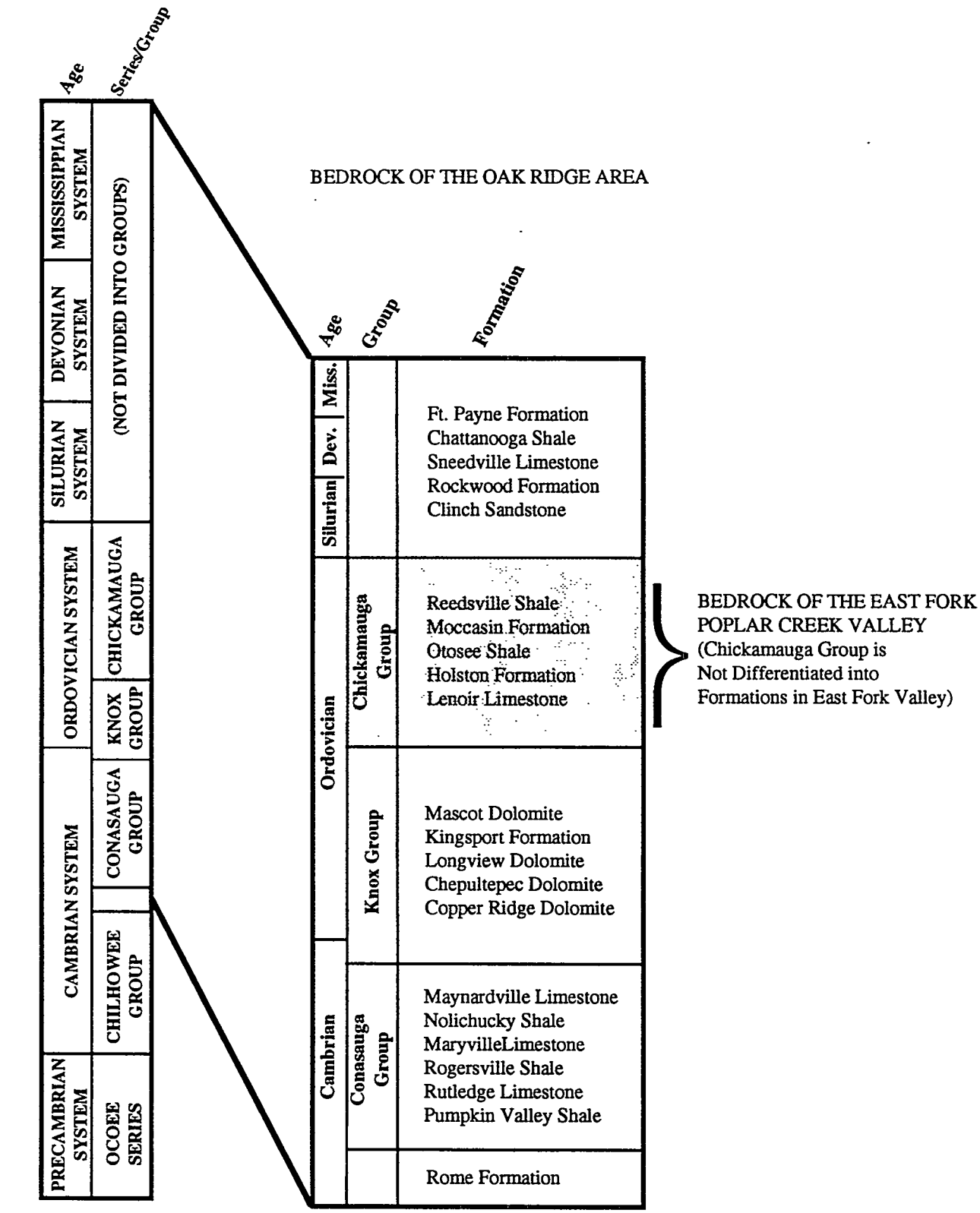


Fig. 2.8. Stratigraphy of East Tennessee and the Oak Ridge area. (after Hatcher et al. 1989)

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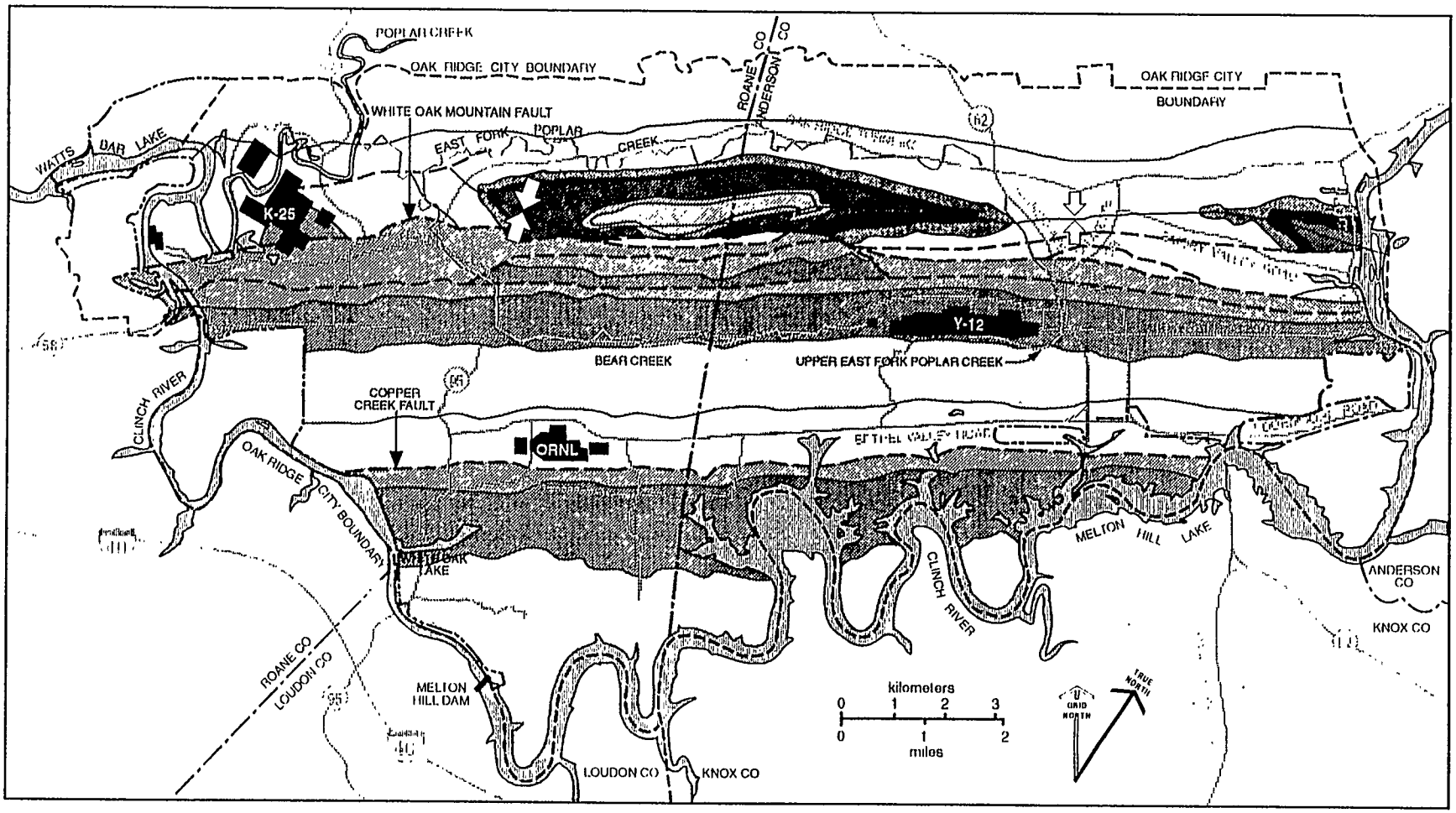
White Oak Mountain fault zone and to the south by the Copper Creek fault. The White Oak Mountain thrust sheet underlies the southern portion of the Oak Ridge area (see Fig. 2.7).

The bedrock geology of the northern (basal) thrust sheet consists of a large-scale monocline structure that includes a double-plunging fold and several small thrust slices. The lowermost units (northern) of this thrust sheet consist of Cambrian Conasauga Group and Cambrian-Ordovician Knox Group rocks which strike between N47°E and N67°E and dip from 35° to 50° to the southeast. Above these units the rocks are deformed by a doubly plunging synclinal structure known as the East Fork Ridge-Pilot Knob syncline (McMaster 1963). The syncline plunges to the northeast and southwest, and forms a saddle along the axial plane. Rocks of Upper Ordovician through Lower Mississippian age are exposed in this structure. The White Oak Mountain fault zone truncates the southern limb of the syncline with imbricate slices of Knox group carbonate found along the strike of this fault.

The White Oak Mountain thrust sheet lies structurally above the basal (northern) thrust sheet. This thrust sheet is bounded to the north by the White Oak Mountain fault zone and to the south by the Copper Creek fault. Rocks within the White Oak Mountain thrust sheet are also contained in a monocline and lie in upright stratigraphic succession. The Cambrian Rome formation lies at the structural base of the thrust sheet. The Rome formation is overlain by the Cambrian Conasauga Group, which is overlain by the Cambrian-Ordovician Knox Group and by the Middle Ordovician Chickamauga Group (Hatcher et al. 1989). These units strike between N35°E and 65°E and dip between 25° and 45° to the southeast (Fig. 2.9).

Stratigraphy. The stratigraphy of the basal (northern) thrust sheet in the Oak Ridge area from bottom to top (north to south), includes the following units and associated geographic features: the Conasauga Group, underlying Sugar Grove Valley; the Knox Group, underlying Black Oak Ridge; the Chickamauga Group, underlying East Fork, Gamble, and Emory Valleys; and the Reedsville, Sequatchie, Rockwood, Chattanooga, and Fort Payne Formations, underlying East Fork Ridge and Pilot Knob.

The White Oak thrust sheet, from bottom to top (north to south), consists of the following: the Rome Formation, underlying McNew Hollow and Pine Ridge; the Conasauga Group, underlying Bear Creek Valley; the Knox Group, underlying Chestnut Ridge; and the Chickamauga Group, underlying Bethel and Raccoon Valleys (McMaster 1963) (see Fig. 2.9).



LEGEND

- Rockwood Formation Sr
- Sequatchie Formation Os
- Reedsville Shale Or
- Chickamauga Limestone Och
- Knox Group OεK
- Fort Payne Chert Mfp
- Conasauga Group εC
- Rome Formation εr
- Chattanooga Shale MDc
- Fault Zone
- Syncline

Fig. 2.9. Geologic map of EFPC and the city of Oak Ridge.

2.4.1.3 EFPC

Geologic stratigraphy, structure, and lithology control the topography of the Oak Ridge area. The course of EFPC reflects this control. The stratigraphy underlying EFPC reflects the structural configuration of the area. The lithology of the bedrock units determines the resistance of the rock to physical and chemical weathering, and thus controls the resulting topography. In general, dolostone, sandstone, and siltstone units are more resistant to weathering in this climate and produce ridges. Limestones and poorly consolidated clastic sedimentary rocks are less resistant and form valleys. East Fork Ridge is underlain by resistant siltstone, shale, and sandstone units of the Rockwood Formation. Pine Ridge is underlain by sandstones and siltstones of the Rome Formation. Chestnut Ridge is underlain by resistant, dense dolostone of the Knox Group. East Fork, Gamble, Emory, and Bear Creek Valleys are underlain primarily by soluble nonresistant units of the Chickamauga Group limestone and the Conasauga Group limestones and siltstones.

EFPC originates at the Y-12 Plant in Bear Creek Valley. From the Y-12 Plant the creek flows to the west-northwest, across Gamble Valley and the strike of the Conasauga, Rome, and Chickamauga Group rocks. EFPC turns to the southwest and meanders along East Fork Valley within the Chickamauga Group until reaching its confluence with Poplar Creek (see Fig. 2.9).

Four different geologic units directly underlie portions of EFPC along its course. These units include, in ascending order: the Rome Formation, the Conasauga Group, the Knox Group, and the Chickamauga Group.

Rome Formation. The Rome Formation, Late Lower Cambrian and Early Middle Cambrian age, is the oldest formation exposed in the ORR (Hatcher et al. 1989). McMaster (1963) informally divided the Rome into upper and lower members, characterized by predominant sandstones or shales, respectively. The upper unit consists of 7.5- to 35-cm (3- to 14-in.) beds of sandstone with thin interbeds of siltstone. The sandstones of the upper unit are composed of fine- to medium-grained, light gray to light brown, well-cemented quartz sand. The siltstones range from dark brown to green brown. Primary features such as ripple marks, rill marks, swash marks, mud-cracks, and raindrop imprints are abundantly preserved. The lower shale member of the Rome Formation is fault-bounded and is thought to represent an older part of the formation (McMaster 1963). This member consists of beds which are green, maroon, red, violet, purple, yellow, tan, and brown in color. The shale is predominantly silt-free but is interbedded with thin silty-clay layers. The thickness of the Rome formation in the Oak Ridge area is difficult to

determine due to numerous internal faults, creating an overestimated apparent thickness (Hatcher et al. 1989). In the ORR, the actual thickness is between 90 and 125 m (297 to 412.5 ft) as reconstructed by McReynolds (1988).

Conasauga Group. The Cambrian Conasauga Group underlies the headwaters of EFPC. This group is divided into six formations (Hatcher et al. 1989):

- **Pumpkin Valley Shale.** The lower Pumpkin Valley Shale consists of reddish-brown and gray to greenish-gray shale with thin interbeds of siltstone and silty, fine-grained sandstone. The sandstones are heavily bioturbated. The upper Pumpkin Valley Shale consists of laminated to thin-bedded, dominantly reddish-brown, reddish-gray, and gray shale with thin, wavy, and planar-laminated siltstone lenses. Shales are generally fissile and may be massive or thinly laminated. Thin partings of fine-grained glauconite pellets are ubiquitous.

- **Rutledge Formation.** The Rutledge Formation consists of light gray, thin-bedded limestone inter-bedded with dark-gray or maroon thin-bedded shale. In general, bedding is thicker, and lithologies are more homogenous in the lower Rutledge Formation. In contrast to the distinct glauconitic partings of the Pumpkin Valley, the frequent incorporation of glauconite throughout the thin limestone beds of the Rutledge is evidence of bioturbation.

- **Rogersville Shale.** The Rogersville Shale contains lower and upper lithologies separated by the Craig Limestone Member (Rodgers and Kent 1948). The lower Rogersville Shale consists of dark-gray and greenish-gray shale containing thinly laminated and bioturbated argillaceous limestone lenses. The Craig Member is recognized in Melton Valley as 3 m (10 ft) of fossiliferous limestone and argillaceous limestone. The upper Rogersville Shale is dominated by thinly laminated maroon shale containing light-gray calcareous siltstone lenses and glauconitic partings.

- **Maryville Formation.** The Maryville Formation consists of intraclastic, oolitic, and wavy-laminated limestone interbedded with dark-gray shale. Shales typically contain wavy-laminated, coalesced lenses of light-gray limestone and calcareous siltstone. In contrast to the underlying more shale-rich formations, the silty limestone content of the Maryville makes it a minor ridge former in Bear Creek Valley and Melton Valley.

- **Nolichucky Shale.** The Nolichucky Shale is generally divided into unnamed lower and upper shale members separated by the Bradley Creek Member (Melton 1967), a limestone unit. The lower Nolichucky is medium- to thick-bedded shale and limestone or calcareous siltstone. Shales are gray, olive gray, and maroon. Limestones are intraclastic or more typically oolitic with glauconite occurring occasionally. The Bradley Creek Member is described in Melton Valley as 10 m (33 ft) of micritic and oolitic limestone. The upper Nolichucky is dark-gray shale with planar and wavy-laminated or ribbon-bedded limestone. Several thick (about 1 m) (3.3 ft) oolitic limestones occur in the upper Nolichucky.

- **Maynardville Limestone.** Regionally, the Maynardville Limestone has been formally divided into a lower Low Hollow Limestone Member and an upper Chances Branch Dolomite Member (Harris and Mixon, 1970; Harris 1965). The Low Hollow Member is generally a ribbon-bedded or mottled, fine- to medium-grained, dolomitic limestone with incipient bedding stylolites and irregular oolitic limestones. Several dark-gray shale beds occur in the lower portions of the member. The Chances Branch consists of bioturbated and thinly laminated, fine- to medium-grained, massively bedded dolomicrite and dolomitic limestone.

Knox Group. Cambrian-Ordovician rocks of the Knox Group underlie EFPC near the confluence of EFPC with Poplar Creek. In eastern Tennessee, the Knox Group can be divided into five formations of dolostone and limestone. The entire group is estimated to be ~731 m (2400 ft) thick in the Oak Ridge area (Lee and Ketelle 1989). In ascending order, the formations in the Knox Group are the Cambrian Copper Ridge Dolomite, the Ordovician Chepultepec Dolomite, the Longview Dolomite, the Kingsport Formation, and the Mascot Dolomite. Significant portions of the areas underlain by the Knox Group are characterized by karst features.

The Copper Ridge Dolomite is a resistant ridge-forming unit consisting of thin- to thick-bedded dolomite that is microcrystalline to coarsely crystalline. The Chepultepec Dolomite is less resistant and underlies relative topographic lows within ridges comprised of the Knox Group. It consists dominantly of dolostone and limestone. The dolostone consists of dolomite which is finely crystalline, thick-bedded, with numerous dolomite-cemented sandstone beds and some silica-cemented sandstones. The limestone is cryptocrystalline to very-fine grained, thick-bedded and locally contains quartz nodules. The Longview Dolomite is a resistant ridge former that consists of both dolostone and limestone. The dolostone is silicious, fine- to coarse-crystalline, thin- to thick-bedded, with rounded quartz grains throughout. The limestone is dense to fine-grained, and medium- to thick-bedded, constituting as much as half of the upper part of the

formation. The Kingsport Formation is a less resistant dolostone and limestone unit. The dolostone is fine- to coarse-crystalline, thin- to medium-bedded, and locally laminated. The limestone is cryptocrystalline to crystalline, and medium- to thick-bedded. The Mascot Dolomite is a resistant unit consisting of dolostone with lesser amounts of limestone. The dolostone is siliceous and locally cherty, cryptocrystalline to fine crystalline, locally laminated, and thin- to medium-bedded. The limestone is cryptocrystalline, medium- to thick-bedded with some silty partings, and commonly demonstrates conchoidal fracture.

Chickamauga Group. Rocks of the middle- to upper-Ordovician Chickamauga Group underlie East Fork Valley and most of the course of EFPC. Rocks of this group are encountered along EFPC, on the northwest side of the White Oak Mountain Fault (Fig. 2.9).

The Chickamauga Group has been divided into as many as eight formations (Stockdale 1951). In East Fork Valley, however, variation in lithology along strike, and the recurrence of similar lithologies at different zones makes formational distinction problematic (McMaster 1963). The lowermost sequence of the Chickamauga Group in East Fork Valley consists of discontinuous, obscurely bedded layers of bentonitic material, gray shale, and siltstone. This sequence, when present, may be up to 15 m (50 ft) thick. A shaly limestone sequence that is 450 m (1500 ft) thick overlies this basal unit. Limestones in the lower part of this sequence are dense- to fine-crystalline, light- to medium-gray and blue gray, and are thinly bedded. Fossils of brachiopods, bryozoans, corals, and crinoid stems are abundant in this zone. Two bentonite beds lie ~12 m (40 ft) apart near the upper portion of the lower sequence. Overlying these beds is an upper sequence of coarsely crystalline, massively bedded, fossiliferous limestone. This unit grades into a fossiliferous, calcareous, thinly bedded shale, recognized as the Reedsville shale, which is the uppermost formation of the Chickamauga. The Reedsville shale is ~60 to 75 m (200 to 250 ft) thick.

Two major unconformities are present in the stratigraphic section of the ORR area: one is between the Lower Ordovician Knox Group and the Middle Ordovician Chickamauga Group; the other separates the Lower Silurian Rockwood Formation from the Upper Devonian - Lower Mississippian Chattanooga Shale (Hatcher et al. 1989). Stratigraphic discontinuities have not been recognized as zones of increased permeability in the bedrock of EFPC. However, zones of solutional (secondary or tertiary) porosity in carbonate rocks are typically stratigraphically controlled. Similarly, large scale structural discontinuities (fault zones) have not been shown to have markedly increased permeability, but smaller-scale fracture sets have been shown to produce the principal permeability in some rock units. Lithology, orientation, and spacing are important variables that affect the significance of fractures on permeability.

A glei layer has been identified from shallow groundwater wells in some areas of the ORR (Carmichael 1989). This is a blue-gray to brown, moderately to highly erosion resistant, silty-clay layer underlying the alluvium and directly overlying bedrock. It ranges from a few centimeters to as much as 1.5 m (a few inches to 5 ft) in thickness (Carmichael 1989). The conceptual model for groundwater during Phase Ia was, in part, predicated on the presence of the glei layer. However, this layer was not found to provide an effective boundary between the bedrock and shallow aquifers during this investigation.

2.4.2 Soils

Soils mapped in the EFPC floodplain in Anderson County belong to the Newark, Newark Variant, and Hamblen series (Moneymaker 1981). Soils in the EFPC floodplain in Roane County are mapped as the Sequatchie, Pope, and Roane series (Swann et al. 1942). Soils in Roane County were mapped in 1938 and classified under a taxonomic system no longer used by the SCS and were mapped at a different scale than the Anderson County soil survey. Consequently, the Roane County soil survey was of considerably less planning and reconnaissance value than the more recent Anderson County soil survey. Many of the Roane County soils would likely correspond more closely with the soil series as mapped in Anderson County today.

In Anderson County more than 40% of the floodplain is mapped as the Hamblen series, about 25% is mapped as the Newark series, and less than 10% is mapped as the Newark Variant series (Moneymaker 1981). In Roane County, Pope and Roane soils each make up more than 25% of the EFPC floodplain, and Sequatchie soils make up about 10% of the floodplain (Swann et al. 1942). A short description of the properties of each soil series follows. More detailed information about soil properties and management is contained in Moneymaker (1981) and Swann et al. (1942).

2.4.2.1 Hamblen series

Hamblen soils are deep, moderately well-drained, nearly level (0 to 2% slope) soils (Moneymaker 1981). They formed in recent alluvium on low areas within floodplains. This soil is medium acid to neutral. It has a high available water capacity. Permeability is moderate and most areas of Hamblen soils are flooded after heavy prolonged rains. Occasional flooding in most areas and excess water in the soil in late winter and early spring limit urban and agricultural use of Hamblen soils. Hamblen soils are classified as hydric soils by the SCS because of inclusions of wetter soils too small in area to delineate separately (SCS 1991). Hamblen soils are mapped at the Sturm site and one of the Hinds Creek reference sites sampled during Phase Ia.

2.4.2.2 Newark series

The Newark series consists of nearly level (slope range 0 to 2%), somewhat poorly drained soils on floodplains (Moneymaker 1981). These soils formed in recent loamy alluvium derived from soils developed in areas underlain by dolomite, shale, limestone, and sandstone. Newark soils are found adjacent to the moderately well-drained Hamblen soils. Newark soils are medium acid to mildly alkaline and have a moderate to high available water capacity (Moneymaker 1981). These soils are saturated with water to within a foot or less of the surface in late winter and early spring. Most areas are flooded for several days after rains of a few days duration. Agricultural, domestic, and commercial uses of Newark soils are limited because of excess water in the soil and frequent flooding. The Newark series is classified by the SCS as a hydritic soil, one criterion of a wetland (SCS 1991; Environmental Laboratory 1987). Newark soils are mapped at the NOAA and Bruner Center sites, as well as one of the Hinds Creek reference sites sampled during Phase Ia.

2.4.2.3 Newark Variant series

The Newark Variant consists of deep, somewhat poorly drained soils that formed in alluvium washed from soils formed in residuum of shale, limestone, and sandstone (Moneymaker 1981). These soils occur on nearly level stream terraces with slopes ranging from 0 to 3%. Newark variant soils are found in association with Hamblen and Newark soils, but they are found on higher topographic positions than are either the Newark or Hamblen soils. These soils are medium acid to moderately alkaline, permeability is moderately low, and available water capacity is high. Wetness and hazard of flooding limit its potential for development.

2.4.2.4 Sequatchie series

Soils of the Sequatchie series are developed from alluvium on stream terraces, which is derived from uplands underlain by sandstone and sometimes shale (Swann et al. 1942). They are well-drained and strongly acid with a moderate to low water-holding capacity. Sequatchie soils are found on nearly level to gently rolling landforms with slopes ranging from 1 to 15%.

2.4.2.5 Pope series

Pope soils are well drained soils found in the nearly level first bottoms of streams (Swann et al. 1942) along streams. They formed in alluvium derived from upland soils underlain by shale and sandstone. They are acid to strongly acid and are subject to periodic flooding. Pope soils have slow external drainage but excellent internal drainage.

2.4.2.6 Roane series

Roane soils occupy strips of bottomland along small creeks. They formed in alluvium derived from upland soils (Swann et al. 1942). Roane soils are subject to periodic flooding and alteration by deposition and scouring associated with flood events. They are acid and occur on nearly level to gently sloping landforms. Roane soils are well-drained and acidic with low water-holding capacity.

2.4.2.7 Soil geotechnical parameters

Soil thickness in the EFPC floodplain ranges from essentially zero, where bedrock is exposed, to as much as 6 m (20 ft) (Carmichael 1989). Detailed soil geotechnical analysis was performed at the Bruners Center, NOAA, and Sturm study sites, as well as the two reference sites at Hinds Creek. Hydraulic conductivity in soils analyzed ranges from 7.3×10^{-8} to 4.09×10^{-5} cm/sec. Bulk density ranges from 67.28 to 96.4 pcf. Porosity ranges from 42.54 to 62.51% and moisture content was between 19.78 and 57%. Soils were analyzed for extractable acidity, bases (calcium, potassium, sodium, magnesium), total organic carbon (TOC), and pH. Samples also were analyzed for particle size distribution using both wet sieve and dry sieve techniques. Please refer to Sect. 3.2.6 for a complete discussion of soil geotechnical data.

2.5 GROUNDWATER

2.5.1 Groundwater Pathway

The conceptual model for groundwater flow in the EFPC floodplain is an extension of the storm flow zone flow model of Moore (1988). In this model, an intermittently saturated "storm flow" zone is formed in the vadose zone of ridge slopes as rainwater infiltration is impeded by a general decrease in vertical hydraulic conductivity with depth. Water in this "perched" zone moves downslope toward intermediate discharge points (e.g., springs, seeps) and the local valley floor where the storm flow zone merges with the true water table aquifer.

Recharge to the groundwater system is supplied by precipitation and takes place primarily during the non-growing season, from about November 1 to April 30 (Sect. 2.3, Climate). Water percolates through the residuum to the water table or the top of rock in locations with shallow soils. The average hydraulic conductivity of the bedrock is typically less than that of the soil; thus water may move laterally downslope along the bedrock surface (Watson and Luxmoore 1986). Some of the water eventually recharges the bedrock aquifer, but the remainder is discharged to streams or is transpired.

In the humid environment of the East Tennessee Valley and Ridge Province, there is typically a close relationship between shallow groundwater movement and the surface water system. Where stream channels like EFPC, located on valley floors, intersect a shallow water table, groundwater discharges into the stream and supplements its flow.

A survey of 12 shallow wells installed during 1987 in the EFPC floodplain by the USGS (Carmichael 1989) indicates that the EFPC floodplain structures (alluvium overlying glei and carbonate bedrock) are hydraulically connected and comprise the water table aquifer. Carmichael postulated that a glei horizon may exist, which may act as a barrier to vertical migration of water and contaminants. However, the results of Phase Ia groundwater sampling, which included recompletion and monitoring of the existing USGS wells in addition to installing four deep wells concurrently with eight shallow wells, failed to show a distinct hydraulic barrier identifiable as the glei layer. The four deep wells (installed as part of Phase Ia sampling and analysis) were augered to refusal and would have encountered the glei layer if it existed as a continuous barrrier. This clay-rich material may be discontinuous over the limestone bedrock.

2.5.2 Bedrock Aquifer

The bedrock aquifer is composed primarily of limestone containing mudstone and shale partings, but there are also lithologies composed of sandstone, calcareous siltstone, shale, and dolostone. These lithologies typically have tightly bound matrixes with insignificant intergranular permeability. However, a moderately well developed secondary porosity permits transmission of groundwater within the bedrock. The secondary porosity is composed of fractures, some of which have been solution enlarged. These fractures, believed to have formed both during lithification (shortly after deposition) and later during the Allegheny Orogeny, are highly variable in length, spacing, and aperture (Welch 1987). Most fractures are of limited lateral extent, but as noted in previous structural studies (Sledge and Huff 1981), different fracture systems commonly intersect one another, providing a moderate degree of interconnection in the bedrock aquifer. Recent studies at ORNL on the Copper Creek allochthon suggest that solution activity and groundwater movement in fractures in the Chickamauga Limestone exhibit a high degree of stratigraphic control (Welch 1989). This supports a previous study (Webster 1976) that postulates a significant flow component parallel to geologic strike. If these interpretations are correct, then secondary porosity should produce locally high hydraulic conductivities along strike and down dip, resulting from solution within a particular stratum or along bedding planes. Hydraulic conductivity across bedding and oblique to dip may be lower because it is dependent in part on solution of fractures that cross lithologies having variable rates of weathering.

Groundwater in communication with EFPC is restricted to the unconfined shallow aquifer within the floodplain and portions of the adjoining bedrock aquifer. While the RI did not investigate deep groundwater flow paths within the bedrock zone, no significant groundwater movement across the drainage divides is conceptualized between the East Fork and adjacent valleys. The fate and transport of contaminants in groundwater within the EFPC floodplain is considered to be the same as the surface waters of EFPC.

Even if this conceptualization was incorrect and EFPC does provide groundwater recharge to deep flow paths within the bedrock aquifer, no significant impact is anticipated. First, groundwater velocities in the deep surface are relatively slow (with notable exceptions in well-developed karst regions) and any impact from recharge would be minimal. Second, the majority of contamination within the groundwater medium is related to particle-bound metals which would not be transported in large quantities into the deep subsurface. Accordingly, the deep bedrock aquifer is not included in the site conceptual model.

2.5.3 Shallow Aquifer

The shallow or alluvial aquifer in the EFPC floodplain consists primarily of alluvial silt and clay with lesser amounts of sand and gravel. Thickness of the shallow aquifer ranges from essentially zero to as much as 6 m (0 to 20 ft) (Carmichael 1989). Water in the shallow aquifer occurs under water-table (unconfined) conditions, with recharge principally from precipitation and discharge through springs and seeps to EFPC and its tributaries. During spring, summer, and fall, evapotranspiration also accounts for the removal of water in storage in the shallow aquifer. Water levels in the shallow aquifer fluctuate seasonally in response to variations in recharge and evapotranspiration. Generally, the depth to water in USGS observation wells within the EFPC floodplain ranged from about 0.3 to 1.2 m (1 to 4 ft) below land surface (BLS) in late winter, and from about 0.6 to 2.1 m (2 to 7 ft) BLS in late fall (Carmichael 1989). The groundwater wells installed as part of this investigation had water depths ranging from 0.39 to 2.08 m (1.29 to 6.92 ft) BLS. During extremely dry periods, the water table recedes below the top of bedrock in some floodplain areas (Carmichael 1989).

The depth of freshwater circulation is an unknown but potentially important issue with regard to inter-basinal transport and contaminant fate analysis. On a large scale, groundwater moves from potentiometric highs beneath area ridge tops to potentiometric lows below valley floors.

Groundwater elevations within the shallow aquifer vary significantly with rainfall as does base flow within EFPC. Seasonal variations produce localized changes in the hydrologic balance between EFPC and the alluvial aquifer. During the wet season EFPC is a gaining stream (groundwater discharge) and conversely during the dry season portions of the creek may experience a net loss (groundwater recharge). However, even under low flow conditions the overall movement of shallow groundwater across the valley (from ridge to ridge) is toward the confluence of EFPC and Poplar Creek. The approximate piezometric surface of the EFPC alluvial aquifer (in relation to MSL - taken from the hydrographs) is at about 875 to 870 ft in the upper reach. The western-most monitoring wells behind the city of Oak Ridge Fire Station show the piezometric surface to be in the 828- to 824-ft range.

2.5.4 Groundwater Contamination

Y-12 has monitored three wells in the EFPC drainage below NHP. Volatile organic compounds (VOCs) were not detected in the groundwater. Dissolved mercury also was below levels of detection. The USGS survey of shallow wells in the EFPC floodplain (Carmichael 1989) produced similar results but indicated the presence of dissolved uranium in the groundwater. Carmichael concluded that contaminants in the water samples from the USGS transect wells were associated with particulates, and thus, likely, artifacts of the installation process and not actual groundwater transport of contaminants.

The groundwater data are discussed in detail in Sect. 3.2.4. Because the conceptual model developed for the Phase Ia Sampling and Analysis Plan (SAP) placed relatively little importance on the role of groundwater transport of contaminants, much of the investigation uses historical data from the USGS transect wells. These data, in addition to the year-long monitoring of the 12 wells installed as part of this study, confirmed that groundwater flow was not a pathway of concern, thus this medium was eliminated from further investigation in Phase Ib. There is no current or planned agricultural, industrial, or residential use of groundwater from the EFPC watershed study area.

An internal SAIC memo from Lori McCartney to Doug Combs memo dated September 17, 1992 confirmed that property owners along EFPC who might potentially be utilizing groundwater wells for residential or livestock use were contacted, and that no groundwater wells for residential or livestock use currently exist on EFPC floodplain property. The State of Tennessee has not promulgated regulations establishing a classification of aquifers.

2.6 SURFACE WATER AND SEDIMENTS

Surface water transport of contaminants in EFPC has been demonstrated to occur by sediment movement during storm events. The instream contaminant study conducted by TVA (1985) found mercury at or slightly above the detection limit in surface water (0.4 μg/L) during base flow conditions. Concentrations increased as much as tenfold during storm events, primarily because of mercury associated with particulates, from 2.0 μg/L to 24 μg/L (TVA 1985). In addition, the flow of surface water over and through areas of contaminated soils and sediments provides a potential for further transportation and redeposition of contaminants within the EFPC floodplain as well as for direct solution of mercury retained in the contaminated soils and sediments by the surface waters. Preliminary investigations reveal that the EFPC sediments (including floodplain soils) are potentially among the most significant contaminant reservoirs in the EFPC watershed, and that surface water is potentially one of the most significant exposure pathways for terrestrial species, including humans.

The watershed of EFPC covers an area of ~77.2 km^2 (29.8 mi^2). The watershed is roughly rectangular, oriented in a northeast to southwest direction about 14.5 km (9 mi) long and 5.6 km (3.5 mi) wide (see Fig. 1.1). The watershed is partially urbanized, containing portions of the city of Oak Ridge and most of the Y-12 Plant. That portion of the Y-12 Plant not contained in the EFPC watershed is contained in the Bear Creek watershed. One major tributary, Bear Creek (Trib. Bear Creek), drains into EFPC at E 23,700 ft. Bear Creek runs to the south of and parallel to EFPC and is separated from EFPC by East Fork Ridge, Pine Ridge, and Gamble Valley (Map 1). Other tributaries draining into EFPC include the Gamble Branch (Trib. TO), which enters EFPC at N 36,000 ft; an unnamed tributary flowing past the Civic Center, which drains most of the downtown and residential portions of Oak Ridge (Trib. CC) and joins EFPC at N 39,150 ft; Mill Branch (Trib. TJ), which has its confluence with EFPC at E 48,500 ft; Gum Hollow Branch (Trib. TF), which enters EFPC at E 36,500 ft; and Pinhook Branch (Trib. TE), which enters the creek at E 35,500 ft.

EFPC and its tributaries produce a trellis-type drainage network. Within this network, EFPC surface water recharges the shallow groundwater over losing reaches, and groundwater recharges to EFPC surface water over gaining reaches. The primary factors affecting the discharge/recharge relationship are surface water elevation and groundwater table elevation. Headward erosion occurs primarily along first and second order tributaries to EFPC. The creek presently has a stable base level controlled by Watts Bar Reservoir on the Clinch River, and Poplar Creek.

The creek originates as an on-site surface water drainage system at the Y-12 Plant, near the western edge of the facility. The headwaters are contained in underground collection pipes that extend to near the central area of the Y-12 Plant, where the above-ground portion of the creek begins. The creek then flows across the plant site and enters Lake Reality, a lined 2.5-acre surface impoundment. The reach of the EFPC from its point of origin to where it feeds into Lake Reality is referred to as UEFPC. The outfall of Lake Reality, at N 30,000 ft, marks the beginning of LEFPC, which is the subject of this report.

After the outfall of Lake Reality, EFPC travels about 1.1 km (0.7 mi) before crossing the Y-12 Plant property boundary and entering the city of Oak Ridge, at N 32,500 ft. EFPC has been channelized from the discharge at Lake Reality to N 30,100 ft, where EFPC enters Pine Ridge Gap. The cross-sectional area within the channelized section of the creek is roughly trapezoidal with limestone rip-rapped banks. Shale and limestone bedrock outcrops occur in the bed of EFPC, and limestone rip-rap also covers the bottom. Bank height is about 3.7 m (12 ft), while bank span is ~9 to 12 m (30 to 40 ft) at ground surface. Shallow-rooted vegetation is common throughout this reach, indicating some degree of bank stability. From the Y-12 Plant boundary, EFPC flows in a well-defined channel until exiting Pine Ridge through a gap that extends from N 30,100 ft to N 32,500 ft. At Pine Ridge Gap, the presence of rock outcrops along the west bank indicates a potential link to the bedrock groundwater system. Here, the creek is about 6 m (20 ft) wide. The creek bottom appears to grade from a rocky limestone rip-rap below Lake Reality to a somewhat smooth and muddy floor, which begins just beyond Pine Ridge Gap at ~N 32,500 ft.

A widening of the creek at the downstream end of Pine Ridge Gap allows deposition of channel sediments. This floodplain area extends to N 35,500 ft, which is just south of Gamble Valley Road. Previous studies (TVA 1985) have indicated that this floodplain area is stable, with little susceptibility to scour, as evidenced by deep-rooted vegetation.

EFPC continues to flow generally northwest, parallel to Illinois Avenue, a major thoroughfare in Oak Ridge. The channel has a muddy bottom and the average width is in excess of 4.6 m (15 ft). The confluence of Gamble Branch with EFPC occurs at N 36,000 ft. Gamble Branch drains all of Gamble Valley, which is a moderately developed residential area. EFPC is about 4.6 m (15 ft) wide at this confluence with a muddy gravel bottom. Continuing to the north, the creek is channelized between N 38,000 ft and N 39,100 ft. In this section of the creek, EFPC receives runoff from highly developed commercial properties near the intersection of the Oak Ridge Turnpike and Illinois Avenue, banks are protected by rip-rap, and no vegetation is present. Lack of vegetation may be due to recent disturbance during development of

commercial property and sufficient time for reestablishment may have passed. In addition, the creek banks are relatively steep and no evidence of bank failure has been recognized along this reach. However, collapsing banks are evident along other reaches of the creek (possibly providing contaminated soil for downstream transport). At N 39,150, the unnamed tributary designated Trib. CC enters EFPC. It drains a large portion of the residential and commercial properties west of Lafayette Avenue.

EFPC turns generally west at N 39,200 ft/E 59,800 ft, in the vicinity of where Illinois Avenue intersects Oak Ridge Turnpike. EFPC then parallels Oak Ridge Turnpike for 17.2 km (10.7 mi), until turning northward at E 21,500 ft. From ~E 59,700 ft to E 46,500 ft, the EFPC floodplain has been significantly disturbed due to construction activities associated with the installation of the SLB (1982-1983), which parallels EFPC from the intersection of Illinois Avenue and the Oak Ridge Turnpike (E 59,700 ft to E 46,500 ft).

In this reach the creek is generally well-defined, although the channel is broad and undefined around E 50,000 ft. This floodplain, about 91.4 m (300 ft) wide, contains significant sediment deposits and deep-rooted vegetation is common. The creek bottom consists of clay, cobbles, and/or gravel. The channel varies from 4.6 to 6.1 m (15 to 20 ft) in width. Rock outcrop is locally present on the south side of Oak Ridge Turnpike.

The confluence of Mill Branch and EFPC occurs at E 48,500 ft. Mill Branch drains a relatively small portion (10 to 15%) of the EFPC watershed, which is primarily woodland and pasture although the Mill Branch watershed does include several houses, a small horse farm, and the western half of a public golf course. At the confluence, the creek is about 6.1 to 7.6 m (20 to 25 ft) wide. Deep rooted vegetation is present and the creek bottom consists of mud and gravel.

Discharge from the Oak Ridge West End Sewage Treatment Plant enters EFPC at E 44,000 ft. Here the creek is about 3 to 4.6 m (10 to 15 ft) wide. In this area, limestone rock outcrop can be observed along the south bank, which may provide a direct link to bedrock groundwater from EFPC surface waters. Downstream of the confluence with sewage treatment outfall, EFPC flows directly over outcropping bedrock.

From the Oak Ridge West End Sewage Treatment Plant (E 44,000 ft), EFPC continues westward until turning northward at E 21,500 ft. At E 36,500 ft and E 35,500 ft, two major tributaries enter EFPC, Gum Hollow Branch and Pinhook Branch. About 15 to 20% of the EFPC watershed drains into Gum Hollow Branch, while about 10% drains into Pinhook Branch. Both branches receive runoff from primarily residential areas, and from the Oak Ridge Country

Club golf course, a potentially important source of pesticides and other contaminants. At Gum Hollow, EFPC is about 4.6 to 6.1 m (15 to 20 ft) wide, and has a muddy to gravelly bottom. Gum Hollow Branch is about 1.8 m (6 ft) wide at the confluence. At Pinhook, EFPC spans from 6.1 to 9.2 m (20 to 30 ft). Pinhook Branch is about 0.9 m (3 ft) wide at this point. Vegetation covers both sides of EFPC in this area, and there is scattered outcrop in and along the stream channel between the two confluences.

EFPC re-enters the ORR at E 32,500 ft, continuing to flow westward until reaching E 21,500 ft. This section of the creek is surrounded by undeveloped woodland. Several unnamed tributaries enter EFPC before its confluence with Bear Creek at E 23,700 ft. The Bear Creek watershed drains an area of 19.2 km^2 (7.4 mi^2).

At E 23,700 ft, EFPC turns and flows to the northwest until reaching E 20,000 ft, near the confluence with Poplar Creek. The creek is 30.5 m (100 ft) wide at this point. EFPC at this confluence has a muddy bottom with a channel depth of 1.2 to 2.4 m (4 to 8 ft). The floodplain is heavily vegetated above the normal water level elevation and extends more than 30 m (100 ft) on the east side of EFPC, and farther on the west. Pooling caused by high water elevations in Watts Bar Reservoir is often evident in this section of the creek. At E 20,000 ft, EFPC turns westward and flows to its confluence with Poplar Creek. Overall stream gradient for EFPC is .0027 (14 ft/mi), producing laminar base flow conditions over most of the length of the creek.

EFPC and the SLB are located in East Tennessee, which is a humid region, receiving about 140 cm (55 in.) of rainfall annually. The largest monthly rainfall occurs in March with 15.77 (5.21 in.), while the smallest occurs in October. Average flows for EFPC, which is perennial, have been measured since 1960 by USGS gauge No. 03538250, located at E 29,000 ft. The average flow for 25 years of record (1960 to 1985) was 1.5 m^3/s (51.4 cfs). The largest known flood since 1900 occurred September 29, 1944, and had a peak discharge of about 1393 m^3/s (4,600 cfs) (Welch 1987).

Flow in EFPC has been augmented by two artificial sources, the Y-12 Plant and the Oak Ridge West End Sewage Treatment Plant, which contributed 0.33 m^3/s (11.7 cfs) and 0.23 m^3/s (7.88 cfs), respectively. The Y-12 Plant primarily contributes plating wastes, process wastewater, cooling tower blowdown, and coal pile runoff. Average daily Y-12 Plant flow was measured at NHP until November 1988, when discharge from NHP was ceased, and averaged ~0.39 m^3/s (13.8 cfs) over a 7-year period. Average daily runoff from the drainage area upstream of NHP was about 0.06 m^3/s (2.1 cfs) before Y-12 Plant construction (TVA 1985). By this adjustment, the Y-12 Plant augments flow by 0.33 m^3/s (11.7 cfs). Discharge from the Oak

Ridge Sewage Treatment Plant enters EFPC at km 12.89 (mile 8.01). The treatment plant has an average daily discharge of 0.23 m^3/s (7.88 cfs). Thus, total flow augmentation from these two sources was about 0.56 m^3/s (19.8 cfs) through 1988, 60% of which was attributed to the Y-12 Plant and 40% to the Oak Ridge Sewage Treatment Plant. The current average flow rate from the Y-12 Plant is about 8.6 cfs.

The hydrology of the EFPC watershed, contaminant loadings associated with storm events, and the transport of contaminants into and out of the EFPC system are closely interrelated (TVA 1985). The sampling program design adopted for Phase Ia was intended to provide an initial description of the interaction of soils and sediments of EFPC with the watershed hydrology and channel hydromechanics of EFPC. In Phase Ib a much more comprehensive sampling effort was undertaken to quantify the distributions, transport-fate, and loadings of problem toxicants in EFPC more completely and accurately. Sediment samples were taken every 200 m in the stream bed. Sediment deposits were mapped on a series of 1 in. = 50 ft topographic maps (1 ft surface contours) created specifically for this project. Sediment thickness was estimated and used for a gross estimate of sediment volumes within the channel at the time of measurement. Higher accuracy was not warranted due to the ephemeral nature of channel deposits. The surface water data and sediment data are discussed in detail in Sects. 3.2.1 and 3.2.2, respectively.

2.7 ECOLOGY

A baseline ERA report is included in Sect. 6 of this RI Report. The reader is referred to that section for specific details. The following is a summary of the environmental setting with respect to the ecological characterization.

The study area is characterized by shrubs, herbaceous plants, and second growth trees, which form thick stands up to the creek banks in many locations as well as areas cleared for agricultural or commercial uses. Floodplain soils are typically silty loams. The forests are dominated by mixed hardwood species tolerant of flooding. Because of different uses in the past, the woods are in various stages of ecological succession. Even in the vicinity of the developed areas, thick stands of trees typically abut the creek. A variety of shrubs and herbaceous species are also present; these flourish in areas where the overstory has been removed and more light is available. Portions of the floodplain have been filled and developed commercially, and in places the creek has been channeled so that it has little or no natural edge. Mid-reaches of the floodplain contain several large agricultural tracts. Other portions of the floodplain consist of

grass and old field habitats. In all these habitats, fauna such as deer, raccoon, birds, and insects are present.

The upper reaches of EFPC average ~ 4 m in width and 0.25 m in depth, increasing to an average width of ~ 10 m and a depth of > 0.5 m where the creek re-enters the ORR, with deeper pools at some locations. The banks of EFPC are characterized by unconsolidated sediments bordered mainly by flood-tolerant bottomland hardwood forests in the lower reaches. The stream contains fish of various species as well as benthic and other organisms. These organisms are typical of aquatic habitats in the limestone rip-rap to smooth and muddy stream bottoms found in east Tennessee.

The EFPC floodplain is used by birds and mammals migrating locally and regionally. Wetlands have been identified and, in places, measured as part of the ERA studies. In addition to domestic livestock and garden vegetables raised by EFPC landowners, fish are potential human food items that may be exposed to contaminants in the EFPC floodplain ecosystem. The FS/EIS did not identify any threatened or endangered species or their critical habitats on the EFPC floodplain.

The Y-12 Biological Monitoring and Abatement Program (BMAP) continues to conduct ambient toxicity tests, bioaccumulation studies (Sect. 6.2.3.1), biological indicator studies, and ecological surveys of stream communities. The ERA collected additional information on body burdens (Sect. 6.2.3.2) and the abundance and distribution of organisms in aquatic and terrestrial communities (Sect. 6.3.3).

3. SITE HISTORY AND CURRENT CONDITIONS

The site history and current conditions within EFPC and its floodplain and the city of Oak Ridge SLB are the subject of this RI. The results of previous investigations have been evaluated and are summarized within this report. The findings of the current investigation of environmental media which are potentially affected by contamination are also presented. The objective of this portion of the RI is to determine the nature and extent of contamination in support of the human health and ecological risk assessments (Sects. 5 and 6) and to provide a basis for the development of remedial alternatives. Section 3 is composed of two main parts, a site description and discussion of the site history (Sect. 3.1) and a discussion of the historical and RI-derived data (Sect. 3.2).

The site description (Sect. 3.1) includes both an overview of the EFPC and SLB as well as the Y-12 Plant. The discussion of the Y-12 Plant and associated processes is not presented in great detail for this report (they will be the focus of other RIs/FSs. Contamination of the EFPC environs is a result of many activities and processes occurring within the plant boundaries over a 50-year time span. For this reason, site-specific information was not relied upon to conduct this investigation. Access to historical studies and general site knowledge provided sufficient information to design an investigation that would identify probable contaminants and migration pathways.

Section 3.2 reports on the data available for use in this investigation. It describes the historical studies conducted on EFPC and its floodplain over the past decade, and the studies performed during this RI. The conceptual site model is briefly summarized in this section to provide a perspective for the data presented. A more detailed explanation of the site model and the data collection considerations is included in Sect. 5. The presentation of data collected during this investigation is divided into the following subsections by physical media:

3.2.1 Surface Water Data
3.2.2 Sediment Data
3.2.3 Sediment Geotechnical Data
3.2.4 Groundwater Data
3.2.5 Soil Chemical Data
3.2.6 Soil Geotechnical Data
3.2.7 Biomonitoring Data

3.2.8 Air Data
3.2.9 Radiation Survey Data

Section 3.3 is a report of the data quality for the EFPC RI.

Each medium was initially considered to be a potential migration pathway for contamination. The investigation was designed to evaluate the nature and extent of contaminants using a multi-tier data collection and evaluation strategy, analogous to a funnel. During the first tier, screening was accomplished for a wide range and a large number of possible contaminants at sites of known contamination in each media. A list of possible contaminants was "funneled down" to those found in quantities that were toxic or contributed to carcinogenicity of the particular media. The contaminants in this group were designated the potential COCs and further evaluated in the subsequent phase of the investigation. During the second tier, the entire data set for COCs (obtained during all phases of the investigation) was funneled into the risk assessment evaluation. The risk assessment established a final group of contaminants that exceed risk-based criteria. The third tier performed an uncertainty analysis on the results using the distribution of the input parameters (concentrations, toxicity, exposure, etc.) in a probabilistic model.

Of all the media, floodplain soil (Sect. 3.2.5) has the largest volume and highest concentration of contaminants. Potential COCs include a suite of inorganic metals (including mercury), a number of organic compounds from the PAH and PCB groups, and several radionuclides (isotopic uranium and thorium). Because mercury accounts for 85% of the total toxicity, most attention was directed toward this metal. It was found to be a reliable predictor of the occurrence of the other metals and radionuclides and was used as a surrogate to determine the distribution and extent of contamination (with exception of the organic compounds). Mercury and most other inorganic contaminants decrease significantly in the lower one-half of the creek, although localized areas with elevated concentrations are present. In fact, mercury and the other inorganic contaminants are situated in defined areas of the floodplain and not randomly scattered throughout its length. The creek bank within a few meters of the water has received at least some contamination along its entire length. Only three primary areas within the floodplain (and several minor locations) display significantly elevated concentrations of mercury and other metals. PAHs and PCBs (organic compounds) are the two groups of carcinogenic contaminants within the floodplain. They appear to be widespread and possibly related to municipal contributions in addition to the Y-12 source. Their presence is most common in the upper segments of the floodplain near commercial development and urban runoff. Organic contaminants decrease

rapidly away from the developed areas and have been detected only in minor amounts in the wooded and undeveloped portions of the floodplain.

The EFPC floodplain was appraised by dividing the length of the creek into nine "exposure" segments. Each segment represents a portion of the floodplain and creek with a unique combination of land use and contaminant levels. An integrated data set of contaminants was compiled for each segment from all phases of the investigation. Exposure pathways were specified for certain land use types and coupled with a contaminant data set for each segment to calculate risk estimates. Areas of elevated contamination were delineated through the use of geostatistical modeling. This effort characterizes the distance-variance relationship between sample points and employed an interpolation method (kriging) to calculate average contaminant concentrations for areas of the floodplain (defined by blocks). Kriging was used for the surface soil layer (0 to 41 cm) with estimates computed for 20- by 20-m blocks. From this process, total volumes of contaminated soil by segment have been estimated for the upper layer.

As would be expected, creek sediments (Sect. 3.2.2) contain the same contaminants as floodplain soils but at lower concentrations. Because of the transient nature of sediments, the distribution of metals is not as predictable as soils. The same general patterns do exist, however. The upper reaches of the creek show somewhat elevated levels of the various metals (arsenic, cadmium, cesium, copper, mercury, nickel, and lead) compared to lower sections of the creek. Occurrences of PAHs and PCBs were restricted to the upper third of the creek. Creek sediments were compared against tributary sediments to evaluate contributions to EFPC from the adjoining watersheds. Significantly higher concentrations of several metals (cadmium, cesium, chromium, copper, mercury, and nickel) were noted for creek sediments compared to tributary sediments confirming an upstream Y-12 source. An unusual occurrence is observed immediately downstream of the confluence of Bear Creek and EFPC. This area displays slightly elevated concentrations of several contaminants over the adjacent segments of the creek. This occurrence is thought to result from either the input of Bear Creek or the "pooling" of the sediments from creek back flow. Back flow of EFPC occurs when the Watts Bar Reservoir is impounded, and reverse flow temporarily takes place in the lower reaches of EFPC.

Surface water (Sect. 3.2.1) was sampled under two conditions, base flow and storm flow, to ascertain ongoing contributions to EFPC. Water quality with respect to contaminant concentrations was measured at several points along EFPC including the outfall from Lake Reality and the confluence with Poplar Creek. Few chemical compounds could be detected in elevated quantities during base flow conditions. Uranium was detected, with a total activity in

the range of 3 to 8 pCi/L. Common metals such as barium, manganese, and zinc were detected at low concentrations, and mercury was observed once at the outfall of Lake Reality and at several ecological study sites, but at low concentration (0.72 μg/L). Samples (total and dissolved metals) were also taken to determine which contaminants might be transported during high flow storm events. All of the potential COCs (except PCBs) attributable to the soil medium were noted in the storm-event samples and in concentrations many times the base flow levels. However, results for filtered samples confirmed that these contaminants were transported in association with soil particles and not as a dissolved phase. The results from the creek storm events were compared with tributary storm samples to distinguish contributions from the Y-12 Plant from adjoining watersheds. No pesticides, herbicides, or unusually high concentrations of metals were detected in adjoining watersheds during either base flow or storm flow.

Groundwater (Sect. 3.2.4) was investigated as a potential pathway for contaminant migration. The conceptual model for groundwater indicates that the EFPC valley comprises an alluvial aquifer receiving surface water from Bear Creek Valley and recharge from the watersheds along Black Oak and East Fork Ridges. Deep groundwater flow paths are not considered to cross these surface water divides. Twenty-two wells were sampled for the complete suite of analytes for four consecutive quarters. Four of the 22 wells were deep wells screened in the bedrock aquifer. Groundwater field parameters and analytical results were examined to determine whether a shallow aquifer exists separately from the underlying bedrock aquifer. Hydrogeochemical modeling was used that demonstrated two findings. First, no difference could be ascertained between deep and shallow groundwaters; therefore, no aquitard is inferred to exist between the two aquifers. Second, the geochemistry of the EFPC groundwaters is such that mercury cannot persist in a dissolved phase and will precipitate out of solution, most likely as a mercury sulfide. COCs for groundwater include the metals and radionuclides listed for soils but none of the organic compounds. Suspended sediment in the unfiltered groundwater analyses produces the same contaminants found in soil.

Biomonitoring data (Sect. 3.2.7) provide an overview of the historical studies performed within the EFPC ecosystem prior to the start of the ERA. Several studies have measured population densities and contaminant body burdens within aquatic (including fish) and terrestrial biota. Miscellaneous studies have investigated mercury uptake in mice and garden vegetables. The EFPC ERA performed a large-scale integrated study to ascertain risk to the ecosystem, which is presented in Sect. 6.

The air data section (Sect. 3.2.8) reports on perimeter monitoring results of the Y-12 Plant and results of floodplain measurements of mercury vapors. The perimeter monitoring at the plant boundary demonstrates that the environment and human health are not exposed to releases of mercury to the atmosphere. On-site (EFPC) tests, performed by ORNL researchers, were conducted in areas of high mercury concentrations within the floodplain and included both short-term (highly sensitive) and long-term (high volume) measurements. The tests indicate that mercury volatilization in the EFPC floodplain cannot be distinguished from background levels. The results are commensurate with the fact that the majority of mercury has been present within the floodplain for the past 30 to 40 years. Any appreciable volatilization of mercury is expected to have already occurred.

Radiation survey data (Sect. 3.2.9) discuss the results of a DOE aerial radiological survey of the entire ORR and EFPC. The flyover took place from March 30 to April 14, 1992. Measurements were made at an altitude of 46 m (150 ft) and calibrated to terrestrial exposure rates at 1 m above ground level. Gross gamma counts were recorded to determine the ground level exposure rates and spectral windows were used for photopeak count rates to identify specific man-made radionuclides. While the majority of the floodplain measurements were less than the background level of 13 μR/h, two sites were identified with rates between 13 and 20 μR/h. These sites correlate with areas of known contamination but are not statistically distinguishable from background, given the measurement error inherent in the method.

3.1 SITE DESCRIPTION

The site description of EFPC and its floodplain and the city of Oak Ridge SLB provides a basis for evaluating the physical and cultural geographic setting of the site and the impact of past activities on current conditions. In this context, the current and future risks posed by environmental contamination, the potential exposure pathways, and remedial design limitations and considerations can be assessed.

This section presents a summary of the physical and cultural geography surrounding EFPC and SLB (Sect. 3.1.1) and a discussion of the specific background and operational information that has contributed to contamination of EFPC and SLB (Sect. 3.1.2).

3.1.1 Geographic Information

EFPC has been divided into two remedial units for the purposes of this investigation: the EFPC and its associated floodplain, and the city of Oak Ridge SLB. EFPC must also be considered in conjunction with the Y-12 Plant because the plant site contains its headwaters and is its major source of contaminants. Activities at the Y-12 Plant are related to weapons component manufacturing and include metal finishing, plating, uranium recovery, and facility cleaning operations. Machining and milling of uranium and other metals, which have taken place throughout the plant's history, have involved a wide range of potential contaminants, and large quantities of mercury have been used in plant processes over much of the operational history of the facility. Large releases of mercury, the main environmental contaminant in EFPC, have been attributed to spills, maintenance operations, and the discharge of a dilute waste stream into the creek.

The city of Oak Ridge also has a pronounced effect on EFPC. Increasing numbers of subdivisions have developed along the Oak Ridge Turnpike, which generally runs parallel to EFPC. Commercial development is encroaching upon the EFPC floodplain along Illinois Avenue. Nonpoint source runoff from these developed areas contributes to contamination of the creek and includes debris and residential/industrial chemicals from the use of fertilizers, pesticides, road salts, and petroleum products (Welch 1987). Major tributaries drain the Gamble Valley area and much of the east end of the city through runoff and storm sewer collectors. In addition, EFPC receives contribution from the west end of the city via runoff and smaller tributaries from Black Oak Ridge to the north and East Fork Ridge to the south.

3.1.2 Background and Operational Information

3.1.2.1 EFPC

The EFPC and its watershed are located near the city of Oak Ridge within Anderson and Roane counties, Tennessee (see Fig. 2.1). The headwaters of EFPC originate from the middle of the Y-12 Plant reservation, which is located within Bear Creek Valley and along the northern slope of Chestnut Ridge. The headwaters of EFPC are contained in 54- to 72-in. underground collection pipes that extend from the west end to the central area of the Y-12 Plant, where the above-ground portion of the creek begins (Welch 1987). The recharge for EFPC consists of groundwater contributions and surface runoff from Bear Creek Valley; however, its perennial nature can be attributed in large part to process outfalls from the Y-12 Plant. EFPC flows northward from its outfall at Lake Reality at the east end of the Y-12 Plant through a gap in Pine Ridge and exits the Y-12 Plant property before entering the city of Oak Ridge. From there,

EFPC flows generally westward, paralleling two major thoroughfares in Oak Ridge on Illinois Avenue and Oak Ridge Turnpike. EFPC continues to flow westward through residential and undeveloped parts of Roane County and re-enters the ORR before its confluence with Poplar Creek in the vicinity of the K-25 Site, formerly the Oak Ridge Gaseous Diffusion Plant. Stream depths range from < 1 m in many areas to 3-5 m in the downstream reaches.

EFPC is, ultimately, a tributary to the Clinch River which is impounded by Watts Bar Dam downstream of the confluence with Poplar Creek. The length of EFPC from the outfall at Lake Reality to its confluence with Poplar Creek is ~23 km (14.5 mi). The floodplain width bounding the creek varies from a few meters in the upstream channelized reach to ~150 m (500 ft) in the flat-lying downstream areas. Although part of the area surrounding the creek and its floodplain is urbanized, much of it remains undeveloped woodlands and open fields.

3.1.2.2 SLB

The SLB was constructed by the city of Oak Ridge during 1982 and 1983 as part of a three-phase upgrade to the city water pollution control facilities. The SLB was designed to serve the east end of Oak Ridge and to replace the existing treatment facility by carrying waste to the newly constructed West End Sewage Treatment Facility. It acts as an interceptor sewer and contains more than 16 km (10 mi) of sanitary interceptor sewers and force-main lines. The eastern portion consists of two branches: a sanitary force-main running parallel to Emory Valley Road and a gravity flow sanitary sewer running parallel to Warehouse Road. The two branches converge near the Daniel Arthur Rehabilitation Center into a gravity flow system, which roughly parallels the Oak Ridge Turnpike to the West End Sewage Treatment Facility (Welch 1987). The SLB is illustrated in Fig. 2.1.

During construction, the top of the SLB was buried a minimum of 75 cm (30 in.) BLS. The trench was backfilled with crushed stone to a minimum of 20 cm (8 in.) above the top of the pipe; the remaining portions of the trench were then backfilled with native fill material. In areas near some public buildings, houses, and schools, the trench was backfilled with native fill material and a 15-cm (6-in.) layer of topsoil. In certain instances, floodplain soils from EFPC were used to provide the topsoil. No records were kept to document the backfill procedures or the locations corresponding to the fill sources (Welch 1987).

3.1.2.3 City of Oak Ridge

During the growth of Oak Ridge, the course and streambed of EFPC have been modified. The creek has been channelized in some sections of town, and rip-rap has been added to protect

the banks. Numerous drainage ditches and lateral culverts traverse the floodplain and discharge to EFPC. Box culverts and bridge piers are present in EFPC at roadway crossings. In addition, creek sediments and floodplain soils were removed and redistributed in Oak Ridge as additions to local gardens, as fill material in topographically lower parts of the city, and as backfill and topsoil for portions of the SLB.

During the early 1980s, mercury-contaminated soils identified by the ORAU study were removed from the Oak Ridge Civic Center and hauled to the Y-12 Plant. These soils are currently being stored on Chestnut Ridge at the Y-12 Plant.

3.1.2.4 The Y-12 Plant

Throughout the operational history of the Y-12 Plant, generation of radiologically and/or chemically hazardous wastewaters occurred as a result of normal facility operations. Over the years, various treated and untreated portions of these wastewaters have been discharged to EFPC, which originates as an on-site surface water drainage at the Y-12 Plant.

Mereury has been the most significant contaminant found in EFPC to date, and several other heavy metals have also been detected. Large-scale use of mercury at the Y-12 Plant was associated with the production of lithium (Li) enriched in the light isotope form, ^{6}Li, for use in nuclear weapons production.

The process enabling successful ^{6}Li production is called column exchange; the process involves partial separation of lithium isotopes as they partition between chemical phases, one of which is a solution of lithium in mercury. Millions of pounds of mercury were required for the successful completion of the project.

Separations research for ^{6}Li production processes began in 1950, and a production plant expansion occurred in 1953. Over a 15-month period, two large facilities were built, and the first separation units went into production in January 1955. Production of ^{6}Li utilizing this process was stopped in 1963.

The engineered modifications significant to the EFPC RI are the aforementioned basins that receive UEFPC water prior to its release to EFPC. The first basin, NHP, operated for 15 years before being closed in accordance with RCRA requirements. The replacement basin, adjacent to the NHP site, is called Lake Reality.

New Hope Pond. NHP was constructed in 1963 and was operated until November 8, 1988, at which time water was diverted away from the pond and into Lake Reality and NHP was closed. NHP was designed as an equalization basin for Y-12 Plant effluents that would reduce their fluctuations in pH and short-term variations in chemical concentrations. The pond was also intended to provide a contingency capacity for control of accidental spills of oils or other substances and to regulate flow in EFPC from its outfall at the Y-12 Plant and its flow toward the city of Oak Ridge (UCC-ND 1983).

The capacity of NHP was ~26 million gal. The discharge from the pond averaged ~8 million gal/day and was monitored in accordance with the conditions set forth in NPDES permit No. TN002968. The pond had a surface area of ~5 acres. Its length varied from 137 to 290 m (450 to 950 ft), and its width varied from 82 to 122 m (270 to 400 ft).

Water treatment at NHP was accomplished in three ways:

- **Sedimentation:** The holding capacity of NHP before closure was considerably less than its design capacity due to sedimentation. The volume of sediments retained at the site is estimated to be ~19,115 m^3 (25,000 yd^3). The presence of mercury and heavy metals in the sludge attests to the fact that the pond has reduced the discharge of certain pollutants to EFPC (UCC-ND 1983). The estimated mercury content of the removed sludge was 6600 lb.

- **Skimming:** An oil retention system was constructed upstream of NHP ~40 ft west of the inlet to the pond (Van Winkle, et al. 1984). This system consisted of a 25- by 40-ft retention basin into which oils and floating debris were diverted by an oil retention boom. Also, a skimmer weir located at the basin outlet retained oil and debris for subsequent removal and disposal.

- **Aeration:** A large aerator was used in NHP to increase the dissolved oxygen content of the water in the pond before it was discharged into EFPC. Also, the water was further aerated as it flowed over the weir at the outlet of the pond.

Lake Reality. Lake Reality was constructed immediately downstream of NHP and commenced operations on November 8, 1988. Water enters Lake Reality from an extension of the NHP diversion ditch and is released through a weir in the west berm into the existing channel of EFPC. An emergency weir is located at the north end of the Lake Reality distribution ditch. The bottom elevation is ~892 ft above MSL, and the average water depth is expected to be ~7 ft. The surface area of Lake Reality is ~2.5 acres, and the lake contains ~6 million gal of water during normal operation (Geraghty and Miller 1989).

Mercury was used extensively at the Y-12 Plant in association with the production of lithium enriched in the light isotope form (^{6}Li) for use in hydrogen or thermo-nuclear weapons. Three different processes were developed to enable large-scale separation of the isotopes. The first of these was the Elex process, an electrically driven chemical exchange process. A production-scale plant was operated in Bldg 9204-4 (Beta 4). In contrast, the Orex process, in which an organic solution of lithium was exchanged with lithium amalgam, never got beyond the pilot-plant scale (Bldg 9202). Research and development in the Colex process began in 1951 in the 9201-2 (Alpha 2) pilot-plant and proved very successful, resulting in the shutting down and dismantling of work on the Orex and Elex processes. Colex production facilities included Bldgs 9201-4 (Alpha 4) and 9201-5 (Alpha 5). Meeting of production targets permitted the shutdown of the Alpha 5 plant in 1959 and the Alpha 4 plant in 1962. The Alpha 5 plant was started up again from a 6-month campaign in 1963, and then all production ceased. The Colex equipment for Alpha 5 was dismantled and disposed of during 1965 and 1966, while the Colex equipment in Alpha 4 remains. Continued contamination from seepage into outfalls to EFPC comes primarily from the Alpha 2, Alpha 4, and Alpha 5 plants, all shown in Fig. 3.1. Losses of mercury to the environment from the column exchange process occurred both during and after production operations ceased. During operations, spills and maintenance activities resulted in releases to land, air, and surface water. Based on a 1983 UCC-ND Task Force study, an estimated 108,600 kg (238,950 lb) of liquid mercury were released to EFPC between 1950 and 1982 (UCC-ND 1983). Figure 3.1 shows the facilities in which lithium isotope separation work was done. Major spills at the Y-12 Plant include three spills at the 9201-2 (Alpha 2) building resulting in a total of 45,360 to 54,432 kg (100,000 to 120,000 lb) spilled with an estimated loss of 43,092 kg (95,000 lb) mercury. Numerous spills occurred at the 9201-5 (Alpha 5) building from 1955 to 1956, resulting in a total spill of 108,864 to 145,152 kg (240,000 to 320,000 lb) of mercury.

The majority of the mercury released—about 90,900 kg (200,000 lb)—was discharged to EFPC from the column exchange waste stream before 1961 as a very dilute, neutralized acid waste. Discharge of this waste stream was eliminated in 1963 (UCC-ND 1983).

Another 13,180 kg (29,000 lb) are estimated to have been lost to the creek from 1950 to 1983 from secondary sources other than the column exchange process waste stream. These secondary sources consisted of building drain systems, sewers, and transfer lines discharging to EFPC. The transfer lines contained mercury in some joints, as well as contaminated sludges that continue to serve as a source of small amounts of mercury to EFPC (UCC-ND 1983). The sewers were relined in 1986-1987 (Welch 1987), reducing or eliminating this source of mercury

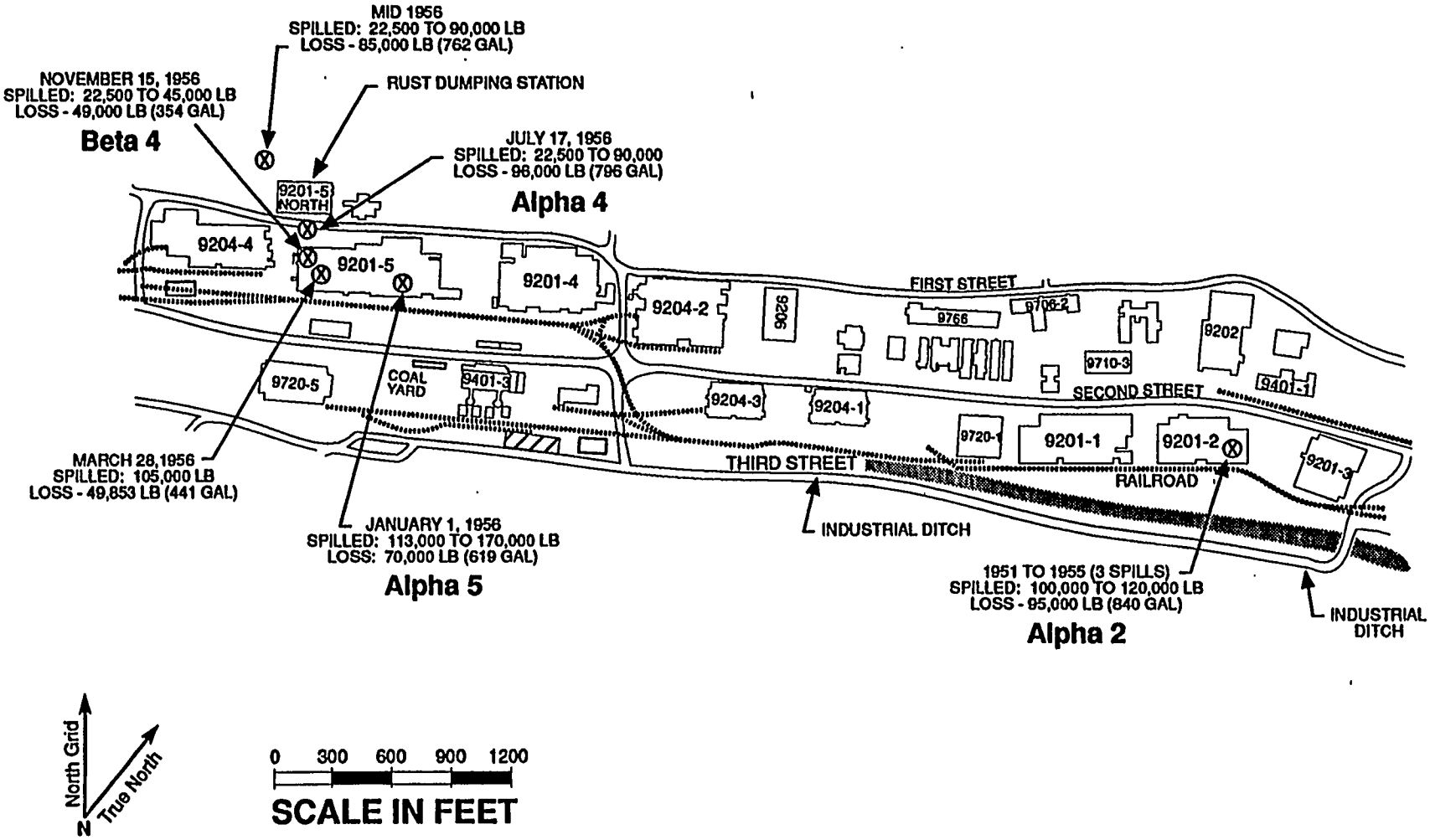


Fig. 3.1. Location of accidental mercury losses to the ground at the Y-12 Plant.

2-041593-122

contamination. NHP was constructed as an equalization basin for UEFPC surface water exiting the Y-12 Plant. From the date of construction in 1963 until 1982, it is estimated that 6810 kg (15,000 lb) of mercury were retained in NHP sediments. In the 1972-73 time period, NHP was dredged and cleaned of its sediments, which contained 6600 lb of mercury. These sediments were removed for disposal to Chestnut Ridge.

Small quantities of mercury continue to be mobilized and transported to Lake Reality and EFPC from historic deposits in buildings and in the drainage system at the Y-12 Plant. Elevated mercury concentrations and discharges have been noted in the vicinity of nearly all the buildings and areas where mercury was formerly used or spilled (Turner et al. 1985). These discharges were attributed to residual deposits of metallic mercury located in the drainage system that are slowly solubilized or resuspended by otherwise uncontaminated surface water and process water that flows through the drainage system and discharges to EFPC. From 1977 to 1985 (see Fig. 3.2), annual average mercury concentrations in NHP effluents ranged from 1.4 to 5.0 $\mu g/L$ and annual average loadings ranged from 11.3 to 76.6 kg (25 to 168 lb), which corresponds to 31 and 210 gal/day (0.07 to 0.46 lb/day), respectively (Turner et al. 1985). TVA, in an ORTF Instream Contaminant Study commissioned by DOE, reported that the average daily mercury load to EFPC from NHP was 0.09 kg (0.2 lb), which amounted to about 34 kg/year (TVA 1985).

NHP was an effective trap for mercury. From July 1983 through June 1984, 26 to 84% of the monthly mercury influx to the pond was released to EFPC, while the remainder was trapped. On an average, it is estimated that NHP reduced total mercury in the effluence by about 50% (Turner et al. 1985), although the pond may have actually served as a net source for methylmercury (Welch 1987). During the course of the Elwood et al. study, it was determined that methylmercury concentrations in the water were lower at the NHP inlet than at the outlet.

Inorganic mercury may be transported into Lake Reality as either an ionic or the elemental form. Both forms may become associated with bottom sediments and equilibrate with pore water. Microbial activity in the sediment removes oxygen, and under anaerobic conditions, a variety of bacteria can transfer methyl groups to metals and metal ions. Inorganic mercury entering Lake Reality and methylated in the bottom sediments is subsequently released into surface water. Either in the sediment or in surface water, methyl mercury may be taken up by plankton to be transferred further through the food chain in Lake Reality and in EFPC.

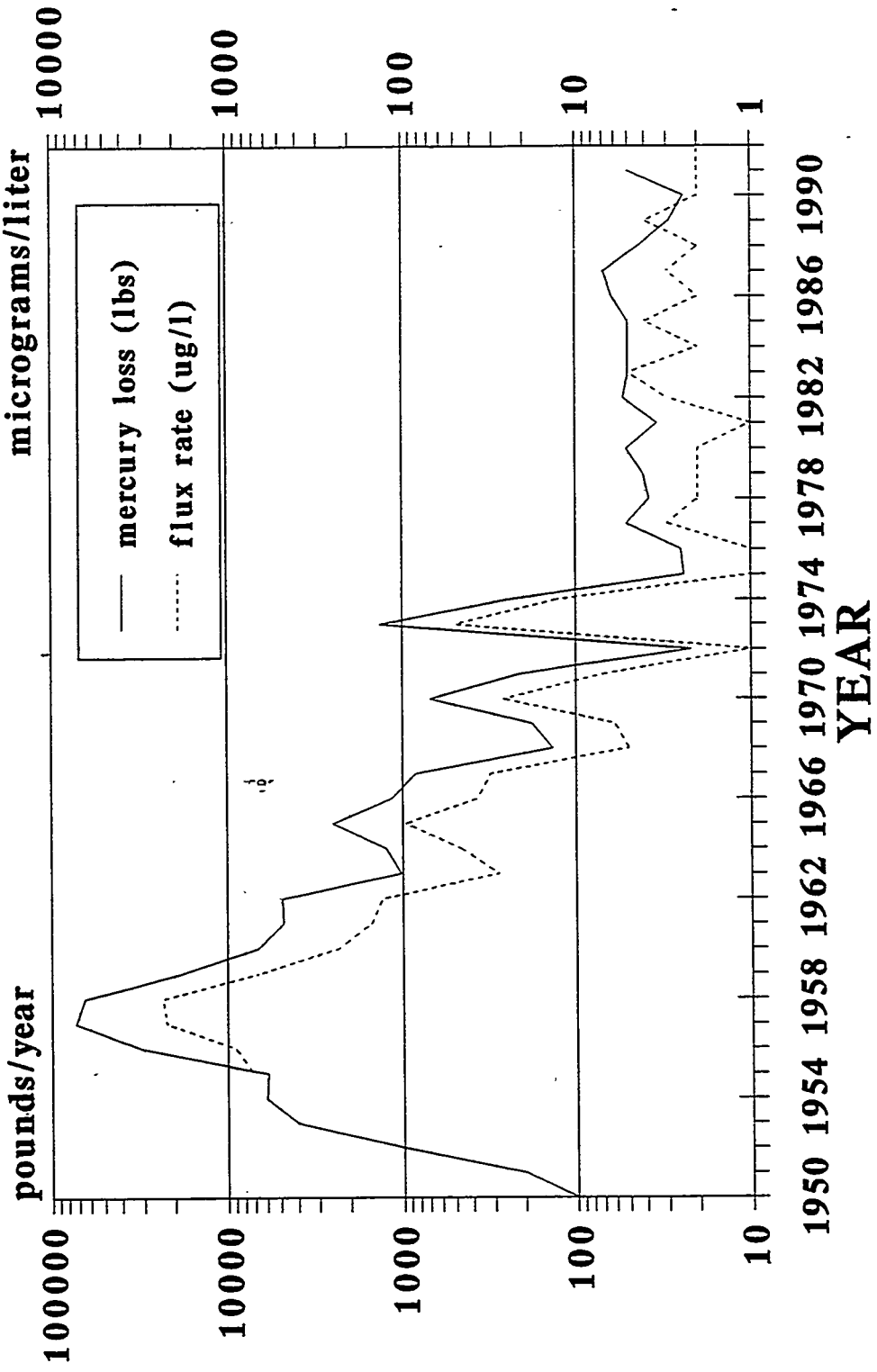


Fig. 3.2. Mercury releases from Lake Reality

3.2 SUMMARY OF EXISTING DATA

Historical Studies

Several studies have collected data concerning the type, extent, and levels of contaminants in the EFPC floodplain (Table 3.1). Since 1977, the mercury concentration in water entering EFPC from the Y-12 Plant has been measured at least weekly and is currently monitored twice daily as part of the environmental surveillance program at the Y-12 Plant. Additional metal and organic concentrations have also been monitored since 1988 (ORR Environmental Monitoring, Energy Systems). These data provide an estimate of contaminant loading to the rest of the floodplain and allow for the examination of trends in concentration and loading with time. Environmental monitoring of the ORR also has included groundwater analysis from a number of wells along EFPC and the sampling of sediment from EFPC.

Several studies have focused on mercury contamination in the EFPC floodplain. Van Winkle et al. (1984) measured mercury concentrations in NHP and in various media in EFPC and Bear Creek. Ralph Turner at ORNL has studied mercury methylation in NHP and Lake Reality and has verbally supplied information regarding this and other unpublished studies.

The Y-12 Plant initiated a BMAP in 1984. Data from this program document the ecological health of selected reaches along EFPC and include periodic surveys of the abundance and diversity of periphyton, macroinvertebrates, and fish. The levels of mercury, PCBs, and ^{137}Cs are measured semiannually in fish, and PAHs are measured in clams. Daphnia and minnows are used to test for water toxicity in EFPC.

The ORTF, established in 1983 to collect data and evaluate the long-term public health impact of contamination in the vicinity of Oak Ridge, has conducted several valuable studies. The instream contaminant study conducted by TVA as part of the ORTF study quantified the presence of metals, radionuclides, and organics in water, sediment, soils, and fish in EFPC. Mercury concentrations were determined on transects at 1-km intervals in EFPC. TVA estimated 170,000 lb of mercury to be contained in the ~16 million ft^3 of soil and sediments within the floodplain. The TVA study also examined the transport of mercury-contaminated sediment throughout the EFPC system to estimate the annual net transport of mercury-contaminated sediment and to predict the degree of scour of the mercury-contaminated floodplain sediments that can be expected to occur from future large floods. Surveys by ORAU at 100-m intervals along EFPC floodplain and SLB revealed the presence of detectable mercury concentrations. ORAU

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Table 3.1. Summary of historical studies of contamination in EFPC

Study	Medium	Contaminant	Scope
ORAU			• 1983-1987
	soil	mercury	• Sampled surface soil (top 3 in.) along transects across floodplain every 100 m from Y-12 to Oak Ridge city limits • Surface samples taken from 650 × 150 m highly contaminated floodplain parcel on a 20 × 20 m grid • Vertical profiles at varied sites • Transect along SLB sampled every 100 m (grids at some sites) • As requested for lawns and gardens in Oak Ridge
		metals	• On 242 samples from floodplain, SLB, and background sites
	vegetation	mercury	• Gardens as requested in Oak Ridge
		metals	• Uptake ratios calculated from vegetables in garden plots and greenhouse and from native vegetation in floodplain
	sewage sludge	mercury	• Quarterly for 1 year
		radionuclides	• Daily for 4 months
		metals	• One time
	groundwater	mercury	• Residences (outside of EFPC floodplain)
	game	mercury	• Two road-killed deer
TVA			• 1984
	soil	mercury	• Sampled cores (9-in.-deep increments) along transects across floodplain every kilometer from Y-12 to confluence with Poplar Creek (30 transects). Measured mercury in particle-size classes
		radionuclides	• 5% of samples
	sediment	mercury	• 19 sites along creek
		radionuclides	
		PCBs	
		organics	
		metals	

Table 3.1 (continued)

Study	Medium	Contaminant	Scope
	surface water	metals	• Base flow (one station) and storm water samples (five stations)
		radionuclides	
		pesticides/PCBs	
		organics	
	fish	metals	• Three stations
		pesticides/PCBs	
		organics	
		radionuclides	
	amphibians	metals	• One station
	crustaceans	metals	• Three stations
	reptiles	metals	• Three stations
USGS			• 1987
	groundwater	metals	• Fourteen shallow aquifer wells at sites of known mercury contamination along floodplain. Two SLB pesticide/PCB sites. Sampled two to four times.
		radionuclides	
		organics	
ORR Environmental Monitoring (Energy Systems)	surface water	mercury	• Outflow from Lake Reality and the former New Hope Pond. Weekly since 1977 and currently twice daily.
		metals	• Weekly since 1985
		radionuclides	
		organics	
	sediment	metals	• Semiannual sampling at confluence with Poplar Creek
Y-12 BMAP (Energy Systems)	fish	mercury	• Semiannual sampling of natural population at five stations
		PCBs	• Along EFPC since 1985
		^{137}Cs	
	clams	PAHs, PCBs	• Bioaccumulation in caged clams at one station annually

Table 3.1 (continued)

Study	Medium	Contaminant	Scope
ORNL BMAP (Energy Systems)	mammals	mercury	• One-time survey of small mammals in floodplain
		^{90}Sr	
Revis et al.	mice	mercury	• Calculated rates of mercury uptake in mice fed with contaminated soil. Assessed risk of dermal contact with contaminated soil. Measured chemical forms of mercury in soil
Van Winkle et al.			• May 1982 rapid assessment of mercury contamination in multiple media
	sediment	mercury	• NHP and seven EFPC sites
	moss/liverwort	mercury	• Three stations
	grass	mercury	• Two stations
	fish	mercury	• Four stations

also conducted a study of vegetative uptake of mercury and other metals. In 1986, groundwater contamination within the EFPC watershed was the focus of a USGS Study (Carmichael 1989). Revis et al. (1989) studied the uptake and toxicity to laboratory mice of mercury in soils of the EFPC floodplain.

These studies were performed in the mid-1980s at a time when field and laboratory protocols and QA documentation were less stringent than current standards. Rigorous documentation of field procedures, confirmed by QA surveillances and audits, sample tracking, verification and validation of laboratory results, and EPA-approved laboratory procedures and documentation [such as the EPA Contract Laboratory Program (CLP)], are lacking in the earlier investigations. These deficiencies must be considered in terms of EPA data usability criteria before incorporation into the RI. The above data have been used for screening level assessment and in developing the conceptual model and sampling strategy to fill data gaps for performing the RI.

QA Program

A QA program has been established for the EFPC RI which is being conducted under the ERP TSC. This program is defined in the Quality Assurance Program Plan (QAPP) (LWA 1991b) which establishes QA requirements and responsibilities applicable to the TSC. The QAPP outlines the administrative methods (detailed in the Quality Assurance Administrative Procedures Manual - LWA 1990a) through which the TSC will implement the requirements of DOE Order 5700.6B. DOE Order 5700.6C generally defines, via reference to American Society of Mechanical Engineers (ASME) NQA-1-1989, *QA Program Requirements for Nuclear Facilities*, the administrative controls and responsibilities used to implement QA objectives at the line organizational level.

This DOE Order requires contractors and their subcontractors to implement QA programs for work performed in support of the DOE-OR ERP. Additionally, the requirements of ASME NQA-3, *QA Program Requirements for the Collection of Scientific and Technical Information for Site Characterization of High-Level Nuclear Waste Repositories*; QA Management Staff (QAMS), Office of Monitoring Systems and QA, Office of Research and Development, EPA QAMS-004/80, *Interim Guidelines and Specifications for Preparing QAPPs*; and EPA QAMS-005/80, *Interim Guidelines and for Preparing Quality Assurance Project Plans (QAPjPs)*, are applicable to the DOE-OR ERP and have been incorporated into the TSC requirements.

The work conducted for the EFPC RI integrates 18 elements from NQA-1 and QAMS-005/80 into a QAPjP (LWA 1990a,b) that provides the framework within which project participants operate (Table 3.2). The requirements stated in the 18 criteria are achieved, in part,

Table 3.2 Elements of QAPjP

QAPjP content requirements per QAMS-005/80	QAPjP section (NQA-1 Criterion)
Title page	Title Page
Table of contents	Table of Contents
Project description	Introduction
Project organization and responsibility	Sect. 1
QA objectives for measurement data	Sects. 3 & 9
Sampling procedures	Sect. 9
Sample custody	Sects. 8 & 9
Calibration procedures and frequency	Sect. 12
Analytical procedures	Sect. 9
Data reduction, validation, and reporting	Sects. 6 & 9
Internal QC checks	Sects. 9 & 18
Performance and system audits	Sect. 18
Preventive maintenance	Sect. 12
Specific routine procedures used to assess data precision, accuracy, and completeness	Sects. 3, 9, 15, & 18
Corrective action	Sect. 16
QA reports to management	Sects. 2 & 18

by adherence to standard operating procedures developed for the various field activities. These procedures are furnished to EFPC team members through controlled distribution of the QA Technical Procedures Manual (LWA 1990b). Table 3.3 lists the current procedures (as of July 7, 1992 - revision 11) used for all sampling tasks that are designed to produce technically and legally defensible data. For the EFPC RI, data collection was directed by the SAP, which furnished both general descriptions and specific details of data collection activities. The SAP is composed of two parts: the field sampling plan and the QA/QC plan. Because of the tiered design of the EFPC investigation, two SAPs were produced. The plan that describes the initial screening of the nature of contamination and the affected media is the *Environmental Restoration Program-East Fork Poplar Creek-Sewer Line Beltway Integrate RCRA/CERCLA/NEPA Assessment - Phase Ia, Part II Sampling and Analysis Plan for Phase Ia* (LWA 1991a). The plan that describes the determination of extent and distribution of contamination is *Environmental Restoration Program-East Fork Poplar Creek-Sewer Line Beltway Integrated RCRA/CERCLA/NEPA Assessment - Phase Ib, Sampling and Analysis for Soil, Sediment and Water* (Radian 1992a) and the *Phase Ib Sampling and Analysis Plan Addendum for Ecological Risk Assessment* (Radian 1992b).

EFPC Data Quality Objectives (DQOs)

DQOs were established during the initial scoping process for the EFPC RI and revised prior to Phase Ib of the RI. With such a large and diverse OU as EFPC and the SLB, it was necessary to consider the results from Phase Ia before development of Phase Ib objectives. Two basic sets of data needs were required for each phase. Phase Ia was intended to identify the effected media and the potential COCs while Phase Ib was designed to define the extent of contamination and answer ancillary questions with miscellaneous supportive studies.

The DQO development generally followed the three-stage process as outlined by EPA (1987a). Meetings were held in 1990 with the primary data users: Region IV EPA, TDEC, DOE, Energy Systems and the EFPC RI team. Historical data, primarily from the ORTF and the TVA study, were reviewed and a conceptual model was developed (see below). The structure of a phased investigation was conceived and the overall project objectives (stated above) were established.

Data uses were identified as primary inputs into the site characterization study, the human health and ecological risk assessments, the initial screening of alternatives, the FS, and the EIS. Three study sites within the floodplain and a non-contaminated reference site were selected for Phase Ia after an appraisal of the quality and quantity of the sampling needed. A decision was

Table 3.3. ERP TSC
technical procedures
revision 11

Procedure no.	Procedure title	Rev. no.	Date
TP-ESP-200	Planning and Performance of Initial Site Survey	0	8/31/90
TP-202	Field Measurements of Physical and Topographic Features	0	9/12/90
TP-ESP-301-1	Water Sampling Using a Dipper	0	8/31/90
TP-ESP-301-3	Sampling with an Automatic Sampler	0	8/31/90
TP-ESP-301-4	Grab Sampling with Kemmerer Bottles	0	8/31/90
TP-ESP-301-5	Stream Flow Measurements	1	10/29/90
TP-301-6	Storm Event Sampling	1	1/29/91
TP-301-7	Water Sampling Using a Manual Pump	0	2/25/91
TP-ESP-302-1	Groundwater Sampling Procedures: Water Level Measurements using Water Level Indicator	0	8/31/90
TP-ESP-302-2	Groundwater Sampling Procedures: Guidelines for Well Pumping	0	8/31/90
TP-ESP-302-3	Groundwater Sampling Procedures: Using a Bailer	0	8/31/90
TP-ESP-302-4	Groundwater Sampling Procedures: Using a Gas Driven Piston Pump	0	8/31/90
TP-ESP-302-5	Groundwater Sample Procedures: Using a Bladder Pump	0	8/31/90
TP-302-6	Soil Pore Water Sampling with a Porous-Tube Vacuum Lysimeter	8	5/8/92
TP-ESP-303-1	Soil Sampling with a Spade and Scoop	0	8/31/90
TP-ESP-303-2	Soil Sampling with an Auger	1	10/29/90
TP-ESP-303-3	Soil Sampling using a Trier	0	8/31/90
TP-ESP-303-4	Penetration Test and Split-Barrel Sampling	1	10/29/90
TP-ESP-303-5	Subsurface Soil Sampling with Shelby Tubes	1	10/29/90
TP-ESP-303-6	Soil Gas Sampling	0	9/26/91
TP-303-8	Subsoil Sampling with a JMC Backsaver Soil Sampler System	1	10/2/91
TP-ESP-304-1	Sediment Sampling Procedures: Streambeds	1	10/29/90
TP-ESP-304-2	Sediment Sampling Procedures: Deepwater (Lakes)	0	11/1/90
TP-ESP-305-2	Low Volume Air Sampling for Particulate Matter	0	7/25/91
TP-ESP-307-1	Field Measurements Procedures: Temperature	0	8/31/90
TP-ESP-307-2	Field Measurements Procedures: pH	0	8/31/90
TP-ESP-307-3	Field Measurements Procedures: Dissolved Oxygen	0	8/31/90
TP-ESP-307-6	Field Measurements Procedures: Organic Vapor Detection	0	8/31/90
TP-ESP-307-7	Field Measurements Procedures: Operation of Radiation Survey Instruments		8/31/90

Table 3.3 (continued)

Procedure no.	Procedure title	Rev. no.	Date
TP-307-8	Field Measurements Procedures: pH, Temperature, and Conductivity	2	7/1/92 | R
TP-ESP-308-1	Composite Procedures	2	2/7/92
TP-ESP-308-2	Wipe Sample Collections	0	8/31/90
TP-ESP-308-3	Container Sampling: Drums and Tanks	0	8/31/90
TP-309-1	Terrestrial Arthropod Sampling	0	9/12/91
TP-309-2	Terrestrial Vegetation Survey using Transects	0	9/26/91
TP-309-3	Terrestrial Small Manual Sampling	0	10/15/91
TP-309-4	Avian Survey	0	9/25/91
TP-309-5	Fish Sampling in Streams	0	10/4/91
TP-309-7	Benthic Macroinvertebrate Sampling (Lotic Habitats)	0	10/4/91
TP-309-8	Terrestrial Subsurface Invertebrate Sampling	0	10/15/91
TP-309-9	Terrestrial Vegetation Sample Collection	0	5/8/92
TP-309-10	Sampling for Indiana Bat and Gray Bat	0	5/8/92
TP-ESP-400	Field Quality Control	1	8/31/90
TP-ESP-500	Manual Chain-of-Custody Procedures	1	8/31/90
TP-ESP-600	Groundwater Sampling Procedures: Well Installation, Development, and Abandonment	0	8/31/90
TP-600-1	Temporary Well Installation Procedures	0	9/26/91
TP-ESP-700	Chemical Analysis	1	8/31/90
TP-ESP-701	Sample Preservation and Container Materials	3	10/17/91
TP-ESP-800	Packaging Environmental Samples for Transportation	0	3/81/90
TP-ESP-900	Cleaning and Decontaminating Sample Containers and Sampling Devices	3	01/17/91
TP-ESP-901	Equipment Decontamination	0	8/31/90
TP-DOE/OR-929	East Fork Poplar Creek and Sewer Line Beltway RCRA Facility Investigation	0	8/31/90
TP-ESP-1100	Statistical Sampling Design	0	8/31/90
TP-ESP-1200	Terms and Definitions	0	8/31/90

made to obtain the highest quality data possible for critical studies (excluding field measurements and some miscellaneous tasks). CLP laboratory analyses and data packages, field and laboratory documentation and QC were chosen as appropriate for Phase Ia and Phase Ib [even neutron activation analysis (NAA), implemented during Phase Ib, was designed according to the CLP format]. Table 3.4 taken from the Phase Ia sampling and analysis plan displays the data objectives, uses, and analytical levels for the EFPC investigation. While certain data gathering activities were added or revised prior to Phase Ib, this table summarizes the DQO development at the start of the project.

The data collection program was compiled into a sampling and analysis plan for each phase of the RI. Procedures were adopted or written to guide field activities and data management tasks (see QA section), and analytical methods were selected for each environmental sampling activity. Phase Ib relied upon NAA, a non-CLP method, for the large-scale soil sampling of the floodplain to determine the extent and distribution of contamination. A study was performed to ensure equivalency of NAA with CLP methods, and laboratory control limits were instituted that were equivalent to the CLP procedures. DQOs for NAA were established to meet the precision and accuracy of CLP methods but with an exception for sensitivity. The desired lower limit of detection for mercury in floodplain soils was determined to be 11 mg/kg. This limit was established to meet any potential remedial action level or risk-based need.

During the design of the data collection activities for Phase Ib, assistance was obtained from the EPA-Environmental Monitoring Systems Laboratory in Las Vegas (see Sect. 3.2.5.3 for details). The question of adequate sampling density/data quantity to properly characterize the floodplain was supported by EPA modeling studies using the historic data set. This led to the approach of sampling 159 transects spaced 100 m apart over the length of EFPC.

A primary goal of the EFPC QA program was to ensure that the results of analysis of all environmental samples are fit for their intended use. DQOs are set to define and establish the criteria against which the fitness of the data will be judged. Both qualitative and quantitative DQOs were established for the EFPC RI. Data verification and validation of the resulting analytical data packages ensured that the laboratories produced an acceptable quality level for results. Control of field activities affecting precision and accuracy were produced by strict adherence to approved procedures and the documentation of field tasks. Field log books noted exceptions to the procedures and chain-of-custody records tracked sample shipments and receipt by the laboratory. Monitoring of field activities that affected accuracy was performed by assessing the results of field and trip blank analyses as well as equipment rinsate analyses. These results confirmed that no cross-contamination due to sample handling practices or inadequate

Table 3.4. Data quality objectives

	Objective	Priority	Sampling media	Sample Types and Phases						Data Use				Analytical level
				Physical/ chemical charact.	Water quality	Metals	Organics	Radio-nuclides	Other (specify)	Site charact.	Risk assessment	Screening and evaluation of alternatives	EIS	
1	Identify contaminants in Lake Reality	High	Sediment	Ia	Ia	Ia	Ia	Ia		X	X	X		IV
2	Identify contaminants in EFPC tributaries	Med	Sediment/ surface water		Ia	Ia	Ia	Ia		X		X		IV
3	Identify contaminants in EFPC floodplain soils	High	Soil			Ia	Ia	Ia		X	X	X		IV
4	Determine partitioning of contaminants in total and dissolved phases in alluvial soils	High	Sediment/ interstitial water			Ia	Ia	Ia		X	X			IV
5	Determine partitioning of contaminants in total and dissolved phase	High	Groundwater			Ia	Ia	Ia	Ia		X	X	X	IV
6	Determine relationship between particulate size and contaminants	High	Sediment and soil	Ia		Ia	Ia	X	X					III
7	Determine if glei layer is an effective barrier to vertical migration of contamination	High	Groundwater	Ia	Ia	Ia	Ia	Ia		X	X	X		IV
8	Determine if shallow groundwater is a significant transport pathway	High	Groundwater		Ia	Ia	Ia	Ia	Ia	X	X	X		IV
9	Determine air concentrations of mercury	Low	Air			Ib					X			III
10	Determine vertical migration of materials in contaminated areas	Med	Soil	Ia		Ia		Ia		X	X	X		IV

Table 3.4 (continued)

	Objective	Priority	Sampling media	Sample Types and Phases						Data Use				Analytical level
				Physical/ chemical charact.	Water quality	Metals	Organics	Radio-nuclides	Other (specify)	Site charact.	Risk assessment	Screening and evaluation of alternatives	EIS	
11	Identify factors influencing contaminant migration in soils	High	Soil	Ia						X	X	X		
12	Identify contaminants in EFPC	Med	Surface water		Ia	Ia	Ia	Ia		X	X	X		IV
13	Determine extent of contaminants in EFPC floodplain	High	Soil			Ib		Ib		X		X		IV
14	Determine extent of contaminants in SLB	High	Soil			Ib		Ib		X	X	X		II/IV
15	Determine temporal distribution of contaminants from Lake Reality	High	Surface water			Ib		Ib		X	X	X		II/IV
16	Characterize body burdens in aquatic and terrestrial flora and fauna	High							Ia literature review		X			II
17	Identify human populations and activities	High							Ib literature review		X		X	II
18	Identify wetlands	High	Soils/ flora	Ib					Ib survey			X	X	N/A
19	Identify biological activity in sediments	Low	Sediments	Ib					Ib survey	X	X		X	N/A
20	Characterize topography	Med		Ib					Ib survey	X		X		N/A

[a]Level I - field screening or analysis using portable instruments. Results are not compound-specific.
Level II - field analyses using more sophisticated portable analytical instruments or monitors. Results are available in real time or several hours.
Level III - CLP procedures, without extensive validation or documentation. Instruments are initially needed to determine presence of contaminants.
Level IV - CLP procedures with rigorous QA/QC protocols and documentation.

equipment decontamination occurred. Sampling precision was estimated by the analysis of collocated samples (field replicates) and split samples (field duplicates). No specific control limits for field precision were established in part because the natural heterogeneity of the environmental media proved to have a much greater influence than that imparted by field activities.

Indicators used to assess both field and laboratory data quality include precision, accuracy, representativeness, sensitivity, and completeness. The following laboratory objectives have been chosen for this project to be in accordance with or roughly equivalent (for radiological analyses and NAA) to those set by EPA for the CLP.

Precision. Precision is the measure of the degree of repetitiveness of a determination of an analytical result. It can be evaluated by measuring the agreement between independent measurements made under identical conditions. Evaluation of laboratory duplicate analyses provides an assessment of the precision associated with the analysis of a batch of data by a particular laboratory method. The relative percent difference (RPD) between two duplicate analysis results has traditionally been used to evaluate duplicate results. CLP criteria requires that laboratory duplicates for inorganic analytes be less than 20% for water and 35% for solid matrices. Analyses greater than this amount will be considered usable but estimated. For organic analyses matrix spike duplicates are used to judge precision. However, this criteria alone has not been used to qualify the data. Professional judgment must be employed with other measures.

The usefulness of the RPD is limited to samples that contain contaminants significantly above the method detection limit so that the random background and signal fluctuations are a small percentage of the signal and, therefore, do not contribute significantly to the measured precision. For radiochemical analyses, the random background and signal fluctuations can be readily calculated and are reported with each result as an uncertainty or confidence range. Therefore, the reported uncertainty can be used to evaluate whether duplicate analysis results are statistically in agreement at any contaminant level. The 95% confidence range has been chosen as the limit of acceptability for duplicate results. If the 95% confidence limits for each analysis overlap each other, the precision of method is acceptable and the data are judged to be usable. The overlap of the confidence ranges is evaluated by calculation of the duplicate error ratio (DER). The DER is defined as:

$$DER = \frac{|S - D|}{(2\sigma_S + 2\sigma_D)},$$

where S = First Sample Value (original)

D = Second Sample Value (duplicate)

$2\sigma_S$ = First Sample Uncertainty

$2\sigma_D$ = Second Sample Uncertainty.

When the DER is less than 1, the confidence limits for the duplicate results overlap and the precision is judged to be acceptable for the batch. This is the DQO for precision.

Accuracy. Accuracy is the closeness of agreement between an observed result and the true value for a sample analysis. Accuracy can be evaluated for a particular laboratory method by measuring the agreement between an observed result from analysis of a reference standard analyzed with a batch and its true value. The difference between the observed analytical result and the known value will be a combination of a random component (measured by precision evaluation) and systematic error component (bias). The bias alone can be evaluated from the average difference when a large number of standards are analyzed.

Accuracy is measured through the use of laboratory control samples (LCSs) and matrix spikes (MSs). The DQO for accuracy measured from the analysis of batch LCSs and MSs is to obtain $\leq$ 20% error for water samples and $\leq$ 30% error for soil samples. Blanks also provide a means for checking for bias resulting from contamination. The DQO for blanks is for the net batch blank to be $\leq$ its 95% confidence limit. The use of calibration standards at acceptable frequencies is also important in limiting the bias of measurements. The DQO is to obtain no more than 10% bias from calibration errors.

The use of chemical or isotopic tracers in radiochemical analyses provides a sample-specific method for correction for chemical recovery in chemical preparations and separations. However, it should be recognized that although this practice increases the accuracy of the measurement, it decreases the precision obtained due to the random uncertainties of the extra measurement. When

the chemical recovery is low, the random uncertainty is increased and the effect of any systematic error in the recovery determination is amplified. Therefore, DQOs have also been set for chemical recovery. The DQO for chemical recovery is 50-100% for water and 40-100% for soil.

Representativeness. Representativeness expresses the degree to which the data accurately reflect the analyte or parameter of interest for the environmental site and is the qualitative parameter concerned most with the proper design of the sampling program (EPA 1987a). Factors that affect the representativeness of analytical data include proper preservation, holding times, use of standard analytical methods, and matrix or analyte interferences. Holding times and sample preservation criteria have been recommended by EPA for drinking water analyses and have been adopted as the DQO for this project for water matrices. Evaluation of preservation and holding times for soils, analytical methods, and matrix or analyte interferences have been left to professional judgment. Comparability of methods can be evaluated through laboratory intercomparison studies and analysis of performance evaluation samples.

The EFPC RI selected sampling methods and repetitive sampling events to ensure that an environmental sample accurately represented the characteristic population from which it was obtained. For example, the EFPC RI sampled groundwater four different times from each well and surface water twice from each location to observe temporal variations. Intervals for soil sampling were chosen to obtain the strata with the highest concentrations of contaminants in order to achieve the most conservative representation and to optimize the number of samples required.

Comparability. Similar to representativeness, comparability is a qualitative parameter expressing the confidence with which one data set can be compared to another. The EFPC RI utilized one laboratory to perform its CLP analyses and the same sampling methods for each medium. A larger effort went into establishing the comparability of NAA to CLP methods (see NAA equivalency study in Appendix I) thereby assuring uniformity between the results of the two.

Completeness. Completeness is a measure of the amount of valid data obtained from the sampling and analysis process. Analytical completeness is expressed as the total number of samples taken for which usable analytical data are generated divided by the total number of samples collected. DQOs for the EFPC RI were set at 90% for the laboratory completeness for both Phase Ia and Ib. Percent completeness for field sampling, however, was established at 90% for Phase Ia but only 70% for Phase Ib. The expected lower value for Phase Ib was due primarily to an anticipated lack of recovery from the deeper soil horizons.

Sensitivity. Sensitivity is the measure of the amount of signal obtained for a given amount of analyte in the sample. The sensitivity affects the amount of analyte in the measured sample that can be statistically distinguished above background. Therefore, the sensitivity of a method can be defined in terms of the instrument or method detection limits. The EFPC RI has adopted the method-specific analytical detection limits per the CLP for inorganic and organic analytes as the minimum standard measure.

For radiological analyses, the detection limit is the amount of analyte that must be present to be 95% confident that the signal will be produced that will be distinguishable from the background with 95% confidence. By specifying the detection limit, the precision from random background and signal fluctuations is controlled and is predictable even at levels above the detection limit. Therefore, detection limit criteria are usually selected at a factor of 10 below the concentration required to meet regulatory objectives. The DQO for sensitivity for this project has been selected to require the method detection limits criteria to be at a concentration equal to that which produces 10^{-5} level of risk of induced cancers as calculated from "Health Effects Assessment Summary Tables" (920115.0060.EPA).

Section 3.3 provides a data quality assessment of the overall project and segments of the data generated from it.

EFPC Conceptual Model

The conceptual model for contaminant transport in the EFPC watershed was based upon the premise that soil genesis in the floodplain has been closely linked with hydrologic events. Contaminants from Y-12 were concentrated in NHP and washed down EFPC during high-flow conditions following rainstorms. At least some of the contaminants (e.g., mercury) from NHP and Y-12 were adsorbed onto sediment particles and transported downstream in a suspended phase (TVA 1985). Other contaminants were transported from NHP in a similar manner or in a dissolved phase. During flood events, the creek flows out of its banks and spreads out across the floodplain. The RI focus was to evaluate surface water, creek sediments, floodplain soils, and groundwater as potentially affected media.

Data collection considerations were determined by the conceptual site model, which describes the source, transport, and deposition of contamination within the site boundaries. The nature and extent of contamination in the EFPC drainage system inferred from historical studies are dictated by a watershed-based approach. For the purposes of this assessment, the physical or spatial boundary of the EFPC site model is equivalent to the entire EFPC watershed (excluding the Bear Creek drainage). The EFPC watershed unit includes areas above and below the Y-12 Plant

extending downstream to the confluence with Poplar Creek and is defined to include air, land (surface and subsurface components), groundwater, and surface water/sediment media.

While the most important inputs of contaminants to the EFPC watershed are associated with the activities occurring within the confines of the Y-12 facility, four sources of materials are considered possible in the conceptual model:

- airborne materials from Y-12;
- waterborne Y-12 releases to UEFPC;
- non-Y-12 releases to EFPC system; and
- outputs from the Bear Creek subsystem to EFPC.

(Note that no groundwater inputs to the EFPC watershed are identified in the model. Existing studies conducted on the ORR (Moore 1988) suggest that groundwater within a particular watershed discharge to nearby streams and does not cross surface water divides.)

The EFPC model is composed of the following four components:

- inputs of water, sediments, and contaminants to the EFPC watershed;
- abiotic media of concern in the several watershed subsystems; and migration routes of contaminants along these media and subsystems, including the sources of materials to the EFPC floodplain;
- human and ecological receptors in the EFPC floodplain subsystem (discussed in Sects. 5 and 6, respectively); and
- outputs from the EFPC system.

Sampling strategies were designed to evaluate the four conceptual components of the system (inputs, outputs, abiotic media, and receptors). Surface water and sediment sampling was established at the system input sites (i.e., Lake Reality and the major tributaries within the watershed) as well as the primary output location (the confluence with Poplar Creek) and intermediary positions within the system.

Groundwater was characterized with a spatial and temporal strategy to define impacts progressively downstream of the Y-12 source, laterally away from the creek, and in proximity to other features of the watershed (tributaries, urban features, contaminant hot spots). Monitoring consisted of four rounds of sampling to identify seasonal variations and/or contaminant migration patterns. Both dissolved and total contaminant analyses were performed to differentiate the contaminant concentrations related to the groundwater medium from the suspended soil medium.

Floodplain soils required a different approach because the medium is essentially static under real time considerations. Characterization must be accomplished for the system as a whole but understood under a temporal scenario. The model for soil genesis in EFPC floodplain is based upon the understanding that the soil development in the floodplain has been functionally dependent upon the hydrologic and depositional conditions established by EFPC. Mercury from NHP/Lake Reality washed into EFPC during high-flow conditions following rainstorms and was adsorbed onto sediment particles being transported in the suspended phase. Other contaminants were carried in a similar manner or in a dissolved phase. As the creek flows out of its banks and spreads out across the floodplain, stream velocity slows, and suspended particles settle out of the water column. The distance that floodwaters spread away from the main channel depended primarily on the magnitude of the hydrologic event and topography. As floodwaters extended across backwater areas, progressively smaller and lighter particles were deposited when floodwaters receded and decreased in velocity. This process of suspension and deposition of sediments has been a major factor leading to contamination of the floodplain soils. The highest concentrations of mercury are located in depositional wetlands areas behind the NOAA Atmospheric Diffusion Laboratory (NO) off Illinois Avenue and across the Oak Ridge Turnpike from the Bruner's Shopping Center on the Wayne Clark property (BR) and Mel Sturm property (WA). These two areas are inundated several times each year during high rainfall events.

The approach to evaluate the human and ecological receptors is explored in Sects. 5 and 6. The human health risk assessment fully develops the conceptual site model to include the exposure pathways to the potential receptors as a function of land use patterns. The ERA utilizes a weight-of-evidence argument to demonstrate impact to the ecological receptors.

EFPC RI

The investigation used a tiered approach (see Sect. 5, Baseline Human Health Risk Assessment) and was composed of two main phases (Phase Ia and Phase Ib). The major effort of Phase Ia was directed toward identifying the affected media and defining the COCs for each medium. The approach was taken to provide a screening-level assessment (Tier 1) from locations with the highest concentrations of all the analytes listed in the Inorganic Target Analyte List from Exhibit C of the EPA CLP SOW 7/88 (EPA 1988) and Target Compound (Organic) List from Exhibit C of EPA CLP SOW 2/88 (EPA 1988). Additional analytes and radionuclides were added to the screening-level assessment from process knowledge of the Y-12 Plant for an approximate total of 182. Data obtained from the Phase Ia investigation allowed the COCs to be derived for each medium within the EFPC floodplain and a measurement of background concentrations to be established for the reference site. Identification of the COCs was used to

reduce the suite of analytes investigated in the floodplain soils during Phase Ib and for the deterministic assessment of human health risks using the creek-wide data set (see Sect. 5).

Phase Ia. Phase Ia was conducted from the autumn of 1990 through the spring of 1991. Base flow surface water and sediment samples were taken from the creek and from its tributaries to define source contributions as shown on Map 4 (Table 3.5). Storm flow samples from the creek were obtained during two flood events and from selected tributaries for one event. Metal analyses were performed for filtered and unfiltered samples to distinguish contaminants attributable to suspended particles from those in solution. Groundwater was sampled for four consecutive quarters from 22 individual monitoring wells. Soil samples for contaminant analyses and undisturbed geotechnical samples for soil chemistry and engineering parameters were taken from three study areas of known contamination [NOAA-(NO), Bruner's Center-(BR), and Sturm-(WA)]. A reference site [Hinds Creek-(HC)] was chosen, and corresponding sampling and analysis were performed to provide a basis for comparison against a noncontaminated but equivalent area.

COCs. The identification of potential COCs for each medium was a primary objective of the Phase Ia investigation. An essential task was to focus the RI and BRA on contaminants that were present at elevated levels and that posed a risk to human health. A narrowing of the "global list" of contaminants was also necessary to implement, in a cost effective and timely manner, the large-scale soil sampling and analysis of the entire floodplain. Analytes were specified from the list of potential COCs for the majority of soil analyses performed during Phase Ib. The other media (sediments, surface water, and a set of other soil samples) were analyzed for the full range of contaminants (except for the elimination of VOCs). The selection of potential COCs allowed the BRA to focus on these contaminants for the creek-wide (Tier 2) estimation of risk.

Potential COCs were identified using a toxicity concentration scoring system (EPA 1989). This system allows the potential health effects of chemicals to be ranked based on measured concentrations and established toxicity measures without making quantitative assumptions about exposures and dose. Identified chemicals were divided into four groups; evaluation is based on the available toxicity measures: (1) carcinogenic compounds (chemicals for which oral cancer slope factors are available), (2) chemicals only evaluated for systemic toxicity [noncarcinogenic chemicals with oral reference doses (RfDs)], (3) radionuclides (with pathway-specific unit risk factors), and (4) chemicals for which toxicity measures are not available. A toxicity score was calculated for each chemical in the first three groups. For radionuclides and carcinogenic chemicals, the score is the product of the concentration and the toxicity measure. For ranking based on noncarcinogenic effects, the score is the concentration divided by the reference dose.

Table 3.5. EFPC RI - media sampling by location

Station	LA	BC	TA	LB	TB	TC	TD	TE	TF	LC	TG	TH	TI	TJ	TK	WA	TL	BR	CG	TM	TN	CC	TO	TP	TO	NO	TR	LE	LR	HC2A	HC2B
Soils																X		X	X							X				X	X
Sediments	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Water base flow	X	X		X					X	X				X		X							X	X					X		X	X
Water storm flow	X			X					X														X	X					X			
Geotechnical soil																X		X									X					
Soil size fraction																X		X									X					
Sediment size fraction	X			X						X						X		X									X				X	X

TA-TR - Tributary stations
BC, CC - Major tributaries (Bear Creek, Civic Center)
LA, LB, LC, LE - Creek stations
HC-Hinds Creek reference site
WA, BR, NO - Floodplain study sites

Within each group, each chemical is ranked by its percentage of the total score for the group. Those compounds that together represented 99% of the toxicity score for that group were considered COCs.

Concentrations used to calculate the toxicity scores were the means of all analytical results of samples taken in EFPC and its floodplain during Phase Ia of the EFPC RI. The primary sampling sites were areas that historically had been shown to have elevated contaminant levels. The analytical results from these stations are therefore more likely to overestimate than underestimate contamination levels throughout the floodplain. Toxicity scores were also computed using the maximum concentrations. Using maxima did not greatly change the rankings but generally meant that fewer contaminants accounted for 99% of the score. Toxicity scores based on the mean concentrations were used because this ranking included more chemicals as COCs and so produced the most conservative approach.

Some factors other than the toxicity scores were considered in determining the COCs. These factors included the frequency of occurrence of a chemical in the samples tested, presence of the chemical in background samples, best professional judgment with a conservative bias, knowledge of the processes used at the Y-12 Plant, and other ARARs [i.e., specifically the Maximum Contaminant Levels (MCLs) established under the SDWA and federal ambient water quality criteria for the protection of freshwater organisms]. Chemicals that were detected in < 5% of the samples tested were not considered to be of concern (EPA 1989). If the mean concentration of a chemical was not significantly different from the mean concentration at the background reference site (from t-test) and the toxicity score for that chemical was < 1% of the total, it was eliminated from consideration. Chemicals were included as COCs if their maximum concentrations in groundwater or surface waters were greater than the MCLs. Some radionuclides that are used in processes at the Y-12 Plant but were not adequately measured in Phase Ia of the EFPC investigation were listed as potential COCs in soils, sediments, and surface water so that they would be further investigated in Phase Ib.

Data from other studies of EFPC were not used in the screening analysis. All of the EFPC RI Phase Ia data used in the scoring have been obtained and analyzed following a consistent set of procedures and QA/QC measures. Contaminants that were not detected in any sample in a given media were eliminated from consideration. Exceptions were made for certain analytes that pose a risk at the analytical detection limit (such as certain species of PAHs). Nutrients (sodium, potassium, calcium, magnesium, and iron) were also eliminated from consideration.

Table 3.6 shows the COCs by medium. The COCs based on sediment analyses are the same as those based on soil analyses. Carbazole (a PAH) has been included because it is of concern as a carcinogenic compound at the detection level. The metal COCs based on groundwater analyses are the same as those based on the soil analyses except that silver was not detected and barium was included. PAHs, PCBs and ^{137}Cs were not found to be significant in groundwater, while total radium was. There are essentially no COCs under base flow conditions (stream flow not related to storm events). The base flow analyses showed that metals and organics were below MCLs and meet ambient water quality criteria for the protection of freshwater organisms. Isotopic uranium and ^{137}Cs were added to the base flow COCs list to be conservative. As expected, the COCs based on storm flow include those of base flow plus some of the sediment contaminants.

Phase Ib. In July 1991, Phase Ib was initiated to determine the extent and distribution of the COCs as well as to provide additional data for the ecological and human health risk assessments (Tier 2). Over 3000 soil samples were taken across 159 transects (extending the width of the floodplain) spaced 100 m apart along the 23 km of the creek. A special analytical technique, NAA, was employed to provide results for mercury and a number of other metals including two isotopes of uranium (^{235}U and ^{238}U). Although the focus was on the large-scale sampling of the floodplain, additional smaller-scale studies were also accomplished. A second round of surface water sampling was accomplished to provide contrasting seasonal data. Soil samples were investigated by optical and electron microscopic methods to ascertain the form of mercury and its association with the soil matrix. Soil samples were also submitted for total methylmercury analyses in lieu of failed lysimeter tests for soil-bound pore water analyses.

3.2.1 Surface Water Data

3.2.1.1 Scope of investigation

Historical Data. Energy Systems has examined surface water outflow from Lake Reality and the former NHP for the presence of mercury, metals, radionuclides, and organics. Mercury concentrations have been monitored weekly since 1977, and twice daily since NHP was closed and replaced by Lake Reality. Metals, radionuclides, and organics have been monitored weekly since 1985. The 1990 annual radiological summary (including parameter, maximum, minimum, average) for Lake Reality outflow is given in the *Oak Ridge Reservation Environmental Report for 1990, Vol. I*, p.60 (Energy Systems 1991). Nonradiological data are summarized in Vol. I, Table 3.14, page 72. The record of mercury loading to EFPC from NHP showed no trend from 1977 to 1984 but did show a great deal of short-term variation related to storm events.

Table 3.6. COCs by environmental medium

Contaminant	Medium				
				Surface Water	
	Soil	Sediment	Groundwater[a]	Base flow	Storm flow[a]
Metals					
Arsenic	X	X	X		X
Barium			X		
Beryllium	X	X	X		
Cadmium	X	X	X		
Chromium	X	X	X		X
Copper	X	X	X		X
Lead	X	X	X		X
Manganese	X	X	X		X
Mercury	X	X	X		X
Nickel	X	X	X		
Silver	X	X			
Vanadium	X	X	X		X
Zinc	X	X	X		X
PAHs					
Benzo(a)anthracene	X	X			X
Benzo(a)pyrene	X	X			X
Benzo(b)fluoranthene	X	X			X
Carbazole[b]	X	X			X
Chrysene	X	X			X
Dibenzo(a,h)anthracene	X	X			X
Indeno(1,2,3-cd)pyrene	X	X			X
Pyrene					X
PCBs					
Aroclor-1254	X	X			
Aroclor-1260	X	X			

Table 3.6 (continued)

Contaminant	Medium				
	Soil	Sediment	Groundwater[a]	Surface Water	
				Base flow	Storm flow[a]
Radionuclides					
^{134}Cs[c]	X	X	X	X	X
^{137}Cs	X	X			
^{234}Np[d]	X	X	X	X	X
^{233}Pa[d]	X	X	X	X	X
Total Radium			X	X	X
^{228}Th[d]	X	X	X	X	X
^{230}Th[d]	X	X	X	X	X
^{232}Th[d]	X	X	X	X	X
^{234}U	X	X	X	X	X
^{235}U	X	X	X	X	X
^{238}U	X	X	X	X	X

[a]COCs for groundwater and storm flow are primarily attributable to suspended solids in the water samples.
[b]Carbozole, while not detected in soils or sediments, is included as a COC because it is a carcinogenic compound and can be of concern even at the detection level.
[c]Cesium-134 could not be measured during Phase Ib due to interfering peaks in the gamma spectrum.
[d]Radionuclides are included as COCs because they were not covered adequately during Phase Ia sampling and analysis. However, thorium was not measured during the second round of base flow sampling.

The TVA study Task 1 (1985) monitored surface water for the presence of metals, radionuclides, pesticides/PCBs, and organics during base flow and storm flow. Base flow water conditions were sampled at one station (located at N 30,100 ft) on May 31, 1984, from the surface at mid-channel. Samples were analyzed for conventional parameters, priority pollutants (organics and metals), and radiological parameters. Storm flow water conditions were sampled during three storms events at five EFPC stations (N 30,100 ft, E 49,800 ft, E 39,500 ft, and E 18,300 ft) on October 22 through 23, 1984 (total precipitation of 2.0 in.); November 10 through 11, 1984 (total precipitation of 1.4 in.); and April 5 through 6, 1985 (total precipitation of 1.1 in.). Storm flow samples were analyzed for total suspended solids, particle size, total and dissolved mercury, and radiological parameters.

All parameters were within normal concentrations for existing standards and/or background levels, except metals (mercury and lithium). Total mercury concentrations were above background levels of < 0.4 μg/L during both base flow and storm flow conditions. The maximum observed concentration at base flow conditions in EFPC was 2.5 μg/L. The greatest concentrations were observed during the storm events, with tenfold increases in total mercury concentrations over base flow conditions. Dissolved mercury concentrations remained relatively constant during the three storms with levels at or slightly above the analytical detection limit (0.4 μg/L); thus, the TVA Task 1 study concluded that increases in total mercury with increasing stream flow were due primarily to the mercury associated with suspended sediments.

EFPC RI Surface Water Data. The preparation of the EFPC ERA and BRA requires quantification of the risks to a reasonably maximum exposed individual and sensitive receptors in the EFPC watershed. These risks arise when receptors are exposed now or in the future to toxicants in contaminated media. Historical investigations indicated that the sediments act as contaminant reservoirs in the EFPC watershed and that surface water is an exposure pathway for aquatic and, to a lesser extent, terrestrial species. In addition, because EFPC is a source of contamination to Poplar Creek, the Clinch River, and ultimately the Tennessee River, its impact on downstream systems must also be assessed.

With the above objectives in mind, the EFPC RI investigated surface water under two conditions, base flow and storm flow. An analysis of filtered samples was performed also for storm events. This allowed the RI to differentiate increased contaminant loading due to high flow conditions at the Y-12 Plant from the addition of suspended sediments (from sheet erosion of the contaminated floodplain). Three tributaries receiving runoff from urban areas were also sampled during base and storm flows to evaluate contributions from adjoining watersheds. The evaluation of storm events indicates that a larger volume of metals is transported during high flow, but the

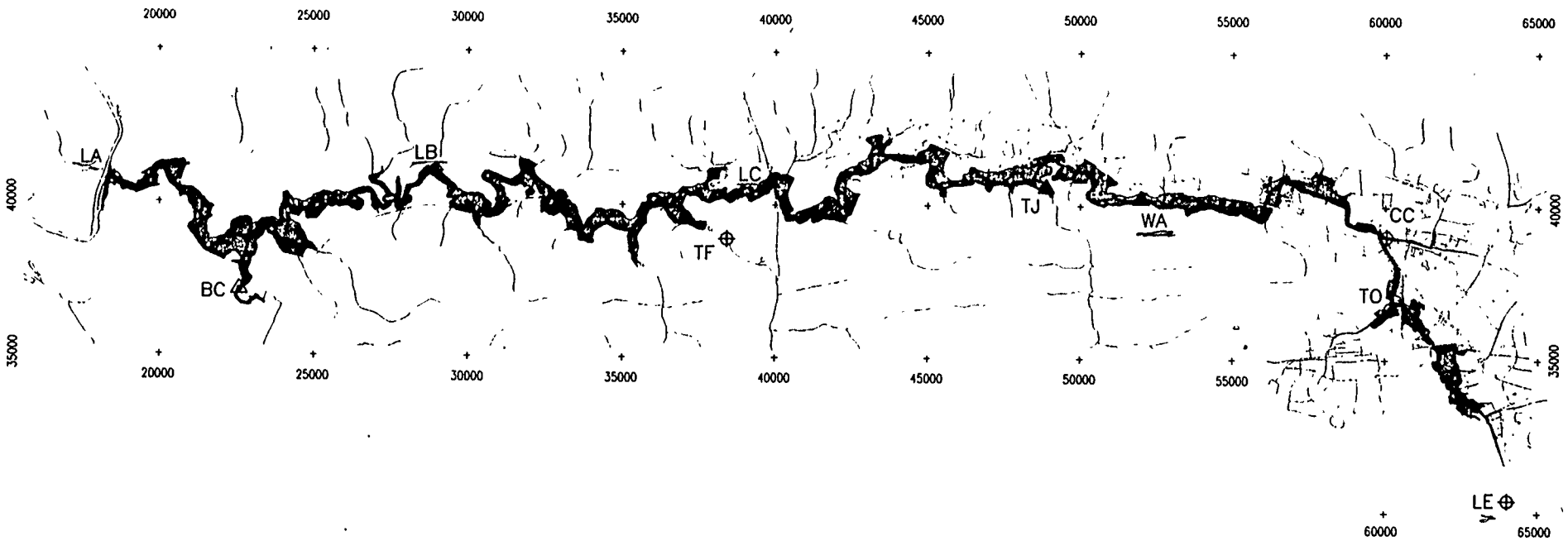
high flow contaminants are metals dominated by the particle-bound phase. Tributaries do not impact contaminant loads.

3.2.1.2 Base flow measurements

Surface water was investigated during Phase Ia for both base flow and storm flow and, again, during Phase Ib for base flow. The first round of base flow sampling occurred during the winter of 1991-92 and the second round took place in October 1992. This part of the investigation was designed to complement water quality data from other sources and to contrast results obtained at different times of the year (low flow vs high flow).

EFPC. Five sampling stations (see Fig. 3.3 or Map 4) within the creek were chosen for surface water sampling: one at the mouth of Lake Reality (LE) to measure input into the EFPC system, one at the confluence of EFPC with Poplar Creek (LA) to measure output from the system, two intermediate stations (LB and LC), and one station juxtaposed to an area of known high contaminant concentrations in the floodplain soils (WA). With the exception of isotopic uranium (Tables 3.7 through 3.11), no COCs established from Phase Ia data were observed during base flow conditions at any of the creek stations. (If the uncertainty value exceeds the activity for a radionuclide, it is considered as a nondetect for this purpose; net negative numbers can result from uncertainties that are greater than their absolute value, indicating the sample count was less than background). With respect to the reference site (HC-Table 3.12), elevated levels of barium, manganese, and copper were detected. As can be observed from Tables 3.7 through 3.11, water quality does not substantially change from LE to LA, and no impact is noted with the surface water in an area of high contamination (WA), either.

Tributaries. Three sites were selected to characterize potential runoff of pesticides, herbicides, and residual hydrocarbon products from residential and commercial areas of Oak Ridge (Fig. 3.3). They are: Gum Hollow Branch (golf course and residential, TF); Mill Branch (residential - Wilshire Subdivision and other residential area, public golf course and Gamble Valley, TJ); and an unnamed tributary also draining the Gamble Valley residential area (TO). Surface water was also sampled at two major tributaries to EFPC: an unnamed tributary draining both residential and commercial areas and entering EFPC near the Oak Ridge Civic Center (CC); and Bear Creek (BC) (base flow only), which is composed of runoff from the western half of the Y-12 Plant reservation. Base flow concentrations at these sites are very similar to EFPC. Tables 3.13 through 3.17 show that barium and manganese are present at each site and that uranium is present in small quantities at BC. No pesticides/herbicides or total petroleum hydrocarbons were detected in runoff from the golf course area, Civic Center, or Gamble Valley.



EAST FORK POPLAR CREEK

PLOTTING INFORMATION:		PEN CONFIGURATION
PROJECT NO: Z-0001	XREFS: Z-0001B/BASRDS, Z-0001B/BASWTR, Z-0001B/FLOODPLN, Z-0001B/TRIBS	1 .5 RED
DWG. FILE:\Z-0001\DWGS\333STRMF		2
		3
DATE. 04-13-93	PLOT FILES:\Z-0001P\ 333STRMF PLT	4
PLOTTED BY: R. BEELER		5 .5 BLUE
SHEET 1 OF 1		6
		7 .5 BLACK
		8 .25 BLACK

LEGEND: SCALE: 1" = 3500'

- BASE FLOW SAMPLE
- STORM & BASE FLOW SAMPLE
- EXIST. ROADS
- CREEKS & TRIBUTARIES
- O. R. ADMIN. GRID TICK
- FLOOD PLAIN

TITLE:

Figure 3.3 Surface Water Sampling Sites Storm & Base Flow

Science Applications International Corporation

Table 3.7. EFPC Phase Ia and Ib results for base flow maximum contaminant concentrations at location LE — NHP

Parameter	Measurement units	Proportion of results >detection limit	Maximum result >detection limit	Radiation counting uncertainty
Aluminum	µg/L	1/2	434	.
Arsenic	µg/L	0/2	.	.
Barium	µg/L	2/2	60	.
Beryllium	µg/L	0/2	.	.
Cadmium	µg/L	0/2	.	.
Chromium	µg/L	0/2	.	.
Copper	µg/L	0/2	.	.
Lead	µg/L	0/2	.	.
Manganese	µg/L	2/2	66.6	.
Mercury	µg/L	1/2	0.72	.
Nickel	µg/L	0/2	.	.
Silver	µg/L	0/2	.	.
Vanadium	µg/L	0/2	.	.
Zinc	µg/L	2/2	59.7	.
^{241}Am	pCi/L	2/2	-20.7	111
^{60}Co	pCi/L	2/2	15	28.8
^{137}Cs	pCi/L	2/2	33.1	47.8
^{237}Np	pCi/L	2/2	75.2	94.4
^{234}U	pCi/L	2/2	6.25	0.39
^{235}U	pCi/L	2/2	0.63	0.12
^{238}U	pCi/L	2/2	10.5	0.51
Acetone	µg/L	1/2	5	.
Chloroform	µg/L	0/2	.	.
Methylene chloride	µg/L	0/2	.	.
Tetrachloroethene	µg/L	1/2	1	.
Carbazole	µg/L	0/1	.	.
Chrysene	µg/L	0/2	.	.
Pyrene	µg/L	0/2	.	.
4,4'-DDT	µg/L	0/2	.	.
Aldrin	µg/L	0/2	.	.
Aroclor-1254	µg/L	0/2	.	.
Aroclor-1260	µg/L	0/2	.	.
Dieldrin	µg/L	0/2	.	.
Endosulfan sulfate	µg/L	0/2	.	.
Endrin	µg/L	0/2	.	.
Heptachlor epoxide	µg/L	0/2	.	.
gamma-BHC (Lindane)	µg/L	0/2	.	.

Source: EFPC Phase Ia and Ib validated data, December 18, 1992.

Table 3.8. EFPC Phase Ia and Ib results for base flow maximum contaminant concentrations at location WA

Parameter	Measurement units	Proportion of results > detection limit	Maximum result > detection limit	Radiation counting uncertainty
Aluminum	µg/L	0/1	.	.
Arsenic	µg/L	0/1	.	.
Barium	µg/L	1/1	51.1	.
Beryllium	µg/L	0/1	.	.
Cadmium	µg/L	0/1	.	.
Chromium	µg/L	0/1	.	.
Copper	µg/L	0/1	.	.
Lead	µg/L	0/1	.	.
Manganese	µg/L	1/1	24.3	.
Mercury	µg/L	0/1	.	.
Nickel	µg/L	0/1	.	.
Silver	µg/L	0/1	.	.
Vanadium	µg/L	0/1	.	.
Zinc	µg/L	0/1	.	.
^{241}Am	pCi/L	1/1	6.32	48.2
^{60}Co	pCi/L	1/1	-2	14.4
^{137}Cs	pCi/L	1/1	-3.94	18.9
^{237}Np	pCi/L	1/1	9.51	40.7
^{234}U	pCi/L	1/1	4.6	0.43
^{235}U	pCi/L	1/1	0.06	0.05
^{238}U	pCi/L	1/1	5.59	0.47
Acetone	µg/L	0/1	.	.
Chloroform	µg/L	0/1	.	.
Methylene chloride	µg/L	0/1	.	.
Tetrachloroethene	µg/L	0/1	.	.
Chrysene	µg/L	0/1	.	.
Pyrene	µg/L	0/1	.	.

Source: EFPC Phase Ia and Ib validated data, December 18, 1992.

Table 3.9. EFPC Phase Ia and Ib results for base flow maximum contaminant concentrations at location LC

Parameter	Measurement units	Proportion of results >detection limit	Maximum result >detection limit	Radiation counting uncertainty
Aluminum	µg/L	0/1	.	.
Arsenic	µg/L	0/1	.	.
Barium	µg/L	1/1	30.2	.
Beryllium	µg/L	0/1	.	.
Cadmium	µg/L	0/1	.	.
Chromium	µg/L	0/1	.	.
Copper	µg/L	0/1	.	.
Lead	µg/L	0/1	.	.
Manganese	µg/L	1/1	13.6	.
Mercury	µg/L	0/1	.	.
Nickel	µg/L	0/1	.	.
Silver	µg/L	0/1	.	.
Vanadium	µg/L	0/1	.	.
Zinc	µg/L	1/1	29.9	.
^{241}Am	pCi/L	1/1	0	120
^{60}Co	pCi/L	1/1	27	26.2
^{137}Cs	pCi/L	1/1	14.2	49.2
^{237}Np	pCi/L	1/1	51.9	92.2
^{235}U	pCi/L	1/1	0.2	0.13
^{238}U	pCi/L	1/1	3.19	0.5
Acetone	µg/L	0/1	.	.
Chloroform	µg/L	1/1	2	.
Methylene chloride	µg/L	0/1	.	.
Tetrachloroethene	µg/L	0/1	.	.
Carbazole	µg/L	0/1	.	.
Chrysene	µg/L	0/1	.	.
Pyrene	µg/L	0/1	.	.
4,4'-DDT	µg/L	0/1	.	.
Aldrin	µg/L	0/1	.	.
Aroclor-1254	µg/L	0/1	.	.
Aroclor-1260	µg/L	0/1	.	.
Dieldrin	µg/L	0/1	.	.
Endosulfan sulfate	µg/L	1/1	0.0085	.
Endrin	µg/L	0/1	.	.
Heptachlor epoxide	µg/L	1/1	0.0057	.
gamma-BHC (Lindane)	µg/L	1/1	0.0045	.

Source: EFPC Phase Ia and Ib validated data, December 18, 1992.

Table 3.10 EFPC Phase Ia and Ib results for base flow maximum contaminant concentrations at location LB

Parameter	Measurement units	Proportion of results >detection limit	Maximum result >detection limit	Radiation counting uncertainty
Aluminum	µg/L	0/2	.	.
Arsenic	µg/L	0/2	.	.
Barium	µg/L	2/2	34.4	.
Beryllium	µg/L	0/2	.	.
Cadmium	µg/L	0/2	.	.
Chromium	µg/L	0/2	.	.
Copper	µg/L	0/2	.	.
Lead	µg/L	0/2	.	.
Manganese	µg/L	2/2	19.8	.
Mercury	µg/L	0/2	.	.
Nickel	µg/L	0/2	.	.
Silver	µg/L	0/2	.	.
Vanadium	µg/L	0/2	.	.
Zinc	µg/L	1/2	23.5	.
^{241}Am	pCi/L	2/2	-27.6	125
^{60}Co	pCi/L	2/2	-15	30
^{137}Cs	pCi/L	2/2	18.9	45.4
^{237}Np	pCi/L	2/2	36.3	100
^{234}U	pCi/L	2/2	2.77	0.3
^{235}U	pCi/L	2/2	0.22	0.09
^{238}U	pCi/L	2/2	3.1	0.32
Acetone	µg/L	0/2	.	.
Chloroform	µg/L	0/2	.	.
Methylene chloride	µg/L	0/2	.	.
Tetrachloroethene	µg/L	0/2	.	.
Carbazole	µg/L	0/1	.	.
Chrysene	µg/L	0/2	.	.
Pyrene	µg/L	0/2	.	.
4,4'-DDT	µg/L	0/1	.	.
Aldrin	µg/L	0/1	.	.
Aroclor-1254	µg/L	0/1	.	.
Aroclor-1260	µg/L	0/1	.	.
Dieldrin	µg/L	0/1	.	.
Endosulfan sulfate	µg/L	1/1	0.011	.
Endrin	µg/L	0/1	.	.
Heptachlor epoxide	µg/L	0/1	.	.
gamma-BHC (Lindane)	µg/L	0/1	.	.

Source: EFPC Phase Ia and Ib validated data, December 18, 1992.

Table 3.11. EFPC Phase Ia and Ib results for base flow maximum contaminant concentrations at location LA

Parameter	Measurement units	Proportion of results >detection limit	Maximum result >detection limit	Radiation counting uncertainty
Aluminum	µg/L	1/2	338	.
Arsenic	µg/L	0/2	.	.
Barium	µg/L	2/2	38.9	.
Beryllium	µg/L	0/2	.	.
Cadmium	µg/L	0/2	.	.
Chromium	µg/L	0/2	.	.
Copper	µg/L	0/2	.	.
Lead	µg/L	0/1	.	.
Manganese	µg/L	2/2	40.1	.
Mercury	µg/L	0/2	.	.
Nickel	µg/L	0/2	.	.
Silver	µg/L	0/2	.	.
Vanadium	µg/L	0/2	.	.
Zinc	µg/L	2/2	22.2	.
^{241}Am	pCi/L	2/2	27.6	123
^{60}Co	pCi/L	2/2	18	38
^{137}Cs	pCi/L	2/2	14.2	47.3
^{237}Np	pCi/L	1/2	5.19	91.3
^{234}U	pCi/L	1/1	4.34	0.52
^{235}U	pCi/L	1/1	0.2	0.11
^{238}U	pCi/L	1/1	4.26	0.52
Acetone	µg/L	0/1	.	.
Chloroform	µg/L	0/1	.	.
Methylene chloride	µg/L	0/1	.	.
Tetrachloroethene	µg/L	0/1	.	.
Carbazole	µg/L	0/1	.	.
Chrysene	µg/L	0/1	.	.
Pyrene	µg/L	0/1	.	.
4,4'-DDT	µg/L	1/1	0.013	.
Aldrin	µg/L	1/1	0.0038	.
Aroclor-1254	µg/L	0/1	.	.
Aroclor-1260	µg/L	0/1	.	.
Dieldrin	µg/L	1/1	0.018	.
Endosulfan sulfate	µg/L	0/1	.	.
Endrin	µg/L	1/1	0.0085	.
Heptachlor epoxide	µg/L	0/1	.	.
gamma-BHC (Lindane)	µg/L	0/1	.	.

Source: EFPC Phase Ia and Ib validated data, December 18, 1992.

Table 3.12. EFPC Phase Ia and Ib results for base flow maximum contaminant concentrations at location HC

Parameter	Measurement units	Proportion of results > detection limit	Maximum result > detection limit	Radiation counting uncertainty
Aluminum	µg/L	0/2	.	.
Arsenic	µg/L	0/2	.	.
Barium	µg/L	2/2	35.8	.
Beryllium	µg/L	0/2	.	.
Cadmium	µg/L	0/2	.	.
Chromium	µg/L	0/2	.	.
Copper	µg/L	1/2	3.1	.
Lead	µg/L	0/2	.	.
Manganese	µg/L	2/2	23.1	.
Mercury	µg/L	0/2	.	.
Nickel	µg/L	0/2	.	.
Silver	µg/L	0/2	.	.
Vanadium	µg/L	0/2	.	.
Zinc	µg/L	0/2	.	.
^{241}Am	pCi/L	2/2	-3.45	120
^{60}Co	pCi/L	2/2	33	40.3
^{137}Cs	pCi/L	2/2	14.2	45.9
^{237}Np	pCi/L	2/2	10.4	98.4
Acetone	µg/L	0/2	.	.
Chloroform	µg/L	0/2	.	.
Methylene chloride	µg/L	0/2	.	.
Tetrachloroethene	µg/L	0/2	.	.
Chrysene	µg/L	0/2	.	.
Pyrene	µg/L	0/2	.	.
4,4'-DDT	µg/L	0/2	.	.
Aldrin	µg/L	0/2	.	.
Aroclor-1254	µg/L	0/2	.	.
Aroclor-1260	µg/L	0/2	.	.
Dieldrin	µg/L	0/2	.	.
Endosulfan sulfate	µg/L	0/2	.	.
Endrin	µg/L	0/2	.	.
Heptachlor epoxide	µg/L	0/2	.	.
gamma-BHC (Lindane)	µg/L	0/2	.	.

Source: EFPC Phase Ia and Ib validated data, December 18, 1992.

Table 3.13. EFPC Phase Ia and Ib results for base flow maximum contaminant concentrations at location CC

Parameter	Measurement units	Proportion of results >detection limit	Maximum result >detection limit	Radiation counting uncertainty
Aluminum	µg/L	0/1	.	.
Arsenic	µg/L	0/1	.	.
Barium	µg/L	1/1	33	.
Beryllium	µg/L	0/1	.	.
Cadmium	µg/L	0/1	.	.
Chromium	µg/L	0/1	.	.
Copper	µg/L	0/1	.	.
Lead	µg/L	0/1	.	.
Manganese	µg/L	0/1	.	.
Mercury	µg/L	0/1	.	.
Nickel	µg/L	0/1	.	.
Silver	µg/L	0/1	.	.
Vanadium	µg/L	0/1	.	.
Zinc	µg/L	0/1	.	.
^{241}Am	pCi/L	1/1	-27.6	118
^{60}Co	pCi/L	1/1	12	22.5
^{137}Cs	pCi/L	1/1	21.3	43.6
^{237}Np	pCi/L	1/1	98.5	94.8
^{234}U	pCi/L	1/1	0.16	0.08
^{235}U	pCi/L	1/1	0.01	0.02
^{238}U	pCi/L	1/1	0.16	0.08
Acetone	µg/L	0/1	.	.
Chloroform	µg/L	0/1	.	.
Methylene chloride	µg/L	0/1	.	.
Tetrachloroethene	µg/L	0/1	.	.
Chrysene	µg/L	0/1	.	.
Pyrene	µg/L	0/1	.	.
4,4'-DDT	µg/L	0/1	.	.
Aldrin	µg/L	0/1	.	.
Aroclor-1254	µg/L	0/1	.	.
Aroclor-1260	µg/L	0/1	.	.
Dieldrin	µg/L	0/1	.	.
Endosulfan sulfate	µg/L	0/1	.	.
Endrin	µg/L	0/1	.	.
Heptachlor epoxide	µg/L	0/1	.	.
gamma-BHC (Lindane)	µg/L	0/1	.	.
Petroleum hydrocarbons	µg/L	0/1	.	.

Source: EFPC Phase Ia and Ib validated data, December 18, 1992.

Table 3.14. EFPC Phase Ia and Ib results for base flow maximum contaminant concentrations at location BC

Parameter	Measurement units	Proportion of results >detection limit	Maximum result >detection limit	Radiation counting uncertainty
Aluminum	µg/L	1/1	234	.
Arsenic	µg/L	0/1	.	.
Barium	µg/L	1/1	41.2	.
Beryllium	µg/L	0/1	.	.
Cadmium	µg/L	0/1	.	.
Chromium	µg/L	0/1	.	.
Copper	µg/L	0/1	.	.
Manganese	µg/L	1/1	13.5	.
Mercury	µg/L	0/1	.	.
Nickel	µg/L	0/1	.	.
Silver	µg/L	0/1	.	.
Vanadium	µg/L	0/1	.	.
Zinc	µg/L	0/1	.	.
^{241}Am	pCi/L	1/1	13.8	114
^{60}Co	pCi/L	1/1	24	40.7
^{137}Cs	pCi/L	1/1	14.2	48.2
^{237}Np	pCi/L	1/1	-13	98.3
^{234}U	pCi/L	1/1	3.1	0.33
^{235}U	pCi/L	1/1	0.33	0.11
^{238}U	pCi/L	1/1	6.25	0.47
Acetone	µg/L	0/1	.	.
Chloroform	µg/L	0/1	.	.
Methylene chloride	µg/L	0/1	.	.
Tetrachloroethene	µg/L	0/1	.	.
Chrysene	µg/L	0/1	.	.
Pyrene	µg/L	0/1	.	.
4,4'-DDT	µg/L	0/1	.	.
Aldrin	µg/L	0/1	.	.
Aroclor-1254	µg/L	0/1	.	.
Aroclor-1260	µg/L	0/1	.	.
Dieldrin	µg/L	0/1	.	.
Endosulfan sulfate	µg/L	0/1	.	.
Endrin	µg/L	0/1	.	.
Heptachlor epoxide	µg/L	0/1	.	.
gamma-BHC (Lindane)	µg/L	0/1	.	.

Source: EFPC Phase Ia and Ib validated data, December 18, 1992.

Table 3.15. EFPC Phase Ia and Ib results for base flow maximum contaminant concentrations at location TF

Parameter	Measurement units	Proportion of results >detection limit	Maximum result >detection limit	Radiation counting uncertainty
Aluminum	µg/L	0/1	.	.
Arsenic	µg/L	0/1	.	.
Barium	µg/L	1/1	27.8	.
Beryllium	µg/L	0/1	.	.
Cadmium	µg/L	0/1	.	.
Chromium	µg/L	0/1	.	.
Copper	µg/L	0/1	.	.
Lead	µg/L	0/1	.	.
Manganese	µg/L	1/1	32.5	.
Mercury	µg/L	0/1	.	.
Nickel	µg/L	0/1	.	.
Silver	µg/L	0/1	.	.
Vanadium	µg/L	0/1	.	.
Zinc	µg/L	0/1	.	.
^{241}Am	pCi/L	1/1	17.2	119
^{60}Co	pCi/L	1/1	9.01	35.5
^{137}Cs	pCi/L	1/1	7.1	45.1
^{237}Np	pCi/L	1/1	15.6	102
Acetone	µg/L	0/1	.	.
Chloroform	µg/L	0/1	.	.
Methylene chloride	µg/L	0/1	.	.
Tetrachloroethene	µg/L	0/1	.	.
Chrysene	µg/L	0/1	.	.
Pyrene	µg/L	0/1	.	.
4,4'-DDT	µg/L	0/1	.	.
Aldrin	µg/L	0/1	.	.
Aroclor-1254	µg/L	0/1	.	.
Aroclor-1260	µg/L	0/1	.	.
Dieldrin	µg/L	0/1	.	.
Endosulfan sulfate	µg/L	0/1	.	.
Endrin	µg/L	0/1	.	.
Heptachlor epoxide	µg/L	0/1	.	.
gamma-BHC (Lindane)	µg/L	0/1	.	.
Petroleum hydrocarbons	mg/L	0/1	.	.

Source: EFPC Phase Ia and Ib validated data, December 18, 1992.

Table 3.16. EFPC Phase Ia and Ib results for base flow maximum contaminant concentrations at location TJ

Parameter	Measurement units	Proportion of results > detection limit	Maximum result > detection limit	Radiation counting uncertainty
Aluminum	µg/L	0/1	.	.
Arsenic	µg/L	0/1	.	.
Barium	µg/L	1/1	28	.
Beryllium	µg/L	0/1	.	.
Cadmium	µg/L	0/1	.	.
Chromium	µg/L	0/1	.	.
Copper	µg/L	0/1	.	.
Lead	µg/L	0/1	.	.
Manganese	µg/L	1/1	24.8	.
Mercury	µg/L	0/1	.	.
Nickel	µg/L	0/1	.	.
Silver	µg/L	0/1	.	.
Vanadium	µg/L	0/1	.	.
Zinc	µg/L	0/1	.	.
^{241}Am	pCi/L	1/1	3.45	123
^{60}Co	pCi/L	1/1	-9.01	33.5
^{137}Cs	pCi/L	1/1	4.73	48.2
Acetone	µg/L	0/1	.	.
Chloroform	µg/L	0/1	.	.
Methylene chloride	µg/L	0/1	.	.
Tetrachloroethene	µg/L	0/1	.	.
Chrysene	µg/L	0/1	.	.
Pyrene	µg/L	0/1	.	.
4,4'-DDT	µg/L	0/1	.	.
Aldrin	µg/L	0/1	.	.
Aroclor-1254	µg/L	0/1	.	.
Aroclor-1260	µg/L	0/1	.	.
Dieldrin	µg/L	0/1	.	.
Endosulfan sulfate	µg/L	0/1	.	.
Endrin	µg/L	0/1	.	.
Heptachlor epoxide	µg/L	0/1	.	.
gamma-BHC (Lindane)	µg/L	0/1	.	.

Source: EFPC Phase Ia and Ib validated data, December 18, 1992.

Table 3.17. EFPC Phase Ia and Ib results for base flow maximum contaminant concentrations at location TO

Parameter	Measurement units	Proportion of results > detection limit	Maximum result > detection limit	Radiation counting uncertainty
Aluminum	µg/L	0/1	.	.
Arsenic	µg/L	0/1	.	.
Barium	µg/L	1/1	38.8	.
Beryllium	µg/L	0/1	.	.
Cadmium	µg/L	0/1	.	.
Chromium	µg/L	0/1	.	.
Copper	µg/L	0/1	.	.
Lead	µg/L	0/1	.	.
Manganese	µg/L	1/1	82	.
Mercury	µg/L	0/1	.	.
Nickel	µg/L	0/1	.	.
Silver	µg/L	0/1	.	.
Vanadium	µg/L	0/1	.	.
Zinc	µg/L	0/1	.	.
^{241}Am	pCi/L	1/1	58.6	113
^{60}Co	pCi/L	1/1	12	35
^{137}Cs	pCi/L	1/1	28.4	41.2
^{237}Np	pCi/L	1/1	-23.3	99.9
Acetone	µg/L	0/1	.	.
Chloroform	µg/L	0/1	.	.
Methylene chloride	µg/L	0/1	.	.
Tetrachloroethene	µg/L	0/1	.	.
Chrysene	µg/L	0/1	.	.
Pyrene	µg/L	0/1	.	.
4,4'-DDT	µg/L	0/1	.	.
Aldrin	µg/L	0/1	.	.
Aroclor-1254	µg/L	0/1	.	.
Aroclor-1260	µg/L	0/1	.	.
Dieldrin	µg/L	0/1	.	.
Endosulfan sulfate	µg/L	0/1	.	.
Endrin	µg/L	0/1	.	.
Heptachlor epoxide	µg/L	0/1	.	.
gamma-BHC (Lindane)	µg/L	0/1	.	.
Petroleum hydrocarbons	mg/L	0/1	.	.

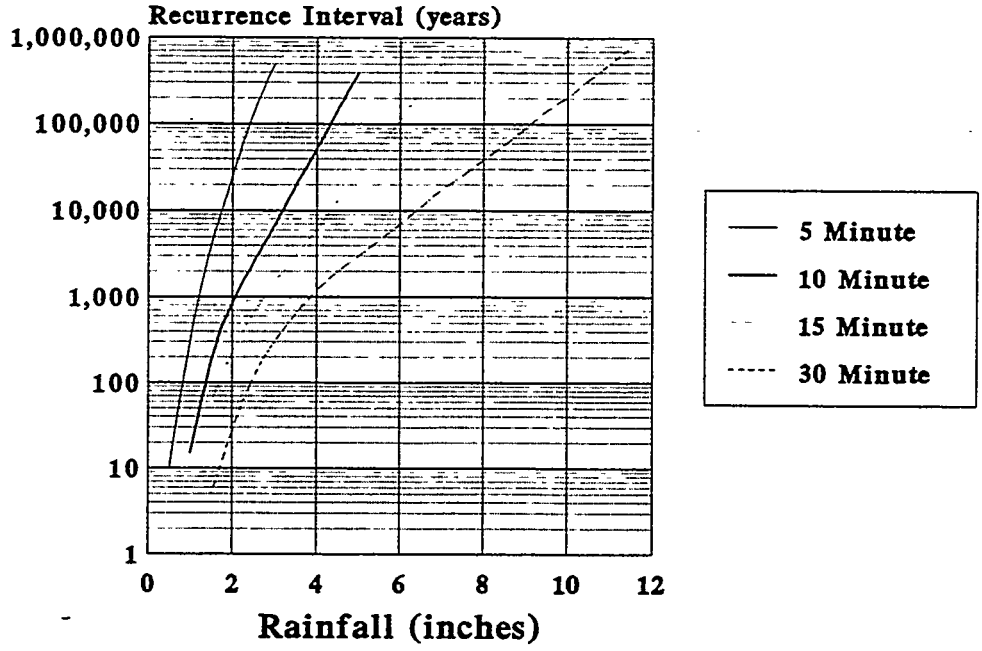
Source: EFPC Phase Ia and Ib validated data, December 18, 1992.

3.2.1.3 Storm flow measurements

EFPC. Initially, three storm flow sampling events were planned for EFPC. After the second storm, it was decided to limit the sampling to two storm events. The probability of successfully predicting a major storm event (above the two already sampled) was small and did not justify the time and resources to conduct a third sampling round. Storm flow samples were taken during the two precipitation events on February 13, 1991 and March 23, 1991. Sampling locations LA, LB, and LE were selected to represent the input (LE), output (LA), and a midpoint (LB) of the EFPC system. Two of the locations (LA and LB) were surveyed for cross-sectional areas and volumetric flow rates were calculated using these cross-sectional areas and flow meter readings. The third station, LE, recorded only the water height at the full well of the calibrate weir near the outfall of Lake Reality. The first storm event furnished 1.41 in. of rain over a 12-hr period, while the second event dispensed 0.80 in. of rain over a lesser time frame. Compared against the local area depth-duration rainfall estimates (Fig. 3.4), neither precipitation event was noteworthy. In fact, both storms displayed a recurrence interval much less than 1 in 10 years (TVA 1991) and could be characterized as a fairly typical rainfall event of modest portions. Resulting flows (in cubic feet per second) in EFPC were, likewise, not significant. At the crest of both storm events, flow was calculated to be ~200 cfs at station LB (222.6 cfs and 175.0 cfs for events 1 and 2). In contrast, a 25-year flood (4% chance of occurrence) is rated at between 4000-5000 cfs (Fig. 3.5) (Weeks 1992). The calibration factor to relate water level in the weir to flow rate has not been obtained for LE. For the record, crest heights were 2.2 ft and 4.2 ft for storm events 1 and 2, respectively.

Data from station LA (the confluence of EFPC with Poplar Creek) are unusable. During the course of both events, water levels in Watts Bar reservoir rose, creating reverse flow at LA. Flow measurements were discontinued midway through the storm, and samples retained for analysis were based on the hydrograph at LB. Due to upstream flow, extraneous contributions to the lower end of EFPC and pooling of contaminants are possible. Analytical results are considered unreliable and misleading because of these conditions.

Samples were collected at incremental rises in the creek. Five samples were selected for analysis from the total number of samples archived over the term of the storm event. Two samples were chosen from the set taken before the crest of the flood, one was identified at the crest, and two were selected subsequent to the crest of the maximum flood stage for determination of the analytes detailed in Table 3.6.



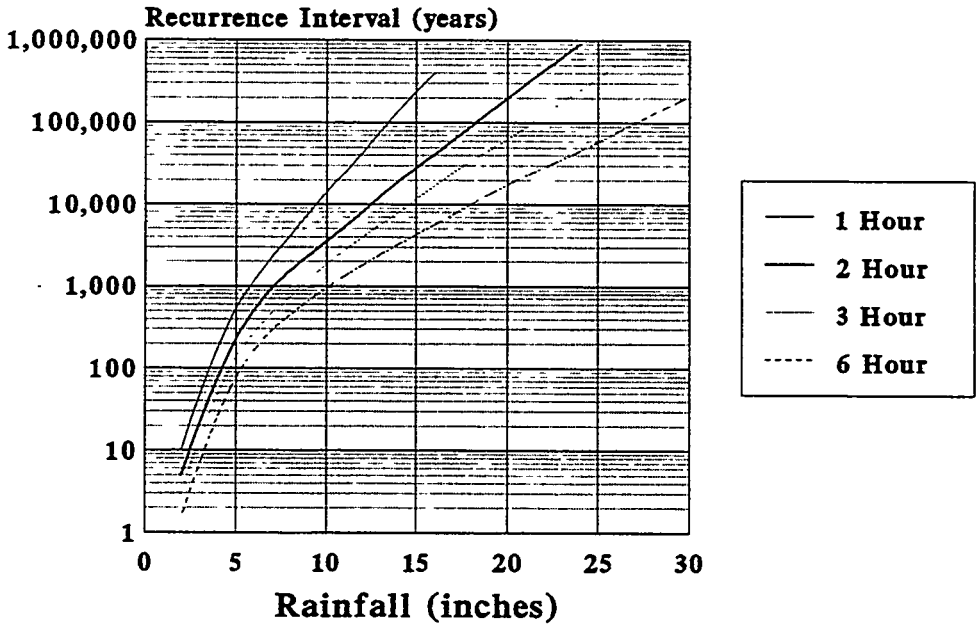


Fig. 3.4. Oak Ridge area rainfall depth-duration.

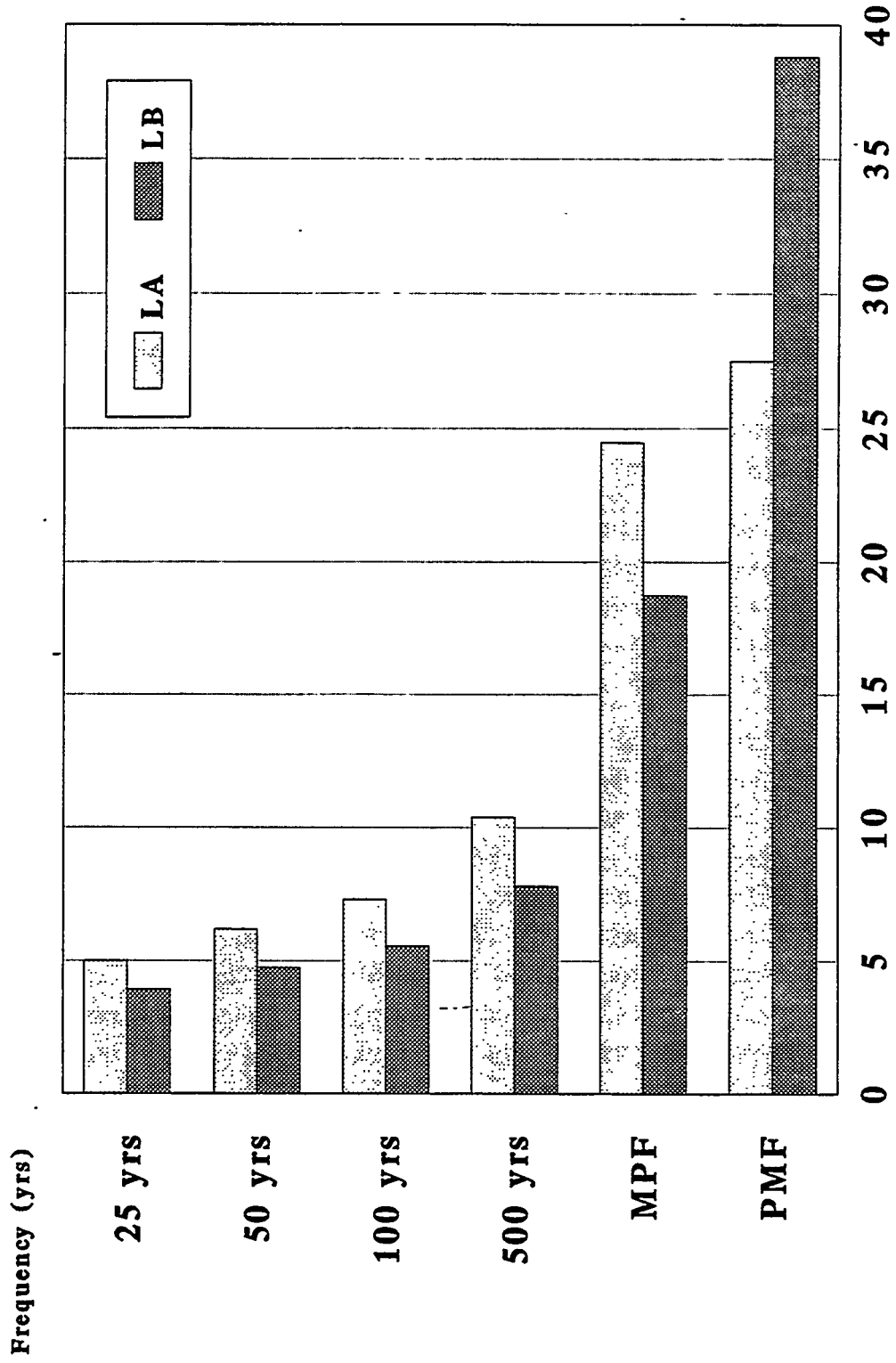


Fig. 3.5. Flow at Creek Stations LA and LB during flooding conditions.

Figures 3.6 through 3.13 display contaminant concentrations for selected analytes at five points during the flood event. A series of samples was taken: at the beginning of the rise in base level, before and after the crest of the maximum flood stage, at the maximum flood stage, and just before the return to base flow conditions. The middle position, irrespective of the number, is the maximum flood stage. From the range of potential COCs, only a limited number of analytes is observed during storm events. Common elements such as barium, manganese, and zinc are present throughout the flood in both dissolved and suspended phases (to a lesser extent, this is also true of vanadium and copper). Several elements such as mercury, chromium, and lead (and arsenic near the detection limit) are found only in the total analyses indicating particle-bound transport. For the most part, the remaining potential COCs were not detected in storm samples. The nondetected analytes include the remaining metals, pesticides and PCBs, semivolatile organic compounds (except PAHs), and VOCs.

Several (4-5) compounds from the PAH group were detected only at station LE (outfall from Lake Reality) and only in samples on the rising limb of the hydrograph (Figs. 3.6 and 3.7). Samples taken after the early part of the flood do not have detectable PAH concentrations. This is interpreted as an initial flushing of PAHs from upper EFPC and Lake Reality. Any later transport of PAHs is probably masked by high flow conditions.

Barium, for the most part, is representative of the total and dissolved analyses for the observed common elements. During storm 1 (Fig. 3.8), concentrations of total barium at station LB follow the rise and fall of the hydrograph. In contrast, total barium at LE decreases slightly over the storm event but for practical purposes may be considered relatively constant. During storm 2 (Fig. 3.9), total barium at station LB displays the same rise and fall as storm 1, but station LE shows a pronounced decrease. Absolute concentrations of barium at station LB are very similar for the two storms (as would be expected from the similar flow rates between the two storms), but total barium at LE for storm 2 is roughly twice the concentration for storm 1. The correlation between flow rates and concentrations between the two storm events is not valid for the change in flow over the course of a storm. Dissolved barium further complicates any interpretation. Both stations display decreasing concentrations during storm 1 (Fig. 3.10) but exhibit erratic, if not, increasing concentrations during storm 2 (Fig. 3.11).

Mercury is typical of the contaminants that undergo particle-bound transport (as noted by a lack of dissolved concentrations). Mercury concentrations increase until the flood crest, then drop off accordingly (Figs. 3.12 and 3.13). It should be noted that this increase is slight in absolute terms but reflects the larger amount of suspended sediments from erosion of the floodplain or collapse of creek banks. Station LE displays higher concentrations than LA for

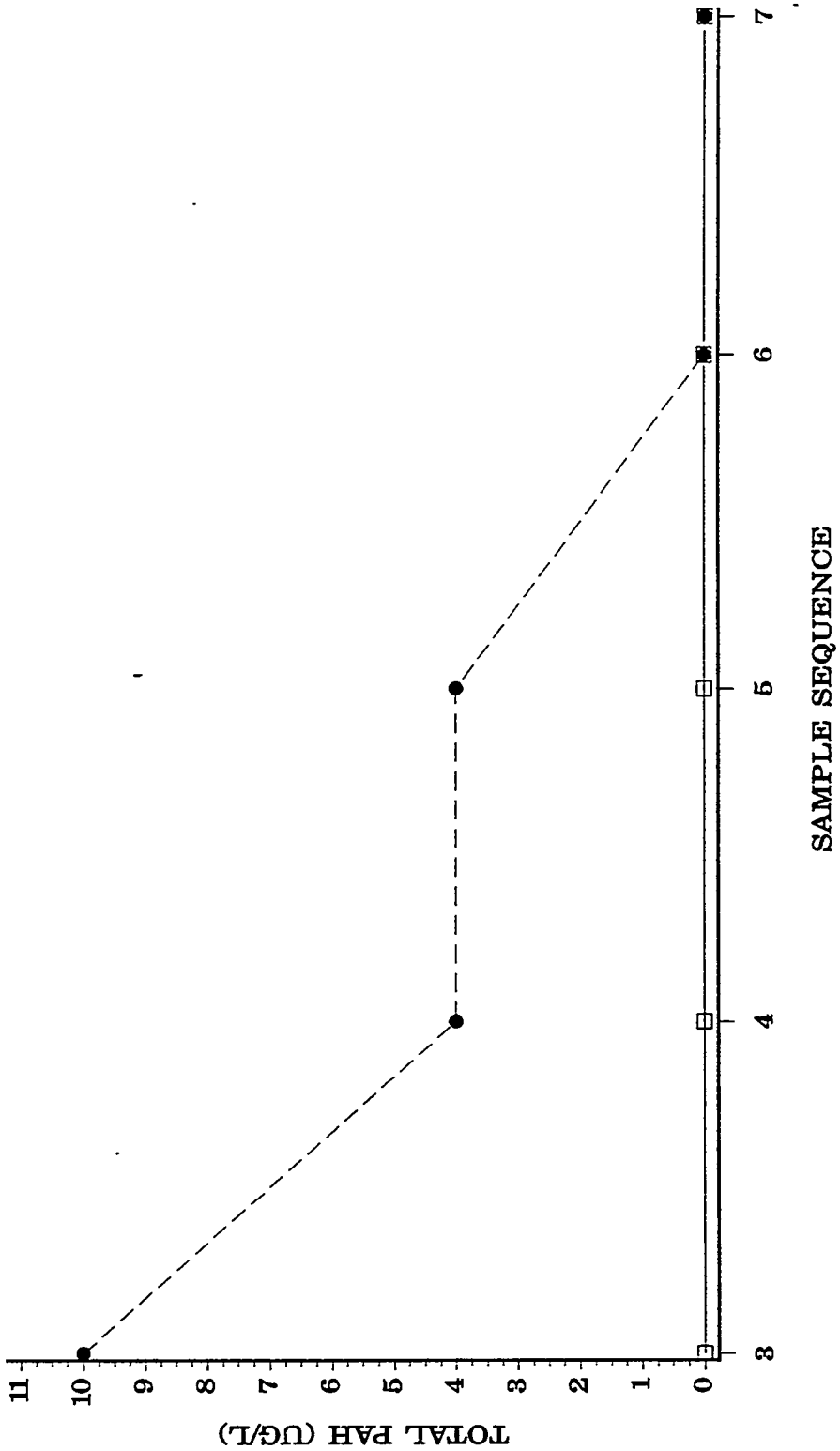


Fig. 3.6. Storm event 1 - PAH concentrations (μg/L) in EFPC storm water. Sampling sequence is centered around peak storm flow. Rejected results have been omitted. Values less than the detection limit for an analyte were set to zero.

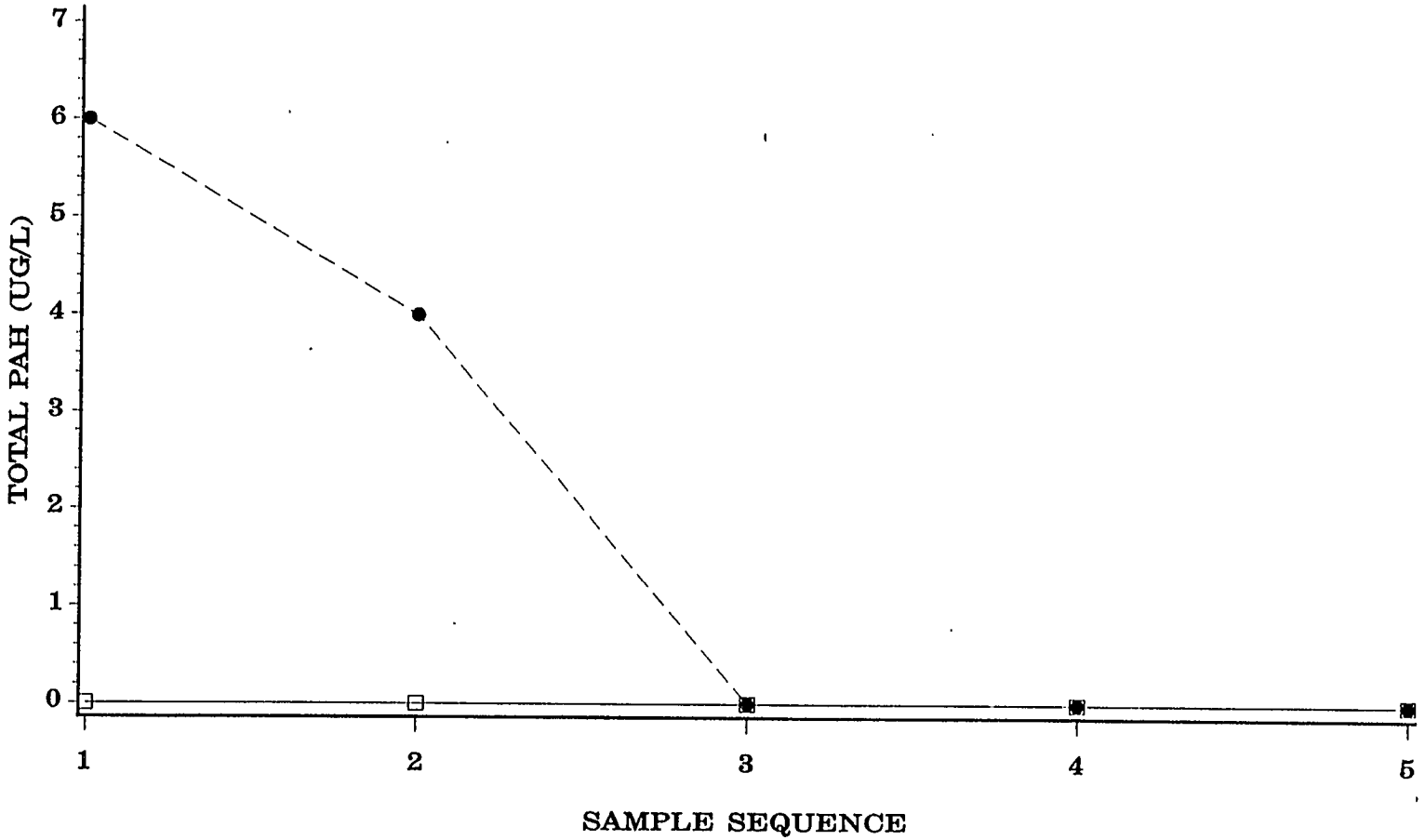


Fig. 3.7. Storm event 2 - PAH concentrations (μg/L) in EFPC storm water. Sampling sequence is centered around peak storm flow. Rejected results have been omitted. Values less than the detection limit for an analyte were set to zero.

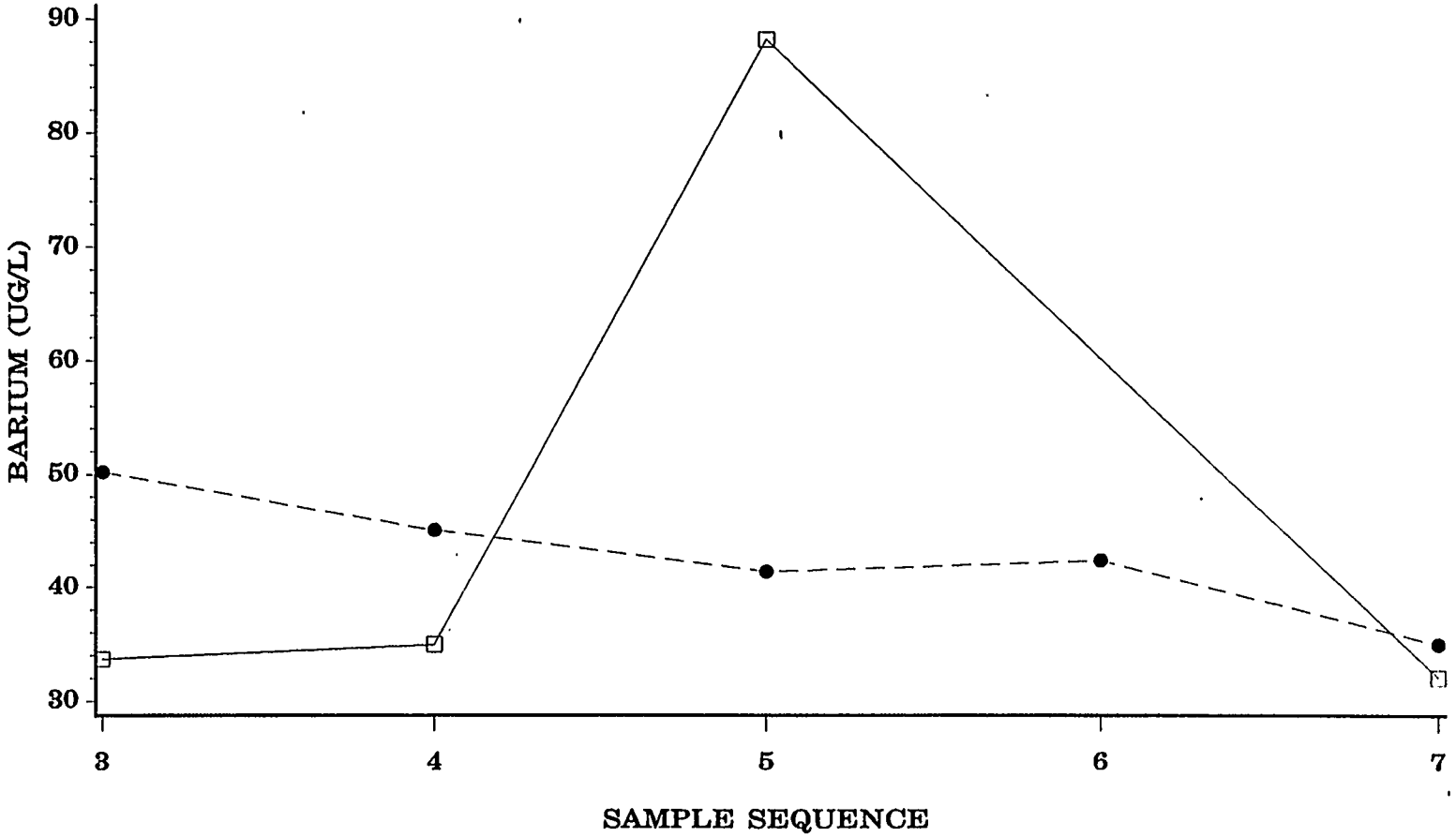


Fig. 3.8. Storm event 1 - Barium concentrations (μg/L) in EFPC storm water. Sampling sequence is centered around peak storm flow. Rejected results have been omitted. Values less than the detection limit for an analyte were set to zero.

LOCATION ⊟-⊟-⊟ LB ●-●-● LE

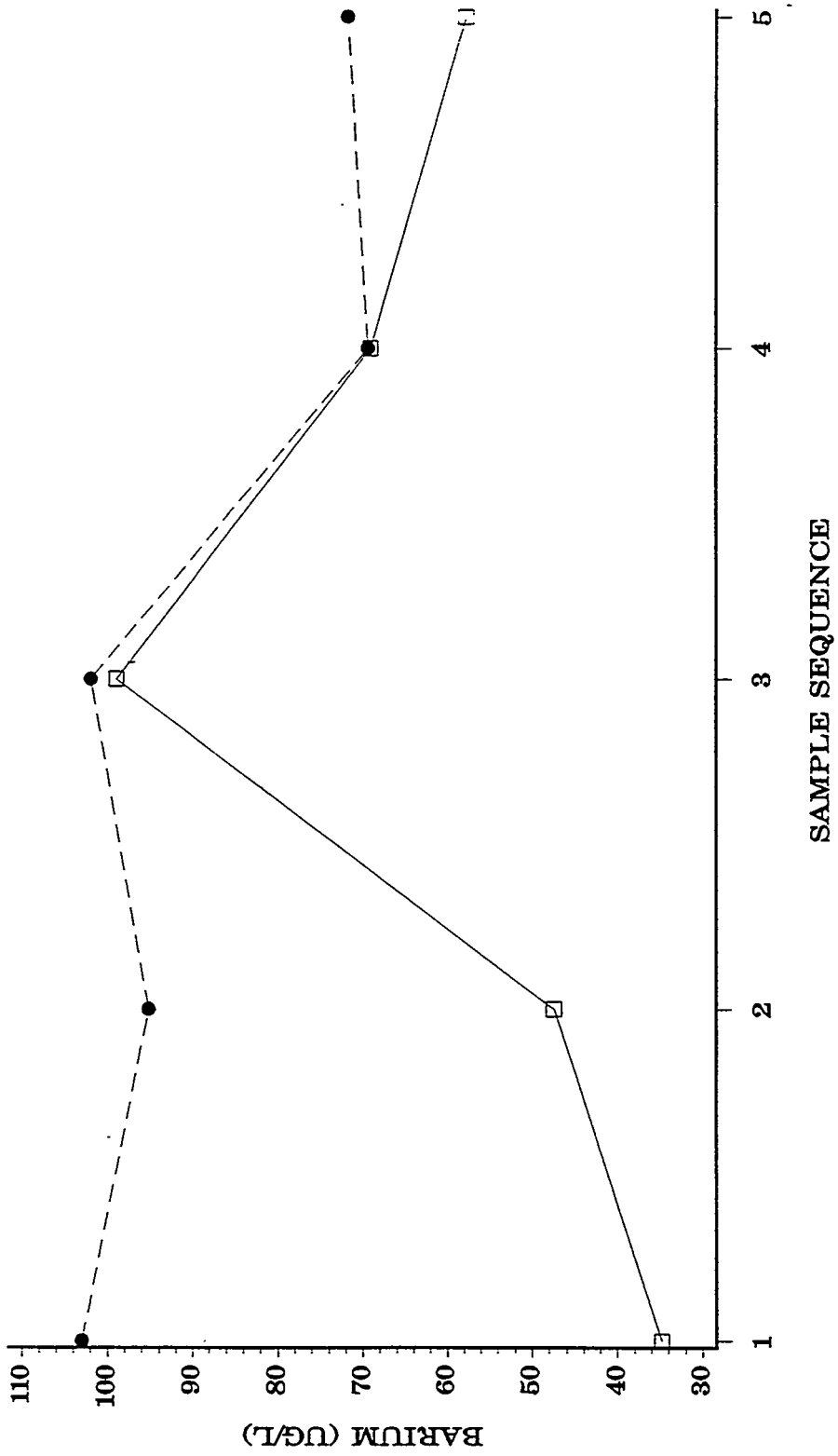


Fig. 3.9. Storm event 2 - Barium concentrations (μg/L) in EFPC storm water. Sampling sequence is centered around peak storm flow. Rejected results have been omitted. Values less than the detection limit for an analyte were set to zero.

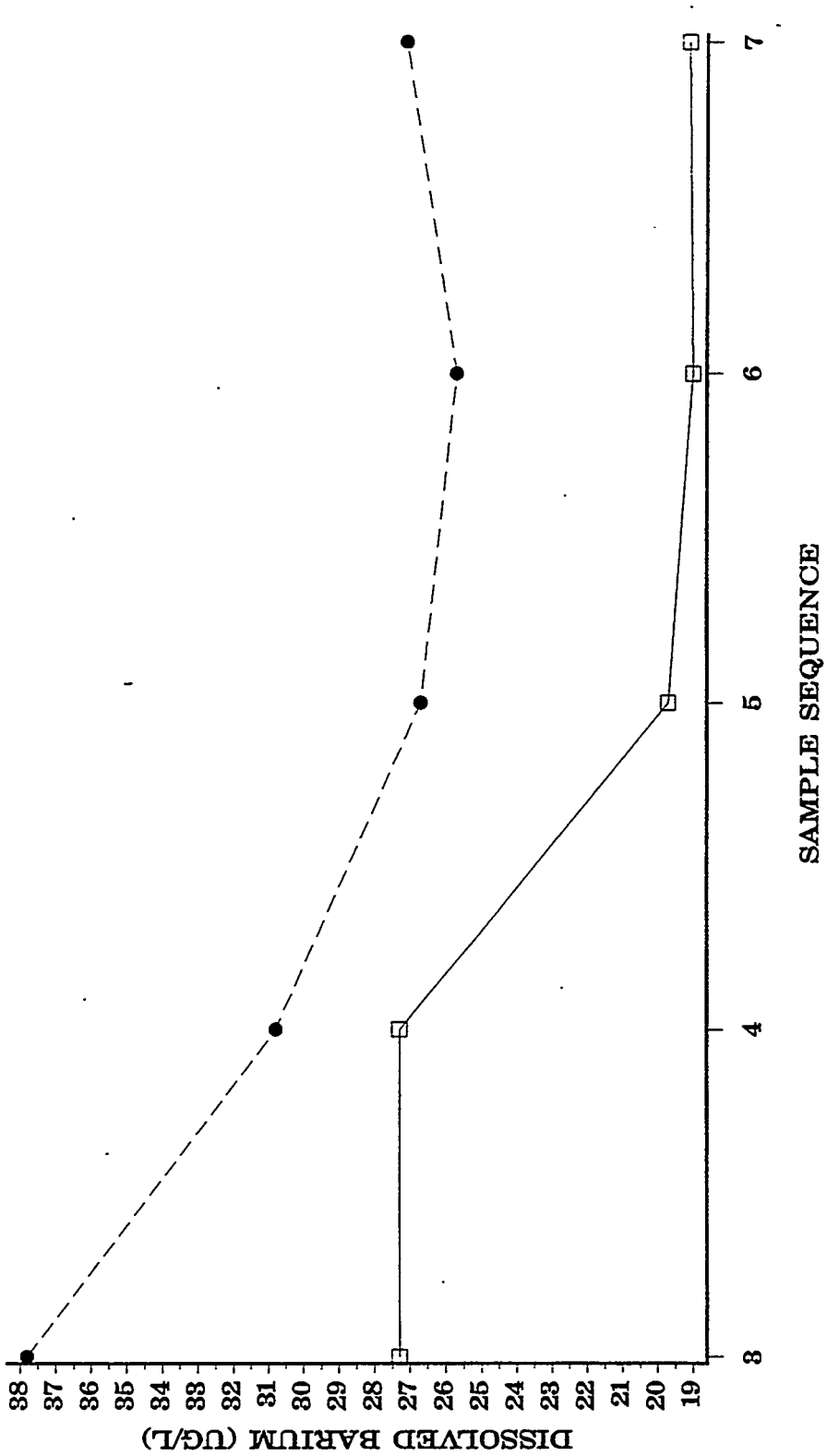


Fig. 3.10. Storm event 1 - Dissolved Barium concentrations (µg/L) in EFPC storm water. Sampling sequence is centered around peak storm flow. Rejected results have been omitted. Values less than the detection limit for an analyte were set to zero.

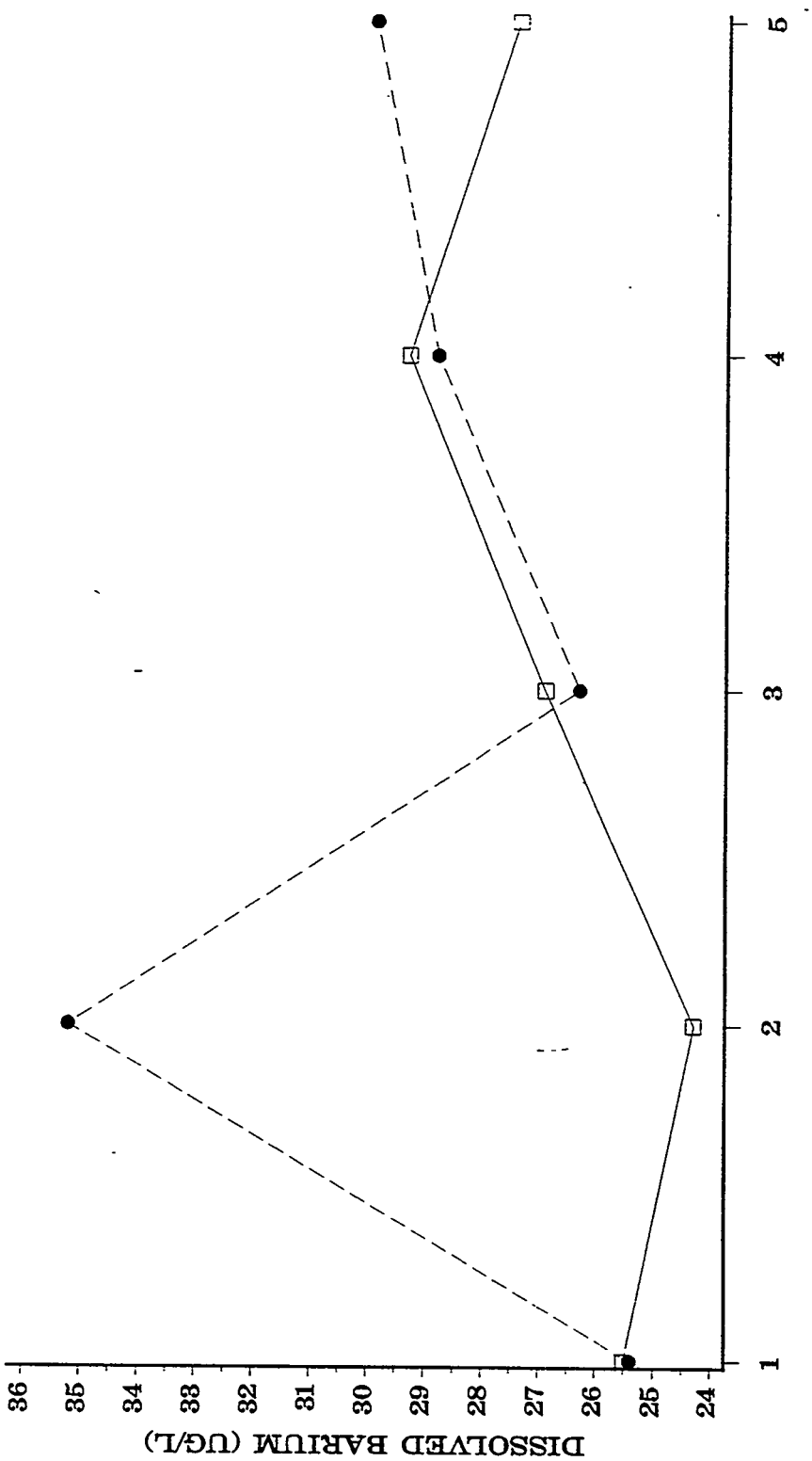


Fig. 3.11. Storm event 2 - Dissolved Barium concentrations (μg/L) in EFPC storm water. Sampling sequence is centered around peak storm flow. Rejected results have been omitted. Values less than the detection limit for an analyte were set to zero.

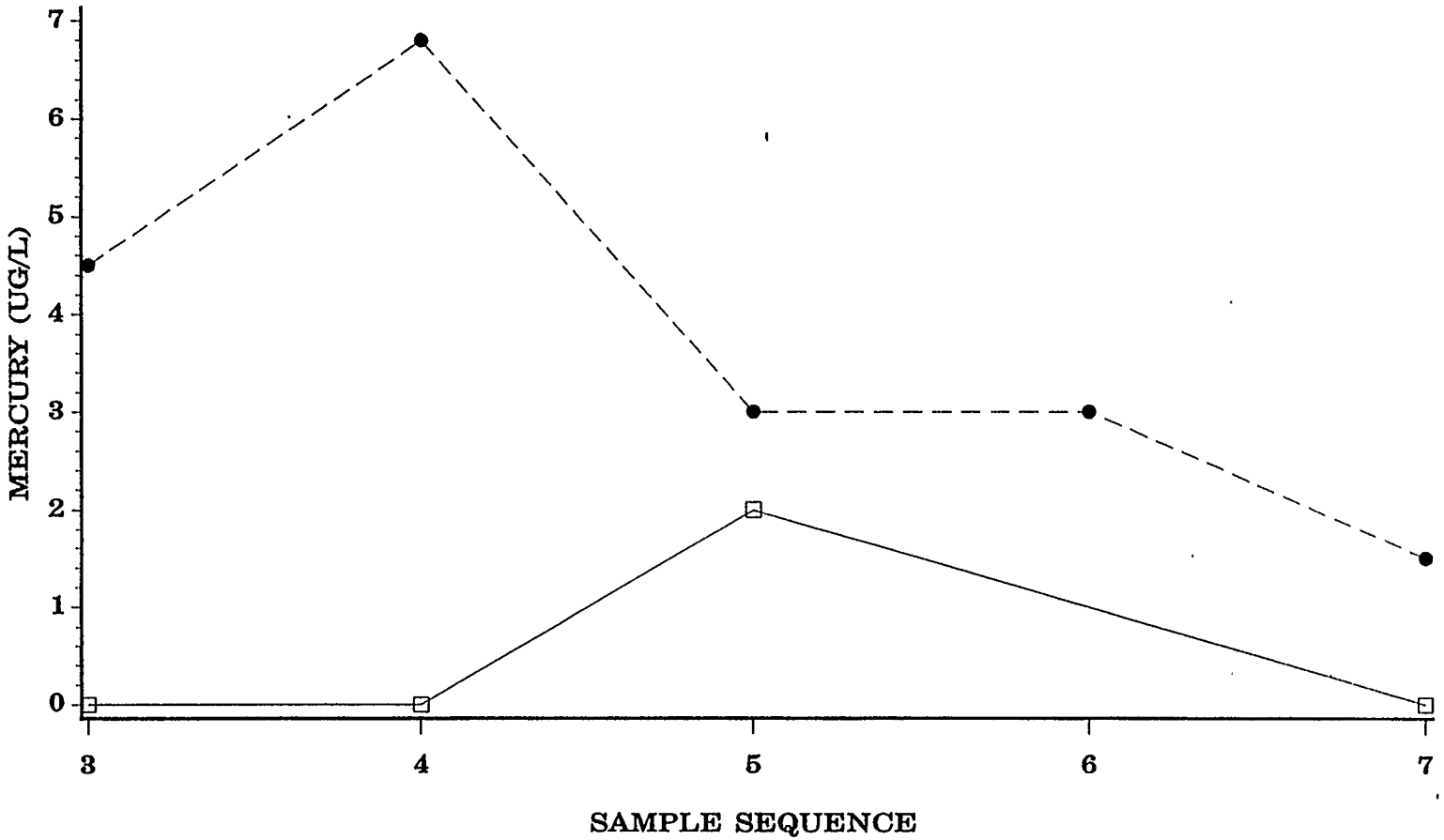


Fig. 3.12. Storm event 1 - Mercury concentrations (μg/L) in EFPC storm water. Sampling sequence is centered around peak storm flow. Rejected results have been omitted. Values less than the detection limit for an analyte were set to zero.

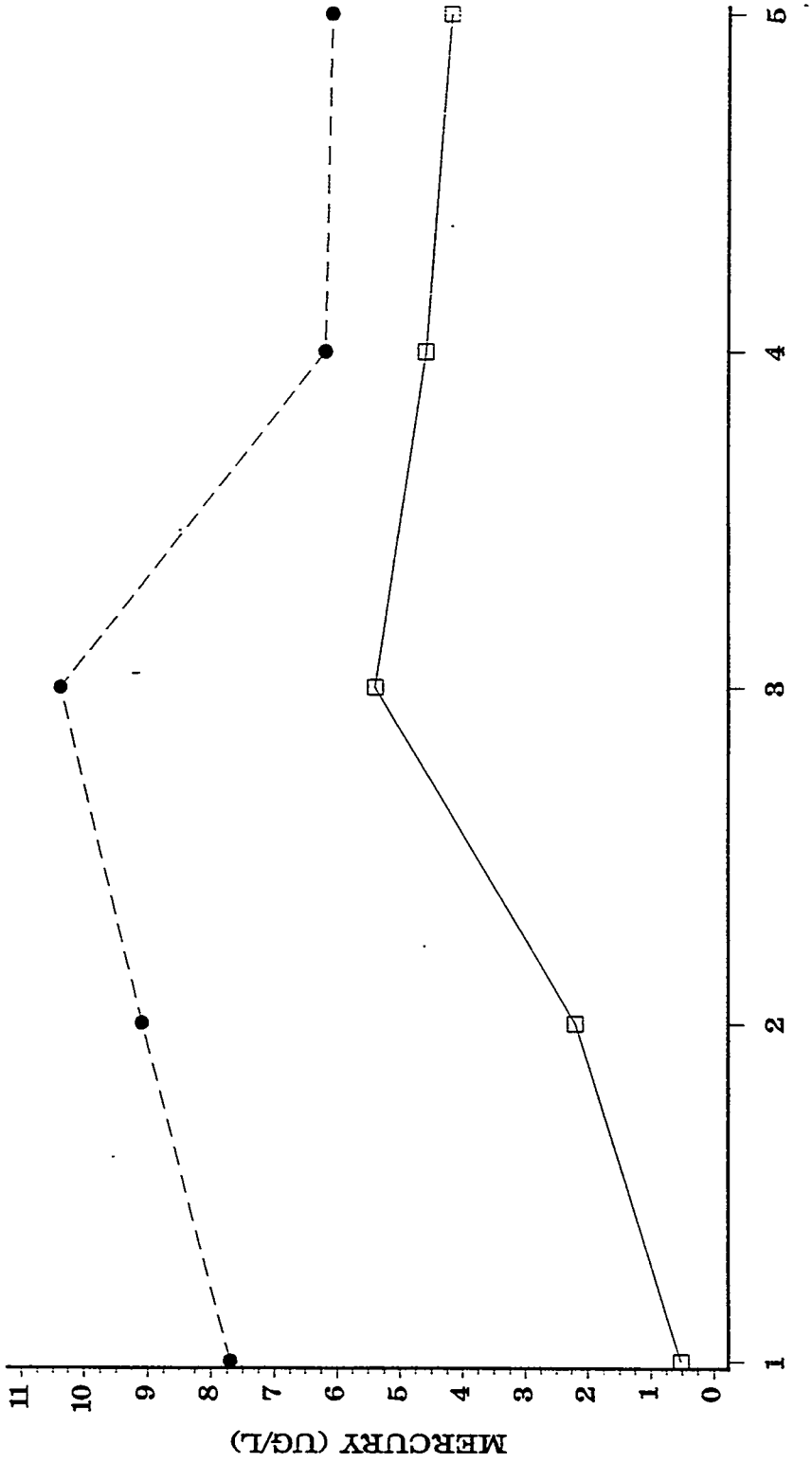


Fig. 3.13. Storm event 2 - Mercury concentrations (μg/L) in EFPC storm water. Sampling sequence is centered around peak storm flow. Rejected results have been omitted. Values less than the detection limit for an analyte were set to zero.

each floodstage. This may be a function of both higher concentrations of mercury mobilized from Lake Reality during storm events and a dilution of contaminants downstream with higher flow rates at LB.

Tributaries. At TF, CC, and TO, storm water samples were taken during the early stage of a storm event (Figs. 3.14 through 3.32). These samples were obtained during different time periods than the EFPC storm events (for station LA, LB, and LE) and consisted of a single surface water sample rather than multiple samples over the course of a flood event. For storm events, each EFPC and tributary water sample was analyzed for total and dissolved metals, total radioactive strontium, total radium, anions, gamma emitters, isotopic uranium, volatile and semi-volatile organics, and pesticides. Tributary samples were also analyzed for total petroleum hydrocarbons and 40 *CFR* 264-Appendix IX herbicides to evaluate the potential contributions of these compounds to EFPC. The results of this procedure provided estimates of dissolved metals and suspended sediments under base and storm flow conditions.

3.2.1.4 Evaluation

Base/Storm-Total/Dissolved Comparisons. An understanding of the surface water quality in the EFPC watershed can be gained by comparing the analyses of the tributary and creek sites during storm events and base flow and for total and dissolved contaminants. Nondetected contaminants are not addressed or shown in the graphs. Figures 3.14 through 3.32 display the contaminant concentrations for all sites graphed from left to right, moving upstream from the confluence of EFPC with Poplar Creek (LA) to Lake Reality (LE). The HC reference site is presented on the far left side of the graph for comparison with background concentrations (base flow only). Each site provides a bar representing the concentrations for base flow (B) and storm flow (S). Analyses for total contaminants are presented on a separate graph from the dissolved (filtered) analyses (storm flow only). For EFPC station (LA, LB, and LE) storm measurements, concentrations on the graphs represent the maximum reported value for five samples taken during two separate measurements (events) at each creek site. It was noted that during EFPC storm sampling at station LA, backflow from Poplar Creek and Watts Bar Dam was encountered.

Arsenic (Fig. 3.14) concentrations are similar to those of many contaminants observed in the surface water at EFPC. Relatively small amounts (3 to 5 μg/L) were detected in the total analyses at the creek sites during storm events; however, none was seen above the detection limit in the tributaries during storm flow or from either the creek or tributaries during base flow. All

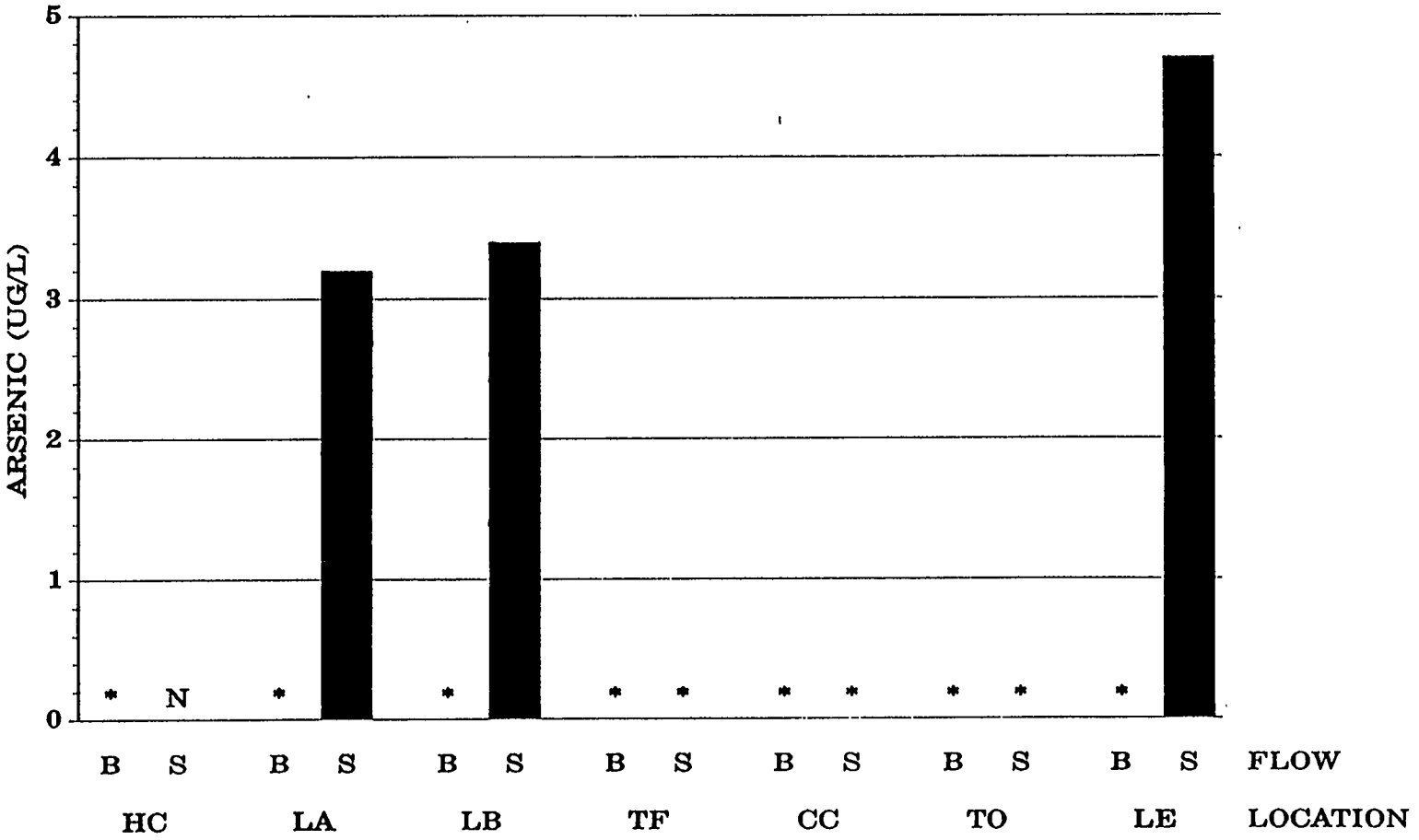


Fig. 3.14. Maximum arsenic concentrations (μg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

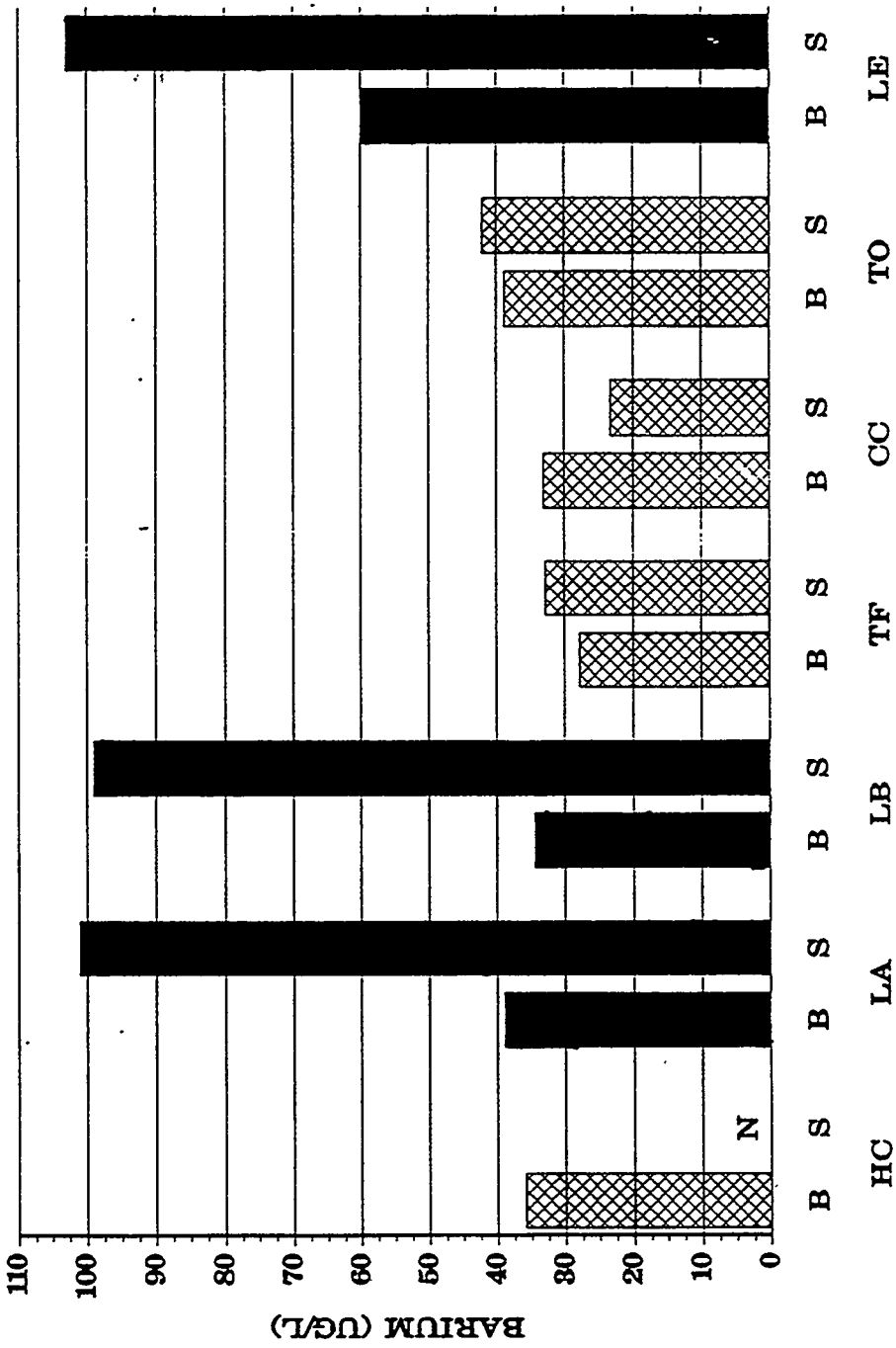


Fig. 3.15. Maximum barium concentrations (µg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

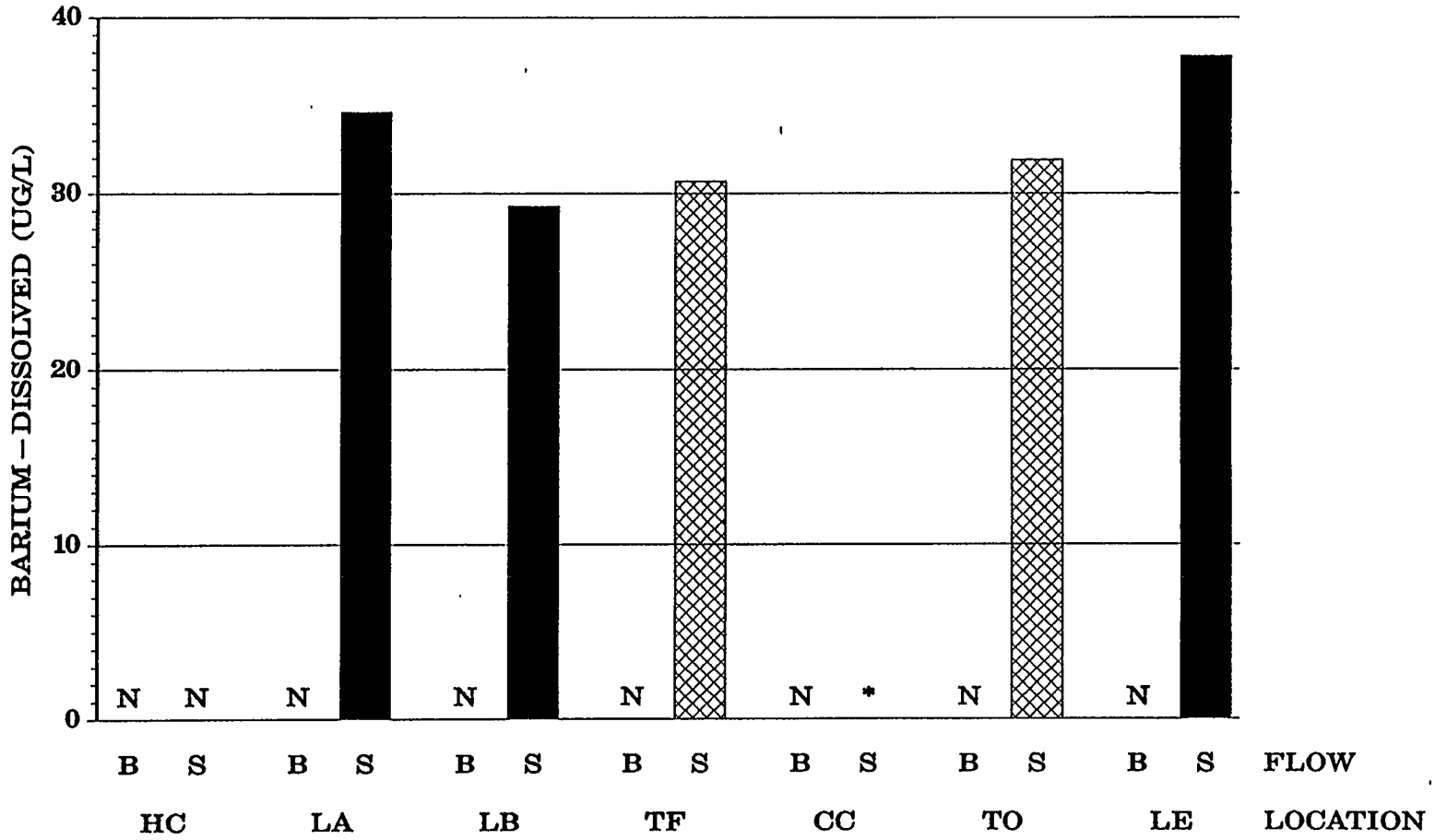


Fig. 3.16. Maximum dissolved barium concentrations (μg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

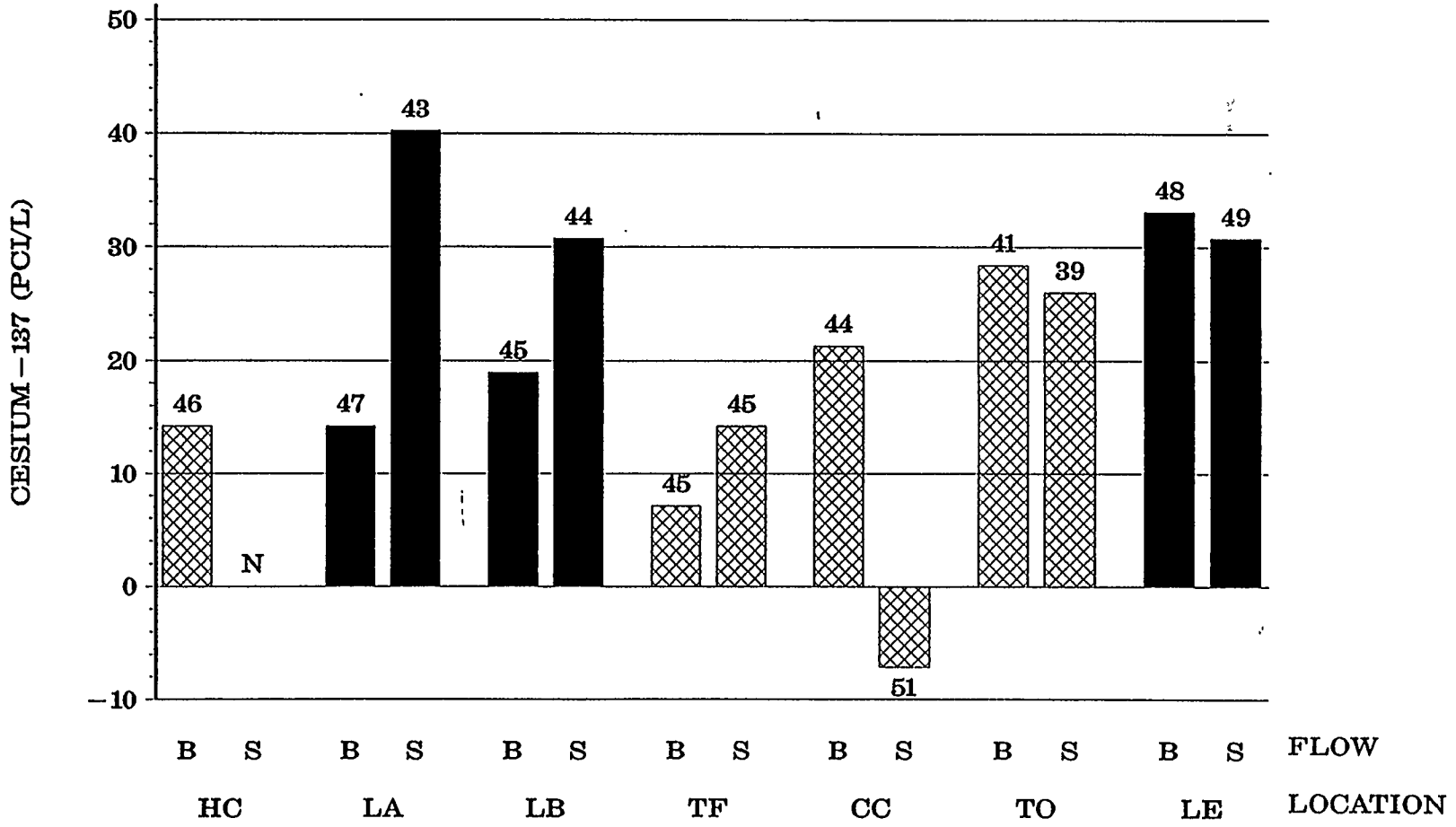


Fig. 3.17. Maximum ^{137}Cs concentrations (pCi/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

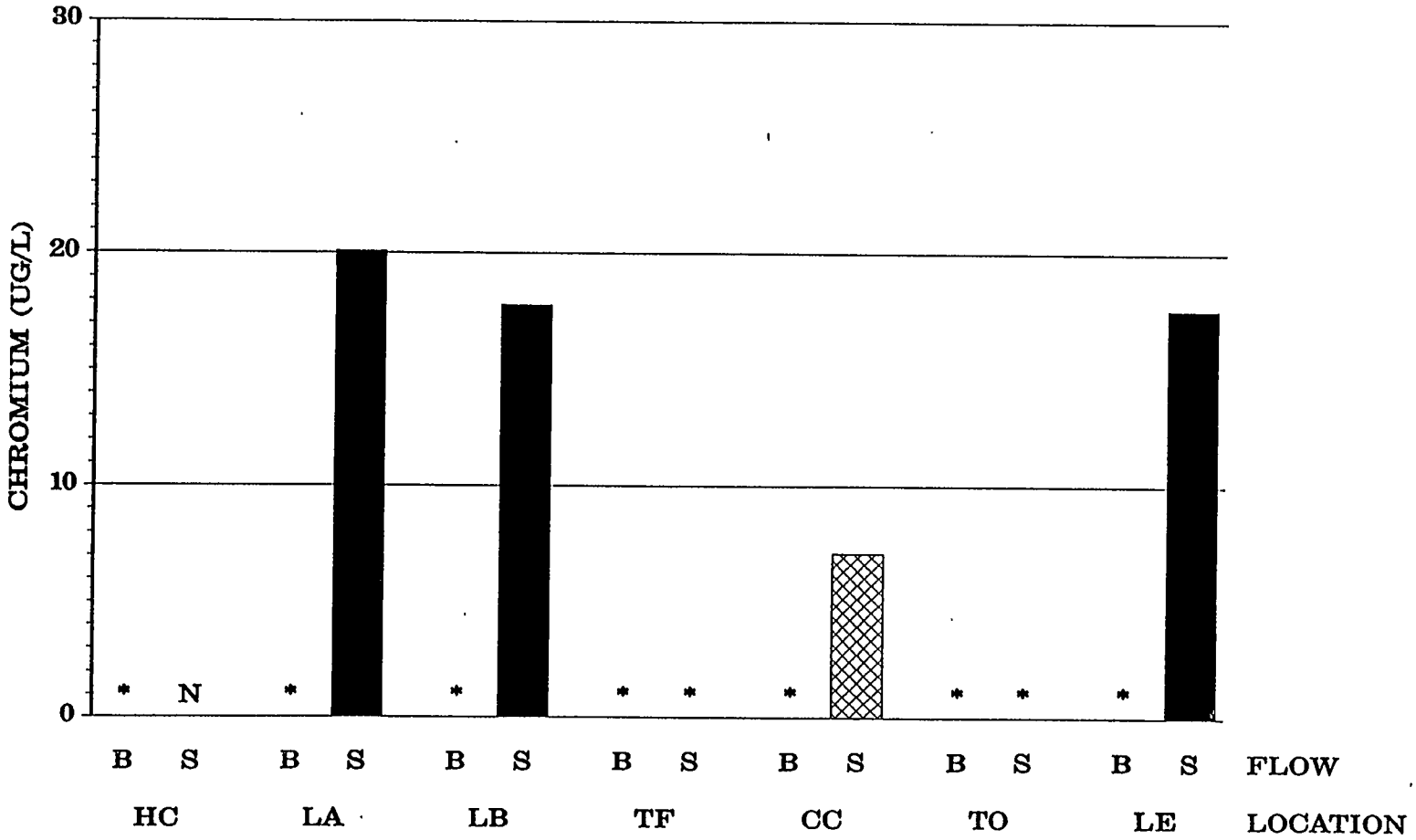


Fig. 3.18. Maximum chromium concentrations (μg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

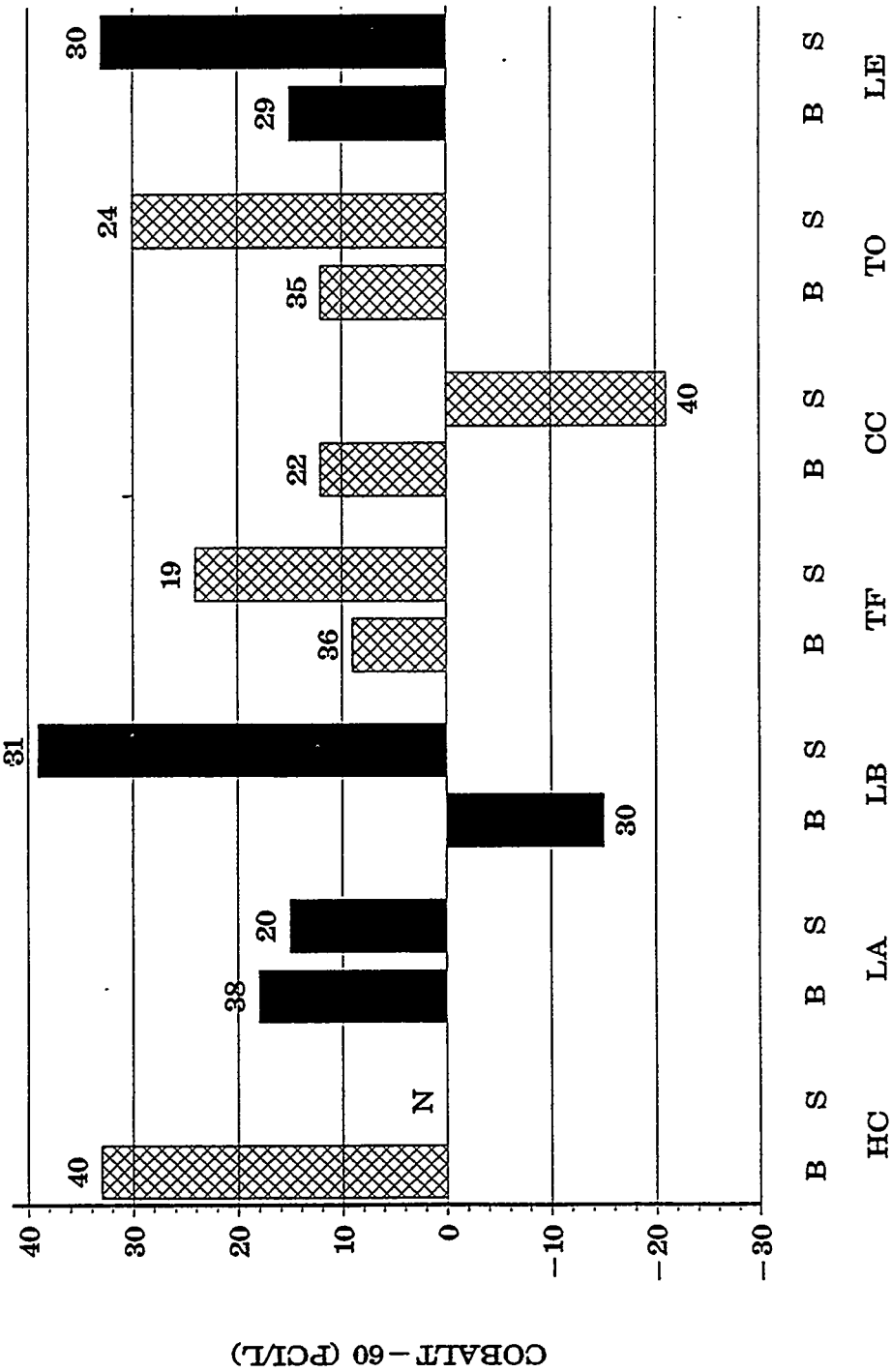


Fig. 3.19. Maximum ^{60}Co concentrations (pCi/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

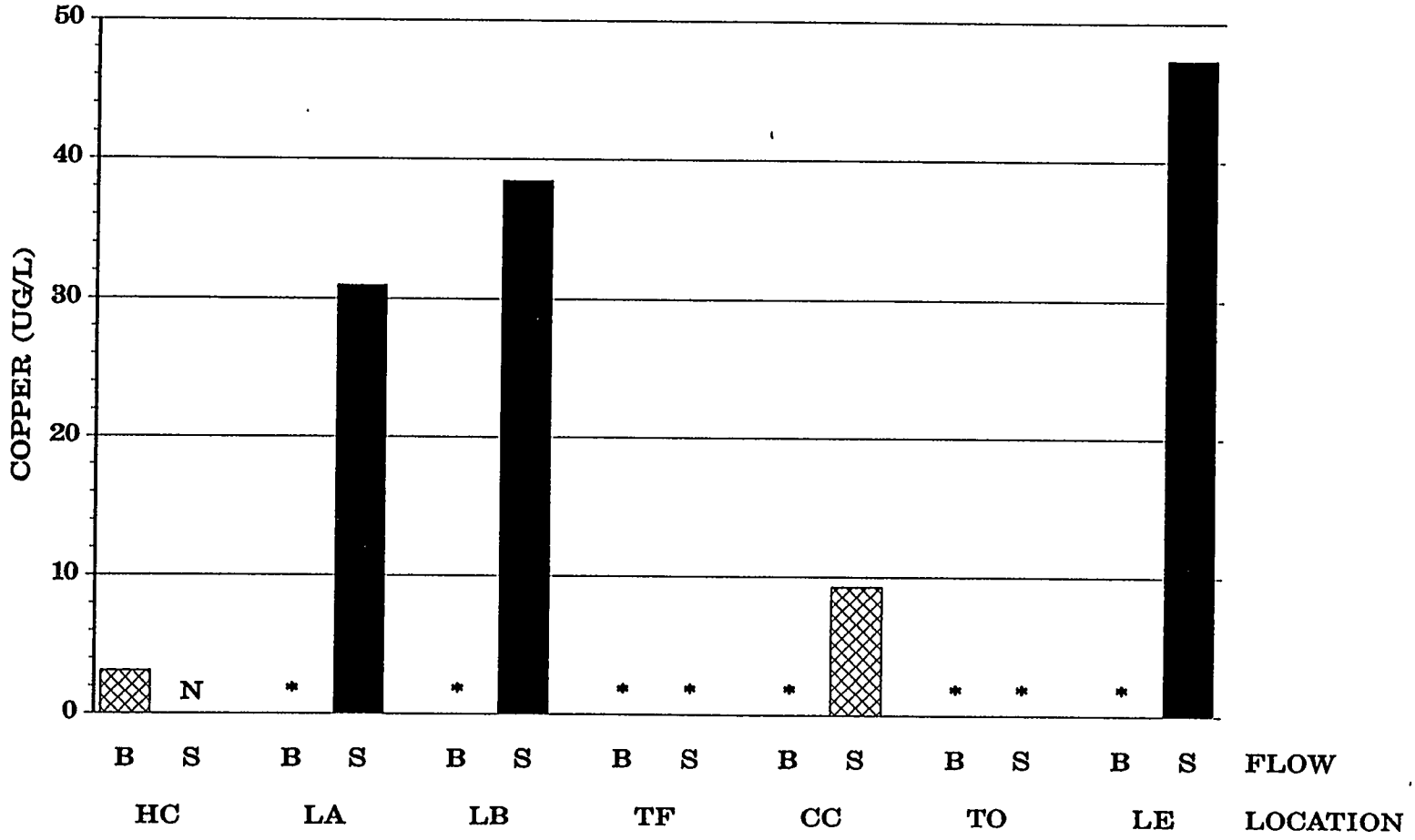


Fig. 3.20. Maximum copper concentrations (μg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

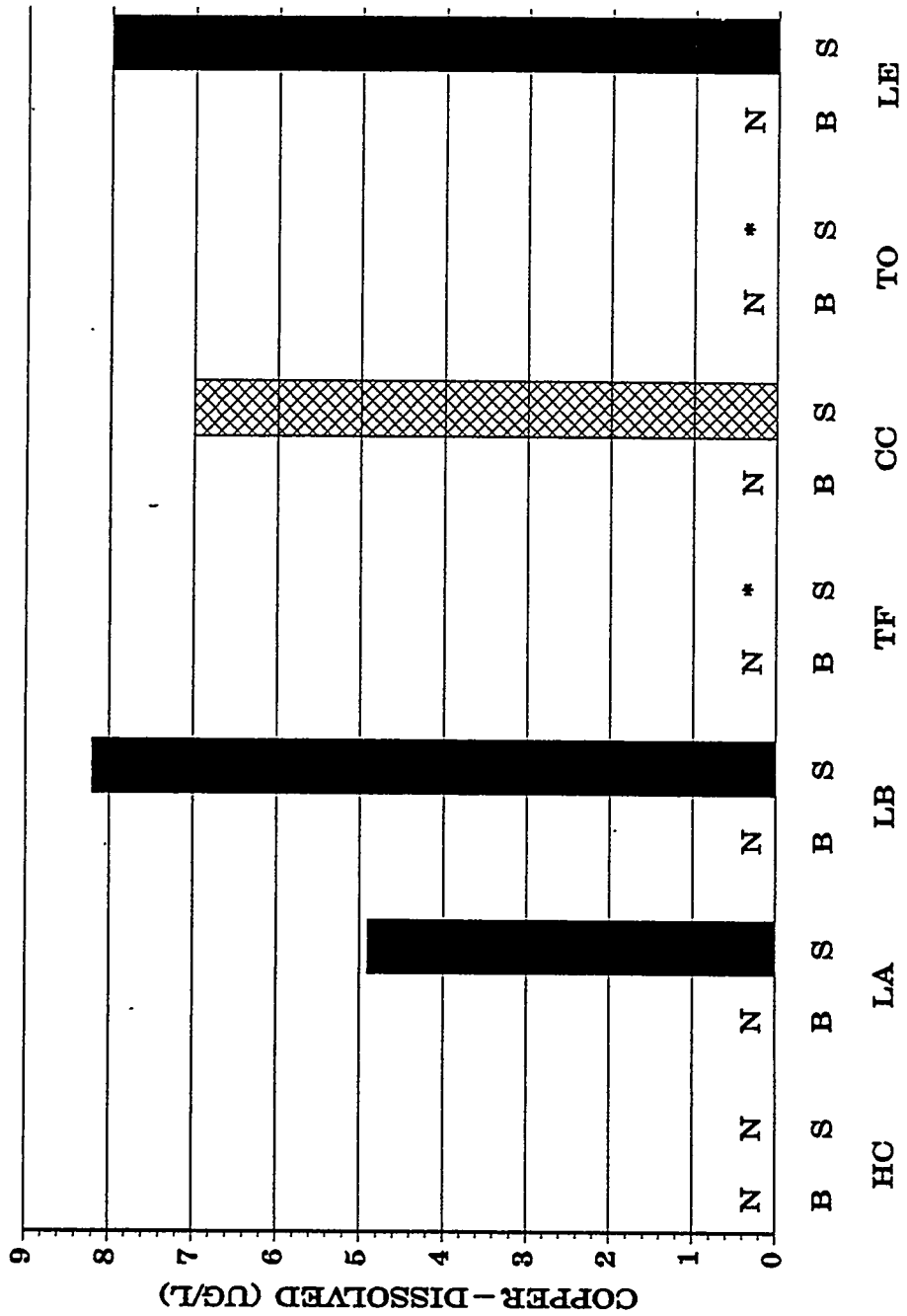


Fig. 3.21. Maximum dissolved copper concentrations (µg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

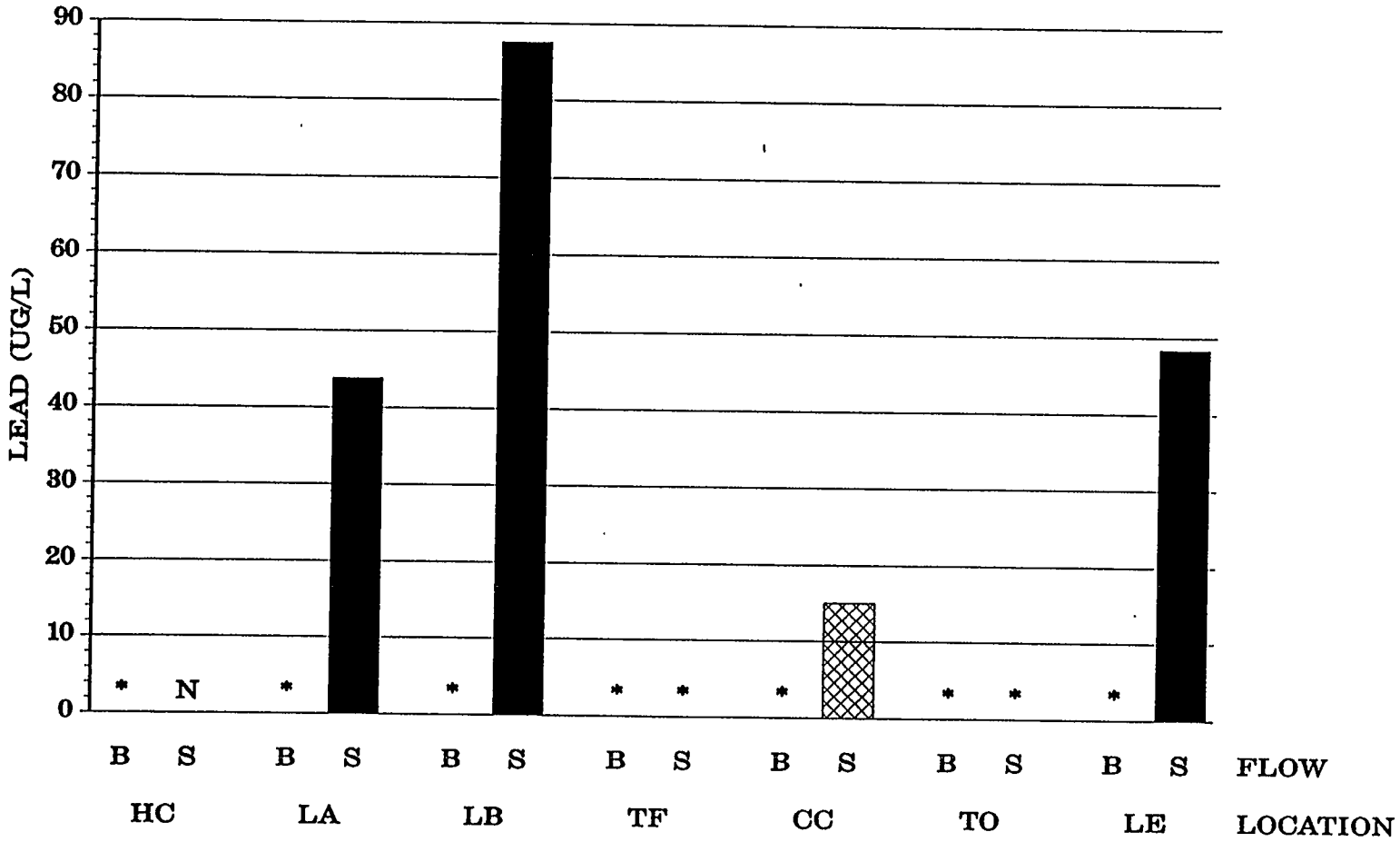


Fig. 3.22. Maximum lead concentrations (μg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

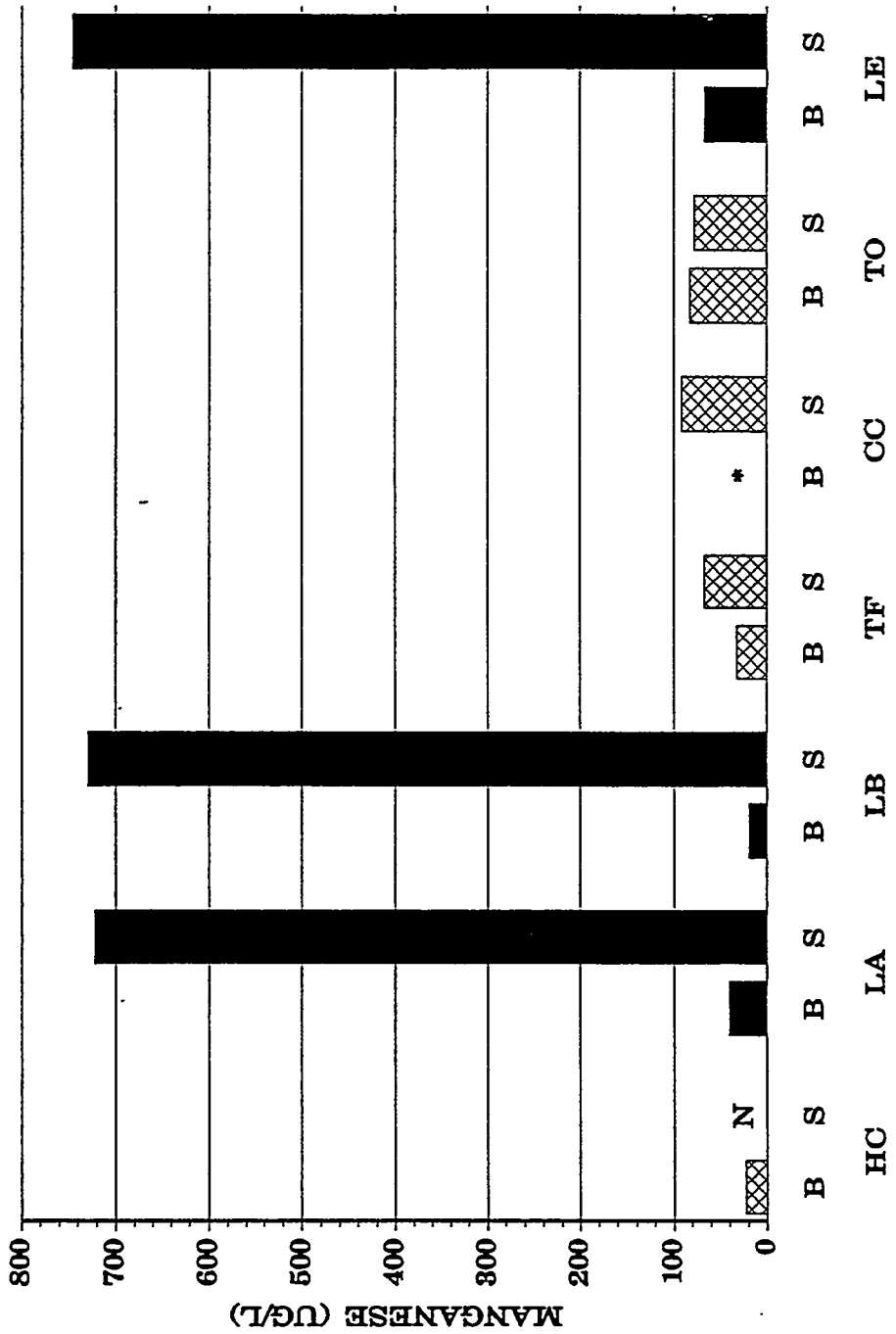


Fig. 3.23. Maximum manganese concentrations (μg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

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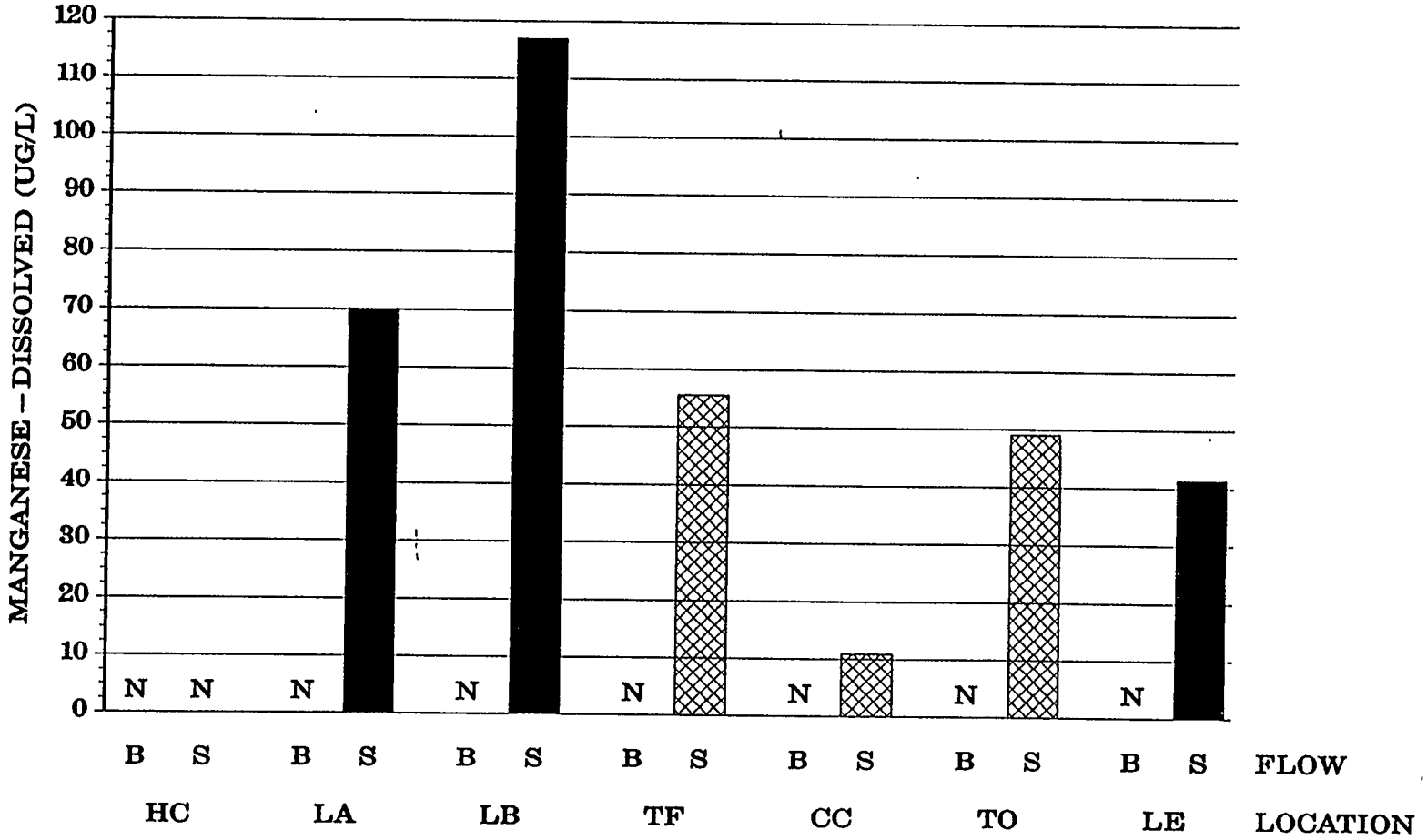

Fig. 3.24. Maximum dissolved manganese concentrations (μg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

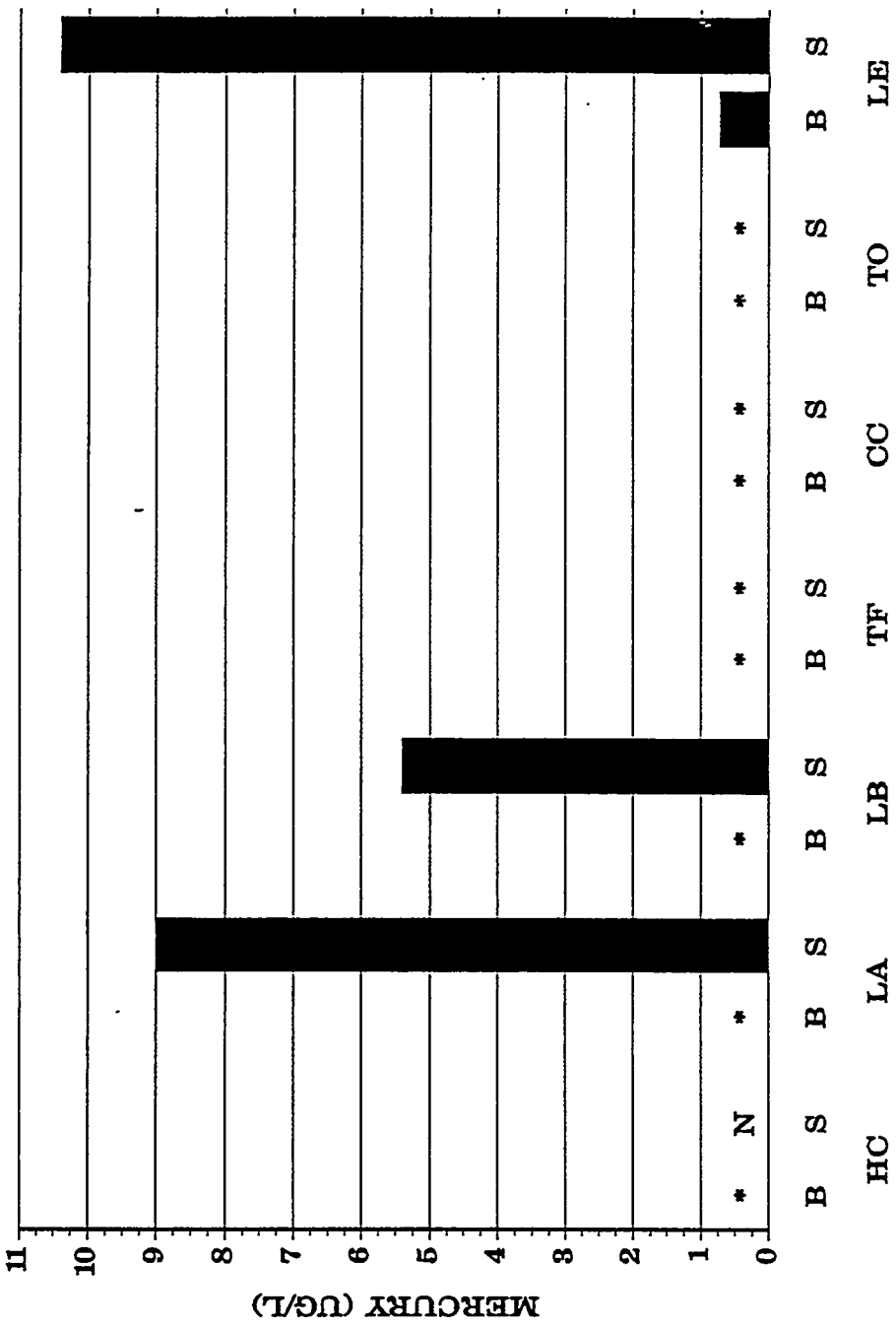

Fig. 3.25. Maximum mercury concentrations (µg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

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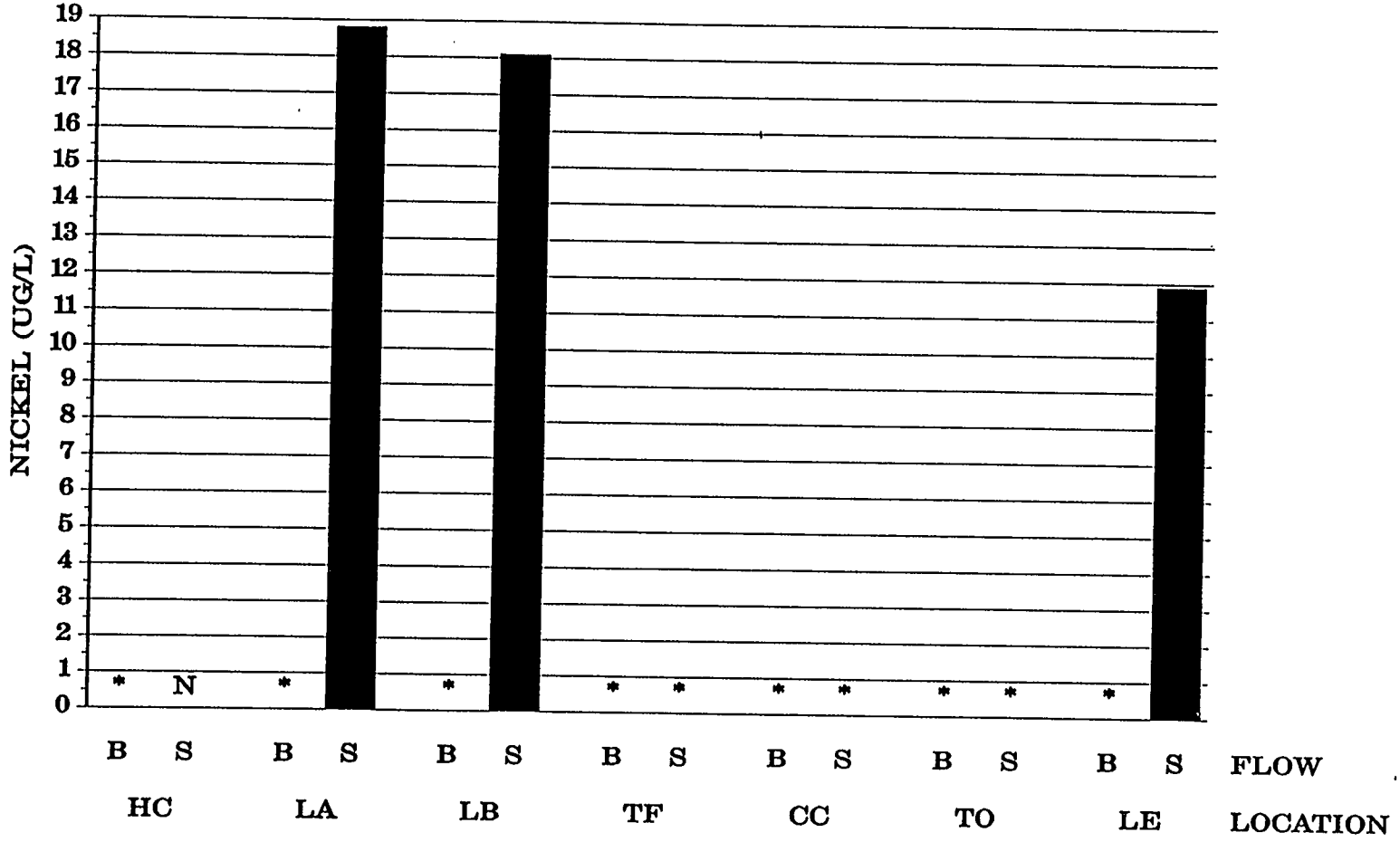

Fig. 3.26. Maximum nickel concentrations (μg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".
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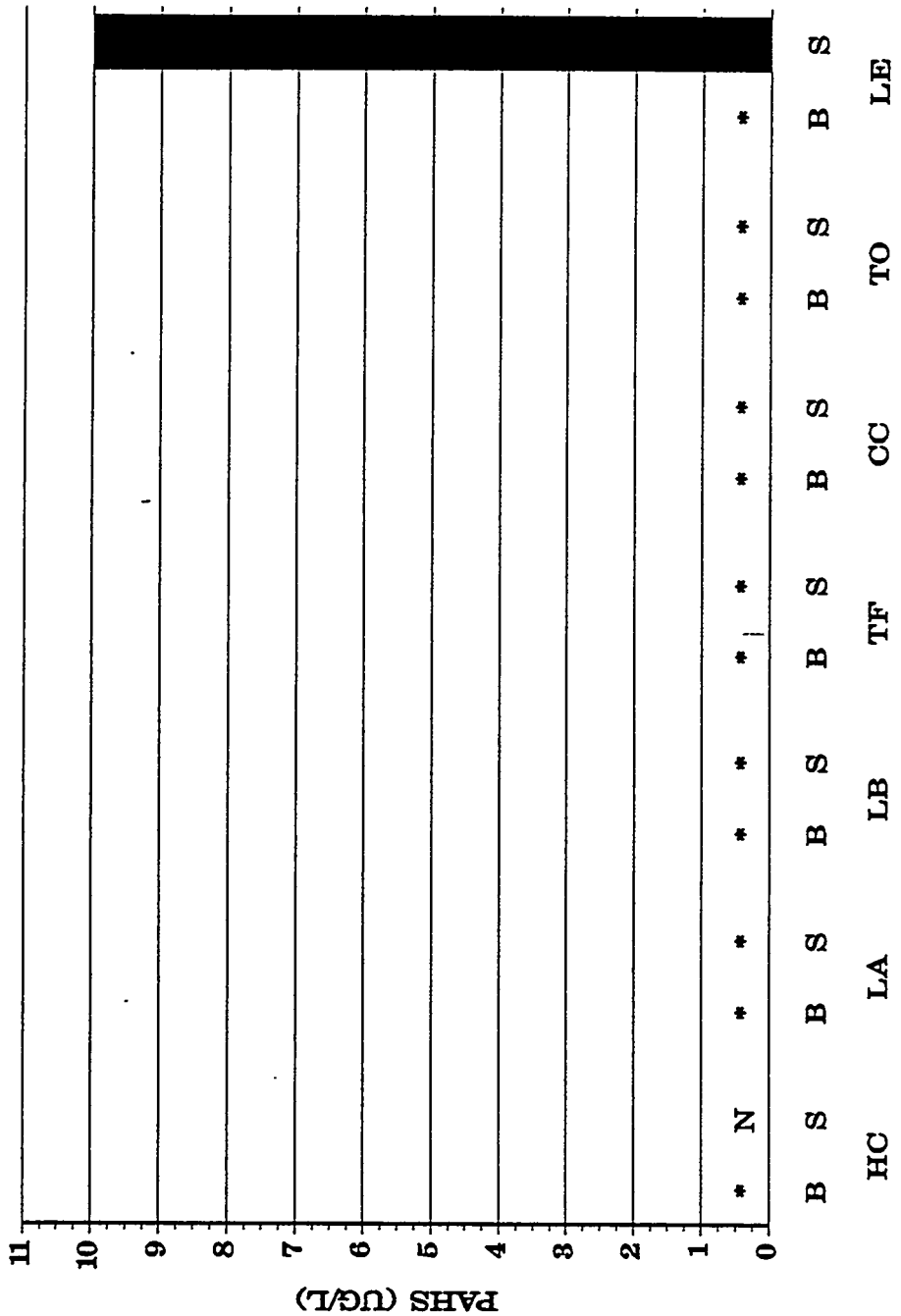

Fig. 3.27. Maximum concentrations (μg/L) of PAHs measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

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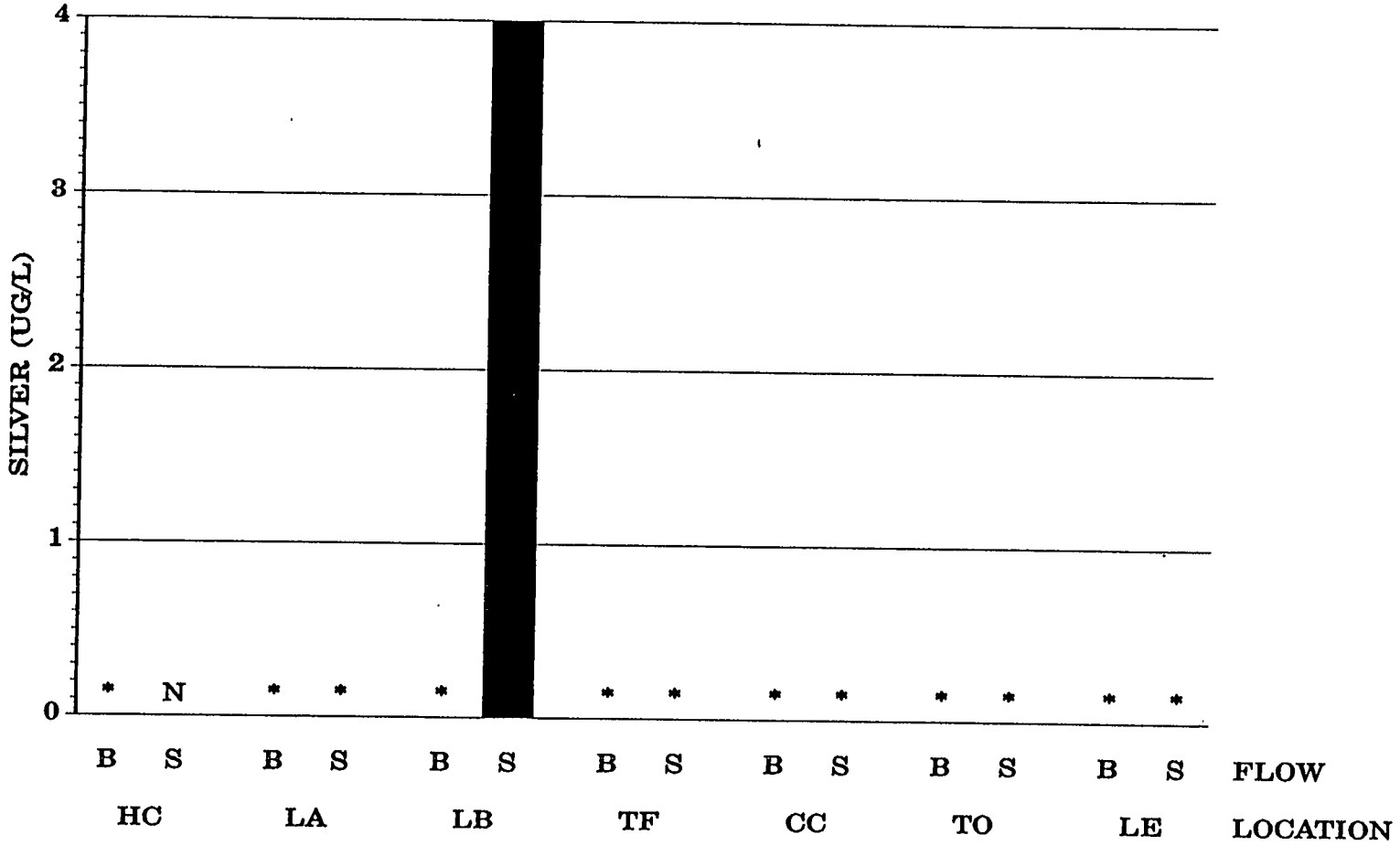

Fig. 3.28. Maximum silver concentrations (μg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

an 'N'.

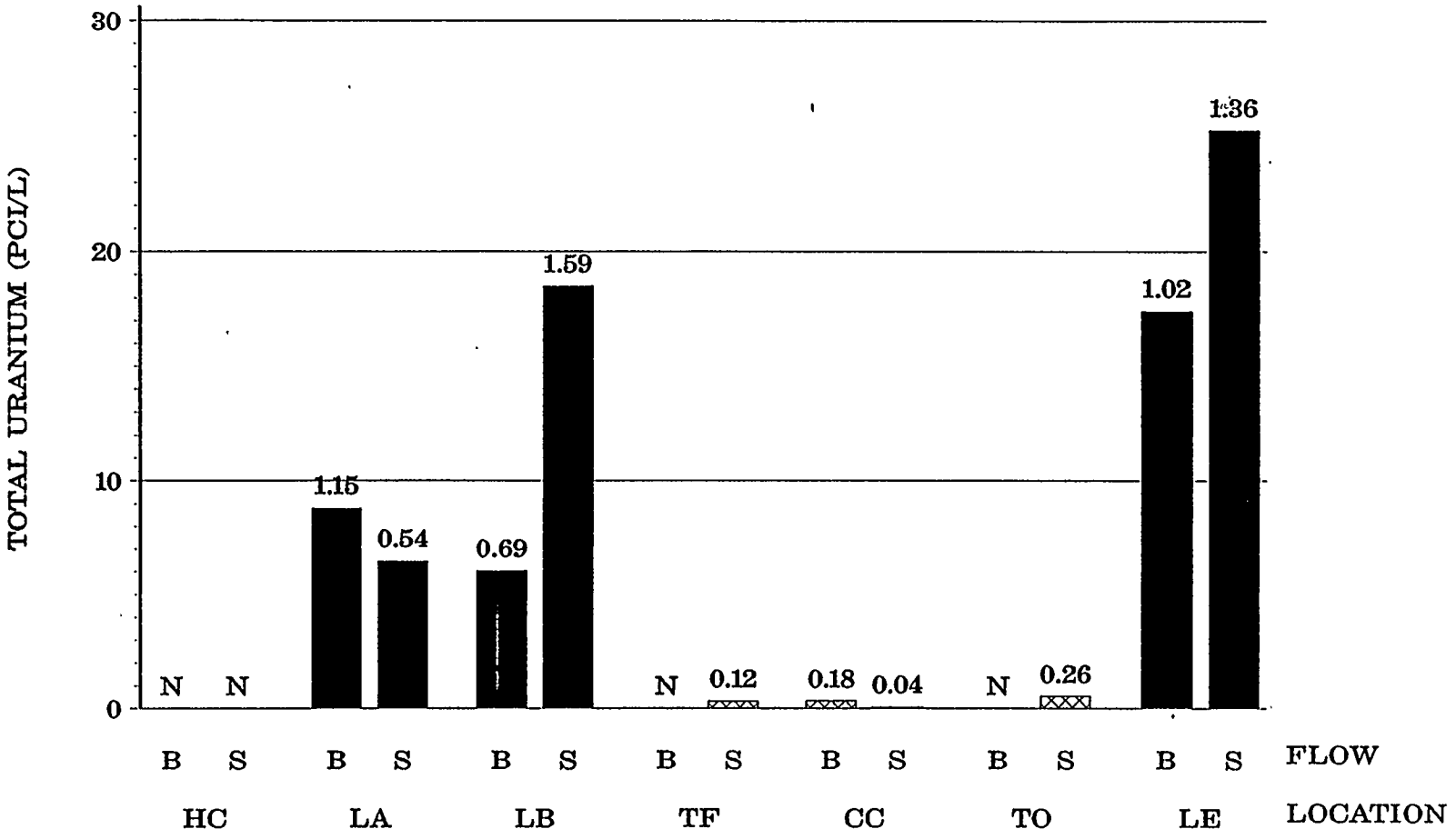

Fig. 3.29. Maximum total uranium concentrations (pCi/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

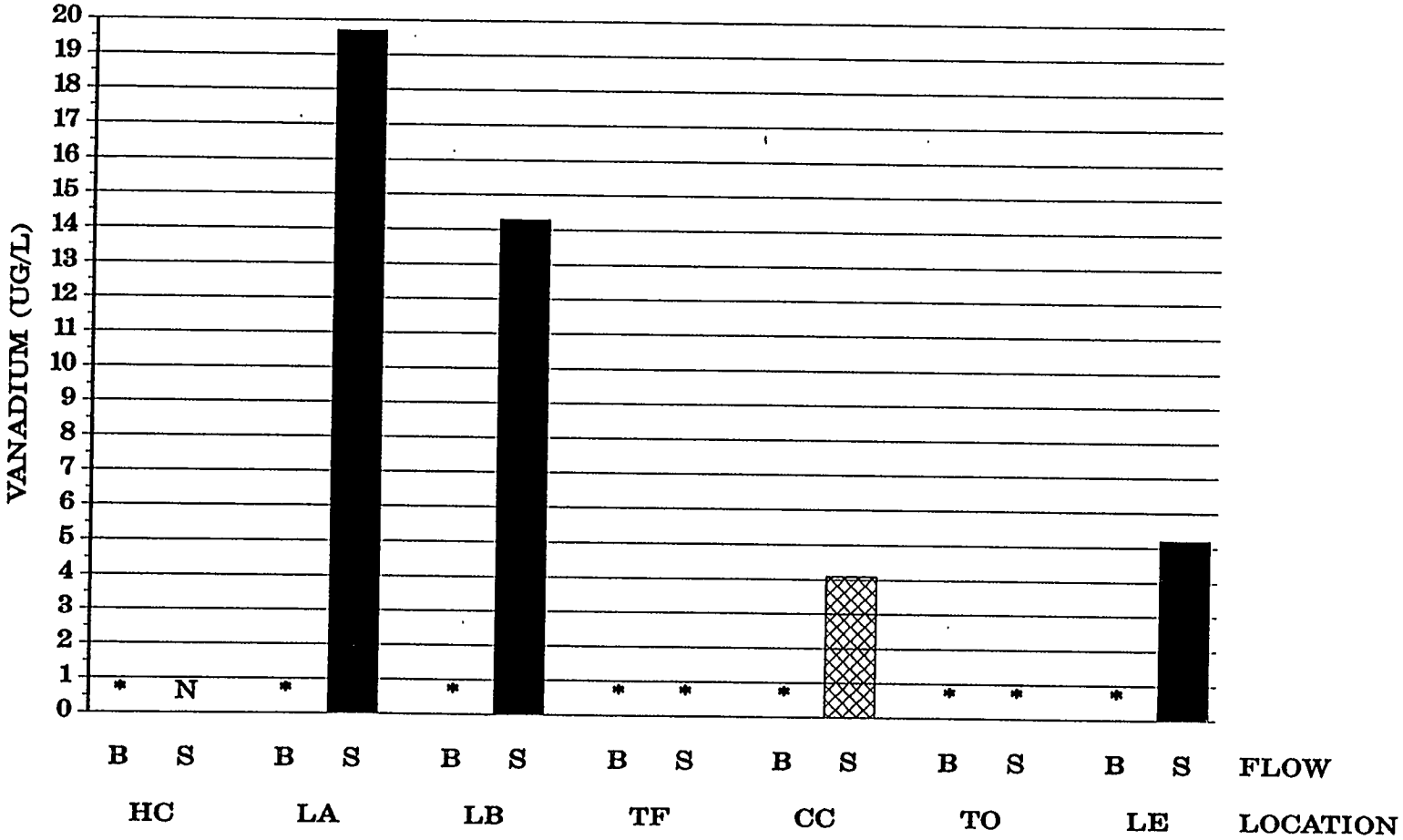

Fig. 3.30. Maximum vanadium concentrations (μg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

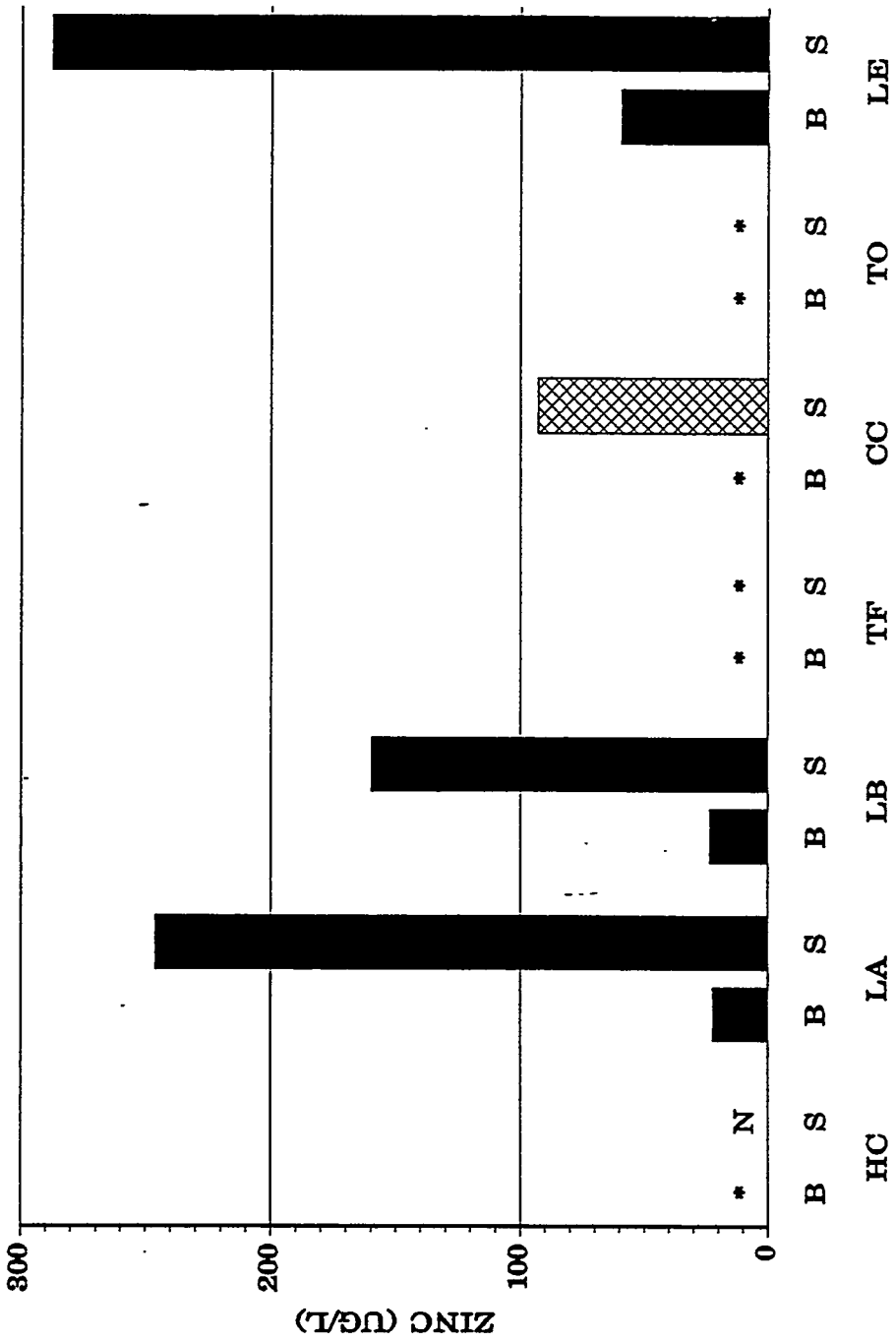

Fig. 3.31. Maximum zinc concentrations (µg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

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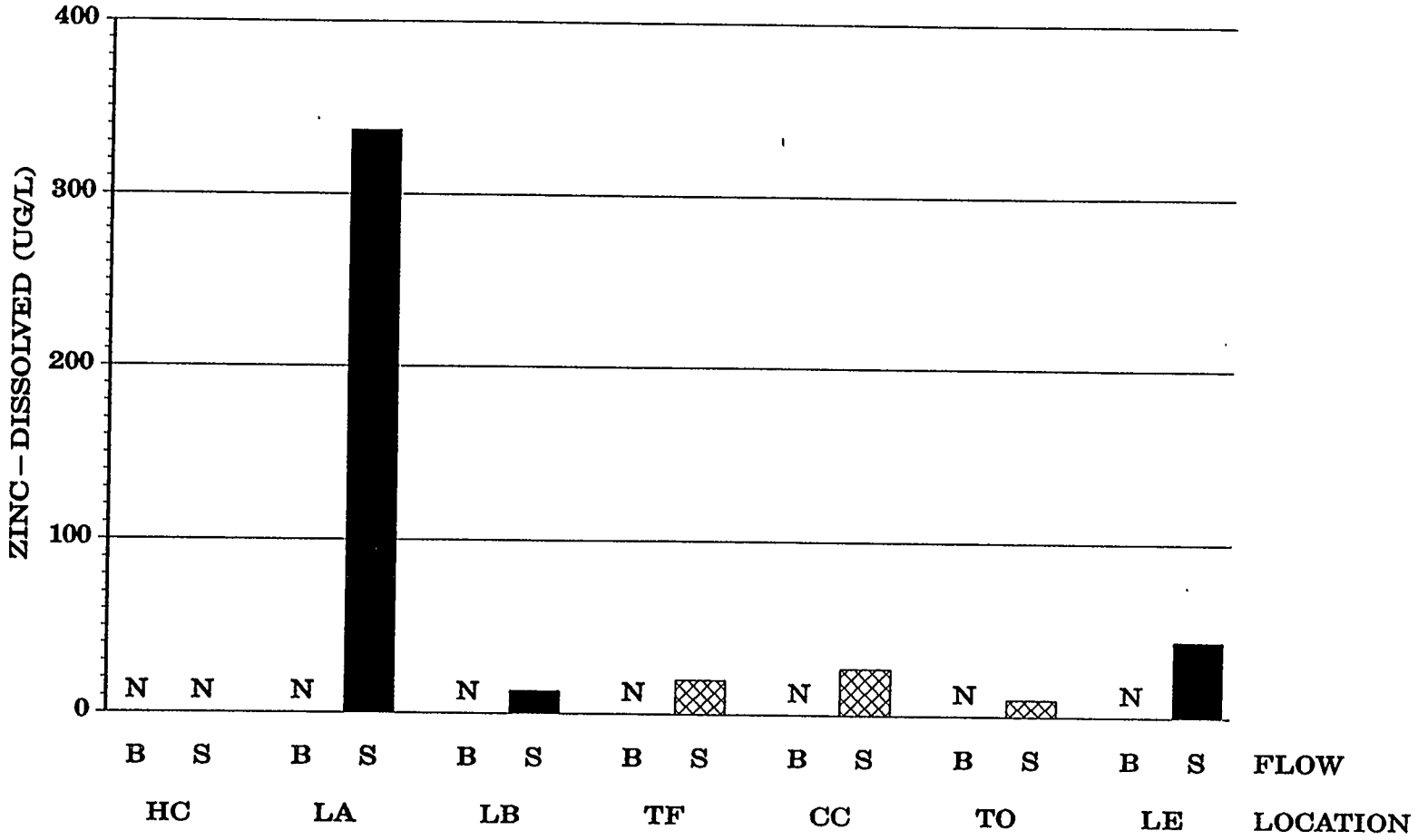

Fig. 3.32. Maximum dissolved zinc concentrations (μg/L) measured at base flow (B) and during storm events (S) in EFPC and its tributaries. Solid bars represent samples from EFPC. Hatched bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N".

dissolved analyses were below the detection limits, indicating that arsenic could be detected as a particle-bound contaminant transported during high-velocity flow resulting from storm events.

Barium (Figs. 3.15 and 3.16) is a common element found in all waters and was noted in similar total quantities in both the base and storm flow tributary samples and the reference sample. Dissolved storm flow concentrations of barium were equivalent to total concentrations at the TF and TO sites. Dissolved barium at LA, LB, and LE exhibited levels equivalent to those in the tributary samples. While total base flow concentrations in the creek were comparable to those in the tributaries, the total storm flow creek samples displayed concentrations 3 to 4 times higher.

Cesium-137 (Fig. 3.17) was shown to be variable at different points in the tributaries and EFPC. However, none of the results can be noted as a detect because the uncertainty for each measurement was greater than the result.

Chromium (Fig. 3.18) was detected in storm flow samples in EFPC and at tributary CC but at none of the other tributaries or any sites during base flow measurements. No dissolved chromium was ever observed above the detection limits, indicating particle-bound transport.

Cobalt-60 (Fig. 3.19) cannot be positively identified at any location for either storm flow or base flow. The uncertainty for each measurement was close to or greater than the result.

Copper (Figs. 3.20 and 3.21) was not detected during base flow at any monitoring sites but was seen at relatively high levels at EFPC sites during storm flow (and the CC tributary at lesser concentrations). Dissolved concentrations were observed at the same locations in the same relative abundances between sites but at only about one-fifth of that measured for total concentrations.

Lead (Fig. 3.22) was seen at the same locations and overall levels as was chromium, but no detects were noted for dissolved concentrations.

Manganese (Figs. 3.23 and 3.24) was measured at relatively high concentrations during storm events at EFPC sites but at much lower levels for the tributaries and during base flow at all the sites. Dissolved concentrations were similar to total concentrations at the tributaries, and dissolved concentrations at EFPC sites were similar to total concentrations during base flow, indicating that storm events mobilized additional particle-bound manganese.

Mercury (Fig. 3.25) was seen only at EFPC locations and only during storm events (except

for LE). Furthermore, mercury levels increased proportionally to flow rates (see Sect. 3.2.1.3). No dissolved mercury was detected. This indicates that storm events mobilized additional particle-bound mercury from the floodplain.

Nickel (Fig. 3.26) was identified in the same manner as mercury but was detected at somewhat higher concentrations.

PAHs (Fig. 3.27) displayed in this graph represent the sum total of all carcinogenic PAHs detected and were only observed at station LE during two storm sampling events. No dissolved PAH analyses were performed.

Silver (Fig. 3.28) was only noted at station LB during a storm event. No dissolved silver was detected.

Uranium (Fig. 3.29) represents the total activity of uranium isotopes and was observed in measurable quantities in EFPC only, during both base and storm flow. Dissolved uranium activity was not analyzed separately.

Vanadium (Fig. 3.30) was detected in the same manner as chromium and lead. No dissolved vanadium was seen.

Zinc (Figs. 3.31 and 3.32) was detected in EFPC at relatively high concentrations during storm flow as compared to base flow. Zinc was detected at all tributaries during storm flow, but only at tributary CC during base flow. Dissolved concentrations of zinc are relatively low except for an anomaly at LA. The reliability of these results as a true measure of dissolved concentration is questionable.

Summary. With the exception of measurable quantities of isotopic uranium, no contaminants were detected at levels exceeding risk-based criteria during base flow conditions for surface water. Consequently, no change is noted along the length of the creek, even in areas of floodplain contamination. During base flow, measurable quantities of isotopic uranium were detected in EFPC and Bear Creek, but not in the tributaries. During storm conditions, several-fold increases of contaminants are noted in EFPC; however, the majority of the storm-related contamination is associated with particle-bound constituents most likely derived from the floodplain. Mercury was observed during storm flow, and only in the total analyses (suggesting particle-bound transport). PCBs were absent during both base flow and storm flow, and PAHs were detected at the outfall of Lake Reality during storm-event sampling. The only radionuclide that could be detected with certainty during storm flow was isotopic uranium. Noteworthy is the

presence of chromium, copper, lead, vanadium, and zinc in the storm flow samples from the Civic Center tributary.

3.2.2 Sediment Data

3.2.2.1 Scope of investigation

Historical Data. Previous investigations on sediment characteristics in the EFPC study area include Van Winkle et al. (1984), the TVA instream contaminant study (Tasks 2 and 3) (1985), and the ongoing ORR Environmental Monitoring (Energy Systems).

In May 1982, ORNL and the Y-12 Plant conducted a 1-month study to assess the concentrations of total mercury in samples from a variety of media in the EFPC and Bear Creek drainage systems (Van Winkle et al. 1984). The investigation also included research into the possibility of current mercury releases from the Y-12 Plant. Samples of sediment, fish, moss and liverwort, and pasture grass were collected at several locations along EFPC and Bear Creek. A sediment core was taken from NHP to determine the historical record of mercury contamination in the pond.

The NHP core was collected in the central portion of the pond and represented the sediment horizon (~1 m) that was deposited from 1973 to 1982. The core was cut into 19 5-cm sections. Sediment samples were collected from the upper surface layers (1 cm or less) at eight EFPC sites, six Bear Creek sites, and two control sites. The samples were wet-sieved and dried.

Total mercury concentrations in the sediment core from NHP were found to decrease over time. The highest concentration (300 μg/g) was measured at the bottom of the core, while sediments in the upper portion had mercury concentrations of 100 μg/g. Van Winkle et al. (1984) concluded that the amount of mercury entering NHP was directly related to storm run-off and believed that the decrease in mercury entering the pond with time was related to the absence of high-runoff-producing storms. Mercury concentrations in fine-grained sediments (<0.125 mm) in EFPC immediately below NHP were reported to be similar to concentrations in the surface sediments of NHP, supporting the hypothesis of a common source for mercury in the creek and pond. Similar concentrations also indicated that mercury was still being lost by the Y-12 Plant and was not completely trapped by NHP. Mercury concentrations in the sediment decreased downstream, indicating dilution of the contaminated sediment with uncontaminated sediment from tributary drainage entering EFPC. Mercury concentrations in fine-grained sediment tested at all stations in EFPC exceeded background by a factor of 60 or more.

TVA's Task 2 involved the analysis of 394 surface-layer and core sediment samples from 130 locations in the channel and floodplain of EFPC; this task was the most inclusive study involving analyses for metals (including mercury), radionuclides, pesticides/PCBs, and organics (see Map 5). (TVA used the general term sediment, while this study further divided sediments into soil and suspended sediment.) The samples were collected between June and November 1984. Samples were analyzed from 122 cores collected along 30 transects in the floodplain of EFPC. Between September 18 and 25, 1984, instream surface sediment samples were collected at 18 of the 30 transects, plus an additional location. Additionally, 16 surface-layer samples [i.e., upper 10 to 15 cm (3.9 to 5.9 in.) of sediment] were selectively collected instream from the channel bed of EFPC to obtain the fine sediment size fractions. All EFPC samples were obtained using a metal scoop. Core sediment data will be discussed in Sect. 3.2.5 (Soil Chemical Data).

In EFPC sediments, seven metals (mercury, arsenic, cadmium, lead, nickel, silver, and zirconium) were found at levels at or exceeding the background concentrations from Clinch River and Norris Reservoir and/or the analytical detection limits. TVA found mercury to be the most notable parameter, with the highest concentrations measured in the floodplain and channel of EFPC. Concentrations ranging from 100 to 1800 mg/kg were detected in the upper stream reach floodplain (from approximately Lake Reality to E 49,800 ft), with concentrations generally decreasing downstream. TVA concluded that 75% of the mercury is located in the upper third of the stream, with the majority located between E 50,040 ft and E 56,100 ft. Mercury concentrations were generally higher in core samples from the floodplain than in surface samples from the stream channel. TVA estimated that there are ~453,120 m^3 (16 million ft^3) of mercury-contaminated sediment in which the mercury concentration exceeds 5.0 mg/kg and that the sediment contains an estimated 77,112 kg (170,000 lb) of mercury.

Ten of 54 priority pollutant organics analyzed [total PCBs, fluoranthene, bis(2-ethylhexyl) phthalate, pyrene, phenanthrene, benzo(a)pyrene, chrysene, anthracene, benzo(a)anthracene, and total phenols] exceeded the analytical detection limit. Because these compounds are not naturally occurring, and because standards, criteria, and background data are not available, TVA suggested that their presence at any level warrants further investigation.

Sediment analyses for radiological parameters showed that isotope levels in EFPC were no higher than in other streams involved in the study (Bear Creek and White Oak Creek), but increased levels of uranium and uranium decay series radioisotopes were identified in EFPC compared to background sites at Clinch River and Norris Reservoir. In general, the results for EFPC indicate the co-occurrence of numerous sediment contaminants, with the greatest number of correlations between metals and between metals and radionuclides.

Task 3 involved analysis of data from historic stream flow records and three storm flow events; TVA calculated that ~15,422,140 kg (17,000 tons) of sediment and 226 kg (500 lb) of mercury are exported annually from EFPC. A comparison of mercury loads between sampling stations suggests that most of the exported mercury is either contributed by the highly contaminated sediment identified in the watershed or discharged directly from NHP. At the estimated net export rate of ~192 kg (425 lb) per year, TVA calculated that 400 years would be required to deplete the estimated 77,110 kg (170,000 lb) of mercury in the channel and floodplain.

Field observations and computer simulations indicated that the floodplain is stable, which will allow most of the contaminated sediment and mercury to remain in the floodplain for many years, serving as a continual source of mercury to downstream waters. Improper disturbance of the floodplain could substantially increase erosion and the downstream transport of mercury.

EFPC RI Sediment Data. The EFPC RI considered creek sediments and surface water as complementary lines of investigation to determine contaminant patterns and to characterize sources. While surface water analyses provide an instantaneous snapshot of ongoing contributions to the creek, sediments can provide a time-integrated picture of historical contaminant contributions. For example, a source of sediments to EFPC prior to 1980 was the back-washing of sand filters at the water treatment plant on Pine Ridge. This practice ceased after 1978 (Loar et al. 1989). Furthermore, sediments can act as a sink to concentrate otherwise disperse contaminants and allow their detection. Investigation of the sediment media took place during both phases of the EFPC RI. At each location where surface water samples were collected, sediment samples were also collected (see Table 3.5). In addition, sediment samples were taken at every significant tributary to EFPC and at numerous sites along EFPC (also at Hinds Creek). Sediments were used in the same manner as surface water: to estimate contribution from watersheds adjoining EFPC, to assess changes in contaminant levels from the input at Lake Reality to the output at the confluence with Poplar Creek, and to assess impacts of contaminated hot spots within the floodplain on nearby sediment accumulations. Sediments also require characterization of their distribution and contaminant concentrations within the creek.

The results show that creek sediments contain the same COCs as floodplain soils but at lower concentrations. The pattern of contamination is not as predictable as in soil, however, presumably because of the transient nature of sediments within the creek. Concentrations noted for cadmium, ^{137}Cs, copper, mercury, nickel, and uranium are significantly higher in the creek than in the tributaries. The logical inference is that these analytes (and probably others) have a Y-12 Plant source. Concentrations of arsenic, cadmium, copper, mercury, nickel, and lead are

higher in the upper portions of EFPC than in the lower sections of the creek. PAHs and PCBs are dominant in the upper one-third of the creek, essentially in areas of commercial development.

3.2.2.2 Lake Reality

Source Area Characterization. A set of sediment samples was taken from Lake Reality to characterize the source term into EFPC. Historical information documented high mercury concentrations in the lake sediments, and an evaluation of their contribution to the contaminant load was necessary. Five deepwater sediment samples were taken on November 7, 1990. Four of the sediment samples were obtained from various parts of the lake; the fifth sampling location was at the upstream intake channel into Lake Reality. The samples were generally described as fine to medium-grained with a grayish-brown color. The degree of fine material varied between samples, but the fifth sample from the intake channel was described as much coarser, containing charcoal or coal-like black material. Each sample was submitted for analysis via the Toxicity Characteristic Leaching Procedure (TCLP) (40 CFR Part 261, Appendix II) for the required set of 8 metals, 10 volatile organic compounds, 17 semivolatile compounds, and 8 pesticides and PCBs. The result for each analyte for each sample was below the detection limit of the analytical method. Total analyses for contaminants were not performed.

Summary. An inference could be made that if geochemical conditions simulated by the TCLP are comparable to conditions in Lake Reality, sediments are not a source of contamination to the surface waters of EFPC. It must be noted, however, that TCLP may not be representative of the complex conditions and seasonal changes exhibited in Lake Reality and a more appropriate conclusion is that the lake sediments are a possible source.

3.2.2.3 EFPC

Sediment Collection. Phase Ia sediment sampling consisted of seven sites within EFPC and 21 tributaries to the creek. Instream locations (see Fig. 3.33 or Map 4) were selected to provide information on inputs (LE) and outputs (LA) to and from EFPC. Intermediary locations were chosen to observe the effects of three known contamination hot spots within the floodplain soils (NO, BR, and WA); and two other points: LC, downstream from the Oak Ridge Sewage Treatment Plant and LB, upstream from the Bear Creek tributary which drains the west end of the Y-12 Plant.

Sediment from each significant tributary to EFPC was also sampled. With only minor exceptions, the tributaries are identified as TA through TR moving upstream (see Map 4). Three sites were selected to characterize potential runoff of pesticides, herbicides, and petroleum

hydrocarbons from residential and commercial areas of Oak Ridge. They were: the Gum Hollow Branch (golf course and residential, TF); an unnamed tributary draining both residential and commercial areas and entering EFPC near the Oak Ridge Civic Center (CC); and Gamble Branch draining the Gamble Valley residential area. A secondary site for urban runoff measurements was a tributary that drains a mostly residential area near the Bruner's shopping center (TL). In addition, sediments were collected from the Hinds Creek study area (HC_{2A} and HC_{2B}), for comparison with a noncontaminated reference site similar in nature to EFPC.

Phase Ib was designed to determine the extent and distribution of contamination, given the transient nature of sediments within EFPC. Twenty-five composite samples, each representing 600 m of the creek, were obtained (see Fig. 3.33 or Map 4) by establishing transects for soil sampling every 100 m (328 ft), for a total of 159 transects, and sampling every other transect; the samples were composited, homogenized, and subsampled for analysis. As an example, samples were taken at Transects 001, 003, and 005; the three field samples were composited, and a laboratory sample labeled 003 was analyzed to represent a 600-m stretch of the creek. Refer to Table 3.18 for a cross reference between administrative grid coordinates, transect numbers, land use segments, tributary locations, and geographic features along EFPC.

Additionally, a sample was obtained following an unexpected encounter with obvious creek sediment contamination. While this was an isolated discovery, its occurrence with such high contaminant concentrations deserves some discussion. On May 6, 1991, a drilling contractor for the EFPC RI moved a backhoe across the creek at the BR site. As the heavy equipment moved across the creek, it exposed a dark-colored, viscous, oily substance at the edge of the creek bed and on the far bank. The material had a very strong odor similar to diesel or fuel oil and contained many partially decayed leaves and twigs. The substance formed a thin oily film on the surface of the water. Samples were taken of the substance (Sample BR0199019) and the water (CC0101041) after its release. Both samples were analyzed for volatile and semivolatile organic compounds, pesticides, and PCBs on EPA's target compound list and for petroleum hydrocarbons, radionuclides, and metals. The substance was also subjected to the TCLP, and the extract was analyzed for metals, semivolatile organics, pesticides, and herbicides. Results of analyses revealed that the oily substance contained:

Table 3.18. Cross reference between transects, segments, and coordinate system

Northing/easting coordinates	Transects #	Segments	Tributaries	Geographic features
E 18371 - E 19682	003 (001-005)	9	0	Confluence w/Poplar Creek
E 20339 - E 21323	009 (007-010)	9	0	DOE Reservation
E 21652 - E 22636	012 (011-014)	9	BC	DOE Reservation
E 23291 - E 24276	018 (016-019)	9	TA	DOE Reservation
E 24933 - E 26244	023 (021-025)	9	0	DOE Reservation
E 26901 - E 28213	029 (027-031)	9	TB	DOE Reservation
E 28870 - E 30182	035 (033-037)	9	LB	DOE Reservation
E 30510 - E 31166	038 (038-040)	9	TC	DOE Reservation
E 31822 - E 33135	044 (042-046)	9	TD	DOE Reservation
E 33791 - E 35103	050 (048-052)	9	TE	Gibson Property
E 35759 - E 37072	056 (054-058)	9	TF	Gibson Property
E 37728 - E 39040	062 (060-064)	8	0	Grand Cove Subdiv.
E 39696 - E 40681	067 (066-069)	8-7	LC, TQ, TG	Sportsman Assoc.
E 41337 - E 42321	073 (071-074)	7	TH	Sportsman Assoc.
E 42977 - E 44290	078 (076-080)	7	TI	Turtle Park
E 44946 - E 45930	083 (082-085)	7	0	Jackson Property
E 46586 - E 47898	089 (087-091)	7	0	Green Property
E 48555 - 49867	095 (093-097)	7-6	TJ	Wilshire Subdiv.
E 50523 - E 51507	100 (099-102)	6-5	0	Sturm
E 52164 - E 53476	106 (104-108)	5-4	TL	Sturm, Bruner's
E 54132 - E 55444	112 (110-114)	4	0	City Property
E 56101 - E 57413	118 (116-120)	3	TM	Tennis Courts
E 58069 - E 59381	124 (122-126)	2	TN	Robertsville Jr. H.S.
N 38713 - N 37405	134 (132-136)	2	0	Along Illinois Ave.
N 36749 - N 35437	140 (138-142)	2	TO, TP	Tulsa Road
N 34781 - N 33468	146 (144-148)	1	0	NOAA Site
N 32812 - N 31499	152 (150-154)	1	TR	

- petroleum hydrocarbons - 22,000 mg/kg (2.2%);
- mercury - 2240 ppm;
- PCBs:Aroclor-1248 - 2200 ppb;
  Aroclor-1260 - 2800 ppb;
- PAHs: phenanthrene, fluoranthene, and pyrene - detected;
- TCLP results - below reporting limits; and
- VOCs - not detected.

Volatile and semivolatile organic compounds, herbicides, petroleum hydrocarbons, and all PCBs were below detection limits for the water sample. Radionuclides were noted at levels similar to other analytical results for EFPC water samples. Total mercury concentration was 53.6 ppb, but dissolved mercury was not detected.

The most likely explanation of this occurrence is that the substance is composed of discarded oil from Y-12 and/or commercial businesses. It acted as a sink by concentrating the mercury and PCBs over time. The BR site is downstream of both a commercialized reach of the creek and an electrical substation. Elevated PCB concentrations also were observed in the composite sediment samples (#118 and #124) immediately downstream of the same substation.

A similar material was possibly noted at the NO site but was not confirmed by analysis. This site was reported to lack the odor detected at the BR site. No other reports have been made of similar substances, but it is likely that oil accumulations exist in areas with thick sediment piles.

3.2.2.4 Evaluation

Tables 3.19, 3.20, and 3.21 show only the analytes detected for the creek sediments, reference area (HC), and tributaries during both phases of the investigation. The tables allow a statistical review to be performed for each analyte. The tables list, by analyte, the number of detects out of the number of analyses performed; the average detection limit for all of the analyses; the minimum, average, maximum, and standard deviation for the group of analyses that had detections greater than the detection limit; and the overall mean for every analysis where results below the detection limit were considered for evaluation purposes to have a value of zero (0). The right-hand column lists the counting uncertainty for radionuclides.

A visual appreciation of the contaminant distribution and probable source can be gained by reviewing Figs. 3.34a and b through 3.50a and b and Map 4. The first graph of each set (a)

Table 3.19. EFPC Phase Ia and Ib results for sediment mean contaminant concentrations

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (< DL = 0)	Radiation counting uncertainty of mean
Aluminum	mg/kg	35/ 35	.	3800	8030	17200	3230	8030	.
Arsenic	mg/kg	35/ 35	.	1.6	4.55	13.5	2.5	4.55	.
Barium	mg/kg	35/ 35	.	37.8	78.1	203	36.1	78.1	.
Beryllium	mg/kg	29/ 35	1.24	0.58	0.977	2.7	0.39	0.809	.
Cadmium	mg/kg	15/ 35	1.34	0.99	2.42	4.1	0.825	1.04	.
Chromium	mg/kg	35/ 35	.	15.6	47.7	119	25.5	47.7	.
Cobalt	mg/kg	35/ 35	.	7.8	13	28.7	4.63	13	.
Copper	mg/kg	35/ 35	.	6.7	24	81.3	20.6	24	.
Lead	mg/kg	35/ 35	.	10.3	53	984	163	53	.
Manganese	mg/kg	35/ 35	.	242	886	2620	522	886	.
Mercury	mg/kg	35/ 35	.	0.88	14.9	95.6	19.2	14.9	.
Nickel	mg/kg	35/ 35	.	8.2	23.1	72.9	16	23.1	.
Selenium	mg/kg	2/ 33	1.02	1.1	1.3	1.5	0.283	0.0788	.
Silver	mg/kg	0/ 35	2.29	.	.	.	.	0	.
Vanadium	mg/kg	35/ 35	.	14.4	29	92.7	16.4	29	.
Zinc	mg/kg	35/ 35	.	35.1	97.1	347	83	97.1	.
^{241}Am	pCi/g	8/ 8	.	-0.2099	-0.113	0.0556	0.0959	-0.113	0.12
^{60}Co	pCi/g	35/ 35	.	-0.0624	0.0266	0.222	0.0584	0.0266	0.0122
^{137}Cs	pCi/g	35/ 35	.	0.0958	0.562	2.05	0.459	0.562	0.0172
^{237}Np	pCi/g	20/ 20	.	-0.0864	0.185	1.82	0.509	0.185	0.0227
^{233}Pa	pCi/g	27/ 27	.	-0.121	0.0497	0.742	0.156	0.0497	0.0313
^{228}Th	pCi/g	2/ 2	.	0.553	0.864	1.17	0.439	0.864	0.0864
^{230}Th	pCi/g	1/ 1	.	0.787	0.787	0.787	.	0.787	0.101
^{232}Th	pCi/g	2/ 2	.	0.543	0.638	0.734	0.135	0.638	0.0704
^{234}U	pCi/g	19/ 19	.	1.62	4.23	9.11	1.89	4.23	0.0559
^{235}U	pCi/g	16/ 16	.	0.08	0.246	0.622	0.145	0.246	0.0156
^{238}U	pCi/g	19/ 19	.	0.154	3.24	6.44	1.54	3.24	0.0492
Acenaphthene	µg/kg	1/ 33	449	79	79	79	.	2.39	.
Acenaphthylene	µg/kg	1/ 33	435	160	160	160	.	4.85	.
Anthracene	µg/kg	7/ 33	432	65	215	850	286	45.5	.
Benzo(a)anthracene	µg/kg	14/ 33	429	49	476	3900	1000	202	.

Table 3.19 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Benzo(a)pyrene	µg/kg	11/ 33	429	81	517	3500	997	172	.
Benzo(b)fluoranthene	µg/kg	15/ 33	427	44	569	4100	1020	259	.
Benzo(g,h,i)perylene	µg/kg	6/ 33	432	91	518	2000	741	94.3	.
Benzo(k)fluoranthene	µg/kg	12/ 33	429	69	469	1600	468	171	.
Benzoic Acid	µg/kg	1/ 6	2140	180	180	180	.	30	.
Butylbenzylphthalate	µg/kg	1/ 33	450	230	230	230	.	6.97	.
Carbazole	µg/kg	3/ 27	433	57	64.7	78	11.6	7.18	.
Chrysene	µg/kg	15/ 33	426	48	425	3700	918	193	.
Di-n-butylphthalate	µg/kg	3/ 33	452	71	387	970	505	35.2	.
Di-n-octylphthalate	µg/kg	1/ 33	450	250	250	250	.	7.58	.
Dibenzo(a,h)anthracene	µg/kg	3/ 33	434	48	246	580	291	22.4	.
Dibenzofuran	µg/kg	0/ 33	449	.	.	.	.	0	.
Diethylphthalate	µg/kg	1/ 33	441	60	60	60	.	1.82	.
Dimethylphthalate	µg/kg	0/ 33	449	.	.	.	.	0	.
Fluoranthene	µg/kg	18/ 33	425	46	737	7100	1630	402	.
Fluorene	µg/kg	3/ 33	434	56	102	140	42.6	9.27	.
Indeno(1,2,3-c,d)pyrene	µg/kg	7/ 33	432	58	497	2200	764	105	.
Naphthalene	µg/kg	0/ 33	438	.	.	.	.	0	.
Phenanthrene	µg/kg	11/ 33	431	50	456	1700	489	152	.
Pyrene	µg/kg	17/ 33	423	48	718	7600	1790	370	.
bis(2-Ethylhexyl)phthalate	µg/kg	15/ 33	458	42	171	1200	288	77.6	.
4,4'-DDD	µg/kg	7/ 34	19.2	0.18	1.03	4.8	1.68	0.212	.
4,4'-DDE	µg/kg	2/ 34	16.9	0.16	0.375	0.59	0.304	0.0221	.
4,4'-DDT	µg/kg	7/ 34	19.2	0.18	0.974	4.7	1.65	0.201	.
Aldrin	µg/kg	14/ 34	12.3	0.071	0.238	1.1	0.323	0.098	.
Aroclor-1254	µg/kg	10/ 34	210	7.1	98.1	420	135	28.9	.
Aroclor-1260	µg/kg	2/ 34	169	17	22	27	7.07	1.29	.
Dieldrin	µg/kg	8/ 34	19.8	0.17	0.391	1.2	0.336	0.0921	.
Endosulfan I	µg/kg	1/ 34	8.31	1	1	1	.	0.0294	.
Endosulfan II	µg/kg	3/ 34	17.3	0.36	0.797	1.3	0.473	0.0703	.
Endosulfan sulfate	µg/kg	6/ 34	18.6	0.14	0.26	0.38	0.0802	0.0459	.
Endrin	µg/kg	11/ 34	21.8	0.27	0.487	0.75	0.147	0.158	.
Endrin aldehyde	µg/kg	12/ 27	4.35	0.26	1.38	5.1	1.54	0.613	.

Table 3.19 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Heptachlor	µg/kg	11/ 34	10.9	0.073	0.144	0.25	0.0543	0.0465	.
Heptachlor epoxide	µg/kg	1/ 34	8.32	0.08	0.08	0.08	.	0.00235	.
alpha-BHC	µg/kg	2/ 34	8.5	0.1	0.155	0.21	0.0778	0.00912	.
alpha-Chlordane	µg/kg	22/ 34	181	0.081	0.78	4.6	1.02	0.505	.
beta-BHC	µg/kg	4/ 34	8.94	0.2	0.592	1.6	0.673	0.0697	.
delta-BHC	µg/kg	2/ 34	8.5	0.51	1.61	2.7	1.55	0.0944	.
gamma-BHC (Lindane)	µg/kg	3/ 34	8.7	0.18	0.467	1	0.462	0.0412	.
gamma-Chlordane	µg/kg	23/ 34	197	0.24	1.18	7.8	1.56	0.799	.

Results less than the detection limit were set to zero to compute grand mean.
Source: EFPC Phase Ia and Ib validated results on December 18, 1992.

Table 3.20. EFPC tributary sediments

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of result >detection limit	Grand mean (≤DL=0)	Radiation counting uncertainty of mean
Aluminum	mg/kg	20/ 20	.	3400	8910	17900	3390	8910	.
Arsenic	mg/kg	15/ 15	.	2.7	9.67	25.5	5.81	9.67	.
Barium	mg/kg	20/ 20	.	44.6	87.2	167	38.9	87.2	.
Beryllium	mg/kg	8/ 20	1.07	0.47	0.816	1.1	0.203	0.327	.
Cadmium	mg/kg	0/ 20	1.14	.	.	.	.	0	.
Chromium	mg/kg	20/ 20	.	14.1	36.7	74.3	16.9	36.7	.
Cobalt	mg/kg	20/ 20	.	9.5	17.4	30.8	6.02	17.4	.
Copper	mg/kg	20/ 20	.	2.6	9.88	24.2	5.34	9.88	.
Lead	mg/kg	20/ 20	.	5.2	41.9	165	38.1	41.9	.
Manganese	mg/kg	20/ 20	.	683	1850	4270	881	1850	.
Mercury	mg/kg	3/ 20	0.131	0.17	0.553	1.3	0.647	0.083	.
Nickel	mg/kg	20/ 20	.	3.7	14.1	33.3	6.94	14.1	.
Selenium	mg/kg	0/ 19	0.829	.	.	.	.	0	.
Silver	mg/kg	0/ 20	1.14	.	.	.	.	0	.
Vanadium	mg/kg	20/ 20	.	23.1	36.8	59.2	10.3	36.8	.
Zinc	mg/kg	20/ 20	.	22.3	72.1	233	46.8	72.1	.
^{241}Am	pCi/g	20/ 20	.	-0.1867	0.00179	0.2	0.0972	0.00179	0.0678
^{60}Co	pCi/g	20/ 20	.	-0.0154	0.00288	0.0278	0.0139	0.00288	0.00688
^{137}Cs	pCi/g	20/ 20	.	0	0.121	0.746	0.168	0.121	0.0107
^{237}Np	pCi/g	20/ 20	.	-0.1471	-0.00832	0.0946	0.0605	-0.00832	0.0181
^{234}U	pCi/g	20/ 20	.	0.22	0.534	1.79	0.333	0.534	0.00843
^{235}U	pCi/g	20/ 20	.	0.01	0.0635	0.9	0.197	0.0635	0.00319
^{238}U	pCi/g	20/ 20	.	0.15	0.472	2.68	0.541	0.472	0.00784
Acenaphthene	µg/kg	2/ 20	459	66	178	290	158	17.8	.
Acenaphthylene	µg/kg	1/ 20	462	51	51	51	.	2.55	.
Anthracene	µg/kg	7/ 20	461	60	251	950	312	87.8	.
Benzo(a)anthracene	µg/kg	10/ 20	456	54	616	2200	688	308	.
Benzo(a)pyrene	µg/kg	9/ 20	457	70	596	1900	628	268	.

Table 3.20 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of result > detection limit	Grand mean (≤DL=0)	Radiation counting uncertainty of mean
Benzo(b)fluoranthene	µg/kg	11/ 20	446	66	869	3400	1060	478	.
Benzo(g,h,i)perylene	µg/kg	6/ 20	462	130	530	1400	443	159	.
Benzo(k)fluoranthene	µg/kg	10/ 20	451	66	812	3400	1060	406	.
Benzoic acid	µg/kg	5/ 20	2180	68	99	150	38.3	24.7	.
Butylbenzylphthalate	µg/kg	0/ 20	460	.	.	.	.	0	.
Chrysene	µg/kg	10/ 20	456	10	655	2500	787	328	.
Di-n-butylphthalate	µg/kg	4/ 20	468	45	47.7	52	2.99	9.55	.
Di-n-octylphthalate	µg/kg	0/ 20	460	.	.	.	.	0	.
Dibenzo(a,h)anthracene	µg/kg	5/ 20	459	84	181	430	141	45.2	.
Dibenzofuran	µg/kg	2/ 20	459	77	129	180	72.8	12.9	.
Diethylphthalate	µg/kg	1/ 20	455	160	160	160	.	8	.
Dimethylphthalate	µg/kg	1/ 20	455	75	75	75	.	3.75	.
Fluoranthene	µg/kg	12/ 20	458	53	1140	5300	1540	685	.
Fluorene	µg/kg	2/ 20	459	65	168	270	145	16.8	.
Indeno(1,2,3-c,d)pyrene	µg/kg	6/ 20	462	120	587	1700	563	176	.
Naphthalene	µg/kg	1/ 20	460	46	46	46	.	2.3	.
Phenanthrene	µg/kg	11/ 20	468	78	766	4400	1250	421	.
Pyrene	µg/kg	13/ 20	444	51	784	3400	1020	510	.
bis(2-Ethylhexyl)phthalate	µg/kg	7/ 20	464	50	164	400	129	57.4	.
4,4'-DDD	µg/kg	0/ 20	22.2	.	.	.	.	0	.
4,4'-DDE	µg/kg	0/ 20	22.2	.	.	.	.	0	.
Aroclor-1260	µg/kg	0/ 20	222	.	.	.	.	0	.
Dieldrin	µg/kg	0/ 20	22.2	.	.	.	.	0	.
Endosulfan I	µg/kg	0/ 20	11	.	.	.	.	0	.
Endosulfan II	µg/kg	0/ 20	22.2	.	.	.	.	0	.
Endosulfan sulfate	µg/kg	0/ 20	22.2	.	.	.	.	0	.
Endrin	µg/kg	0/ 20	22.2	.	.	.	.	0	.
Heptachlor	µg/kg	0/ 20	11	.	.	.	.	0	.
Heptachlor epoxide	µg/kg	0/ 20	11	.	.	.	.	0	.
alpha-BHC	µg/kg	0/ 20	11	.	.	.	.	0	.

Table 3.20 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of result > detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
alpha-Chlordane	µg/kg	0/ 20	110	.	.	.	.	0	.
beta-BHC	µg/kg	0/ 20	11	.	.	.	.	0	.
delta-BHC	µg/kg	0/ 20	11	.	.	.	.	0	.
gamma-BHC (Lindane)	µg/kg	0/ 20	11	.	.	.	.	0	.
gamma-Chlordane	µg/kg	0/ 20	110	.	.	.	.	0	.

Results less than the detection limit were set to zero to compute grand mean.
Source: EFPC Phase Ia and Ib validated results on December 18, 1992.

Table 3.21. Hinds Creek sediments

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (< DL = 0)	Radiation counting uncertainty of mean
Aluminum	mg/kg	2/2	.	13000	13700	14400	990	13700	.
Arsenic	mg/kg	2/2	.	2.9	4.25	5.6	1.91	4.25	.
Barium	mg/kg	2/2	.	149	167	184	24.7	167	.
Beryllium	mg/kg	0/2	0.935	.	.	.	.	0	.
Cadmium	mg/kg	0/2	1.1	.	.	.	.	0	.
Chromium	mg/kg	2/2	.	28.1	28.7	29.4	0.919	28.7	.
Cobalt	mg/kg	2/2	.	11.4	12.3	13.3	1.34	12.3	.
Copper	mg/kg	2/2	.	11.9	14.2	16.5	3.25	14.2	.
Lead	mg/kg	2/2	.	4.9	6.15	7.4	1.77	6.15	.
Manganese	mg/kg	2/2	.	541	631	721	127	631	.
Mercury	mg/kg	0/2	0.12	.	.	.	.	0	.
Nickel	mg/kg	2/2	.	22.7	23.4	24	0.919	23.4	.
Selenium	mg/kg	0/2	0.795	.	.	.	.	0	.
Silver	mg/kg	0/2	1.1	.	.	.	.	0	.
Vanadium	mg/kg	2/2	.	26.3	28.4	30.6	3.04	28.4	.
Zinc	mg/kg	2/2	.	54.5	54.8	55.1	0.424	54.8	.
^{241}Am	pCi/g	2/2	.	-0.0526	-0.033	-0.0133	0.0278	-0.033	0.229
^{60}Co	pCi/g	2/2	.	-0.0133	-0.0133	-0.0132	0.0000707	-0.0133	0.0281
^{137}Cs	pCi/g	2/2	.	0.0267	0.0463	0.0658	0.0277	0.0463	0.033
^{237}Np	pCi/g	2/2	.	-0.04	0.0129	0.0658	0.0748	0.0129	0.0562
^{234}U	pCi/g	2/2	.	0.22	0.23	0.24	0.0141	0.23	0.0141
^{235}U	pCi/g	2/2	.	0.01	0.01	0.01	0	0.01	.
^{238}U	pCi/g	2/2	.	0.16	0.17	0.18	0.0141	0.17	0.0141
Acenaphthene	μg/kg	0/2	440	.	.	.	.	0	.
Acenaphthylene	μg/kg	0/2	440	.	.	.	.	0	.
Anthracene	μg/kg	0/2	440	.	.	.	.	0	.
Benzo(a)anthracene	μg/kg	0/2	440	.	.	.	.	0	.
Benzo(a)pyrene	μg/kg	0/2	440	.	.	.	.	0	.
Benzo(b)fluoranthene	μg/kg	0/2	440	.	.	.	.	0	.

Table 3.21 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Benzo(g,h,i)perylene	µg/kg	0/2	440	.	.	.	.	0	.
Benzo(k)fluoranthene	µg/kg	0/2	440	.	.	.	.	0	.
Benzoic Acid	µg/kg	0/2	2150	.	.	.	.	0	.
Butylbenzylphthalate	µg/kg	0/2	440	.	.	.	.	0	.
Chrysene	µg/kg	0/2	440	.	.	.	.	0	.
Di-n-butylphthalate	µg/kg	0/2	440	.	.	.	.	0	.
Di-n-octylphthalate	µg/kg	0/2	440	.	.	.	.	0	.
Dibenzo(a,h)anthracene	µg/kg	0/2	440	.	.	.	.	0	.
Dibenzofuran	µg/kg	0/2	440	.	.	.	.	0	.
Diethylphthalate	µg/kg	0/2	440	.	.	.	.	0	.
Dimethylphthalate	µg/kg	0/2	440	.	.	.	.	0	.
Fluoranthene	µg/kg	0/2	440	.	.	.	.	0	.
Fluorene	µg/kg	0/2	440	.	.	.	.	0	.
Indeno(1,2,3-c,d)pyrene	µg/kg	0/2	440	.	.	.	.	0	.
Naphthalene	µg/kg	0/2	440	.	.	.	.	0	.
Phenanthrene	µg/kg	0/2	440	.	.	.	.	0	.
Pyrene	µg/kg	0/2	440	.	.	.	.	0	.
bis(2-Ethylhexyl)phthalate	µg/kg	0/2	440	.	.	.	.	0	.
4,4'-DDD	µg/kg	0/2	21.5	.	.	.	.	0	.
4,4'-DDE	µg/kg	0/2	21.5	.	.	.	.	0	.
4,4'-DDT	µg/kg	0/2	21.5	.	.	.	.	0	.
Aldrin	µg/kg	0/2	10.5	.	.	.	.	0	.
Aroclor-1254	µg/kg	0/2	215	.	.	.	.	0	.
Aroclor-1260	µg/kg	0/2	215	.	.	.	.	0	.
Dieldrin	µg/kg	0/2	21.5	.	.	.	.	0	.
Endosulfan I	µg/kg	0/2	10.5	.	.	.	.	0	.
Endosulfan II	µg/kg	0/2	21.5	.	.	.	.	0	.
Endosulfan Sulfate	µg/kg	0/2	21.5	.	.	.	.	0	.
Endrin	µg/kg	0/2	21.5	.	.	.	.	0	.
Heptachlor	µg/kg	0/2	10.5	.	.	.	.	0	.
Heptachlor Epoxide	µg/kg	0/2	10.5	.	.	.	.	0	.

Table 3.21 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
alpha-BHC	µg/kg	0/2	10.5	.	.	.	.	0	.
alpha-Chlordane	µg/kg	0/2	105	.	.	.	.	0	.
beta-BHC	µg/kg	0/2	10.5	.	.	.	.	0	.
delta-BHC	µg/kg	0/2	10.5	.	.	.	.	0	.
gamma-BHC (Lindane)	µg/kg	0/2	10.5	.	.	.	.	0	.
gamma-Chlordane	µg/kg	0/2	105	.	.	.	.	0	.

Results less than the detection limit were set to zero to compute grand mean.
Source: EFPC Phase Ia and Ib validated results on December 18, 1992.

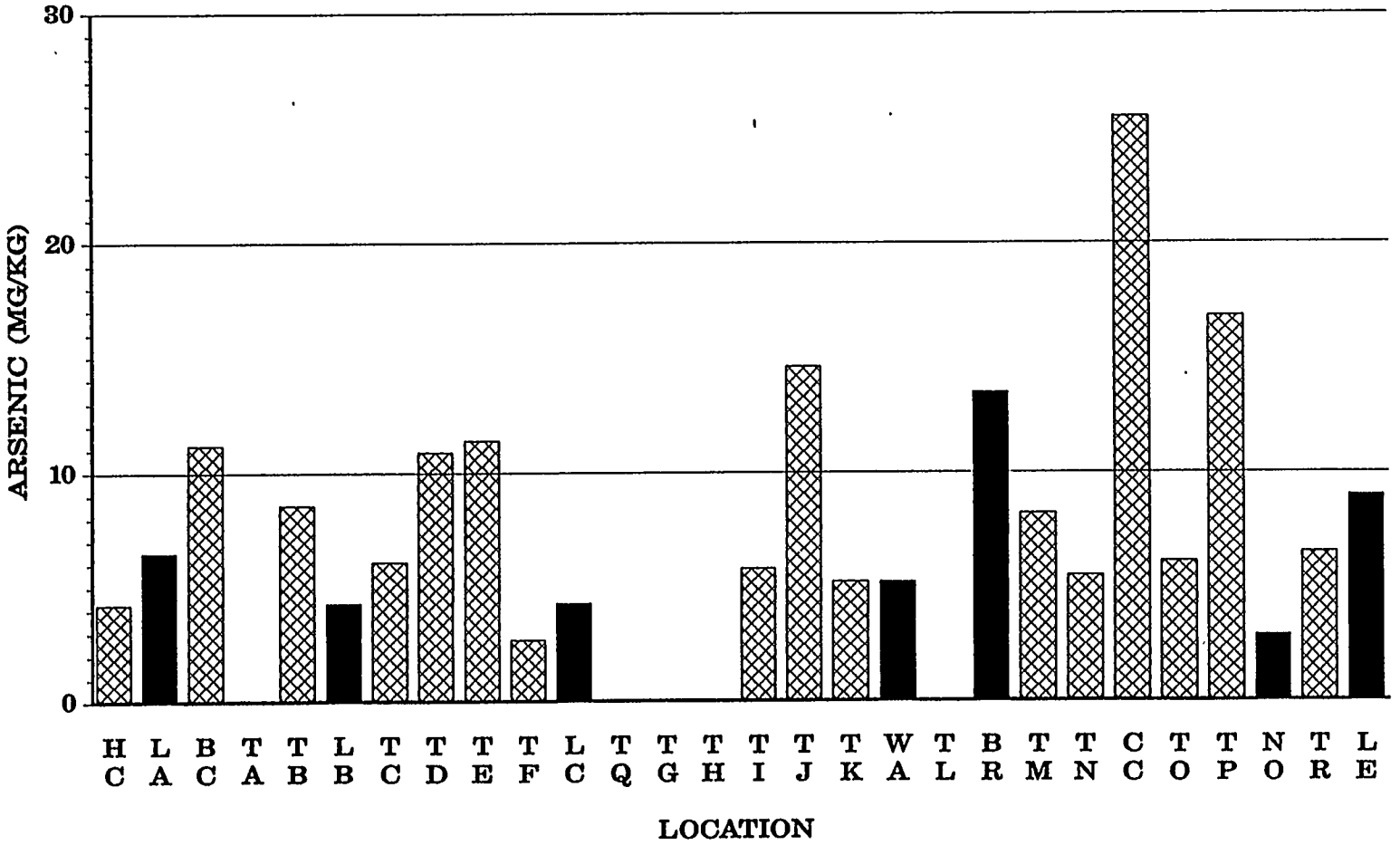

Fig. 3.34a Arsenic concentrations (mg/kg) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

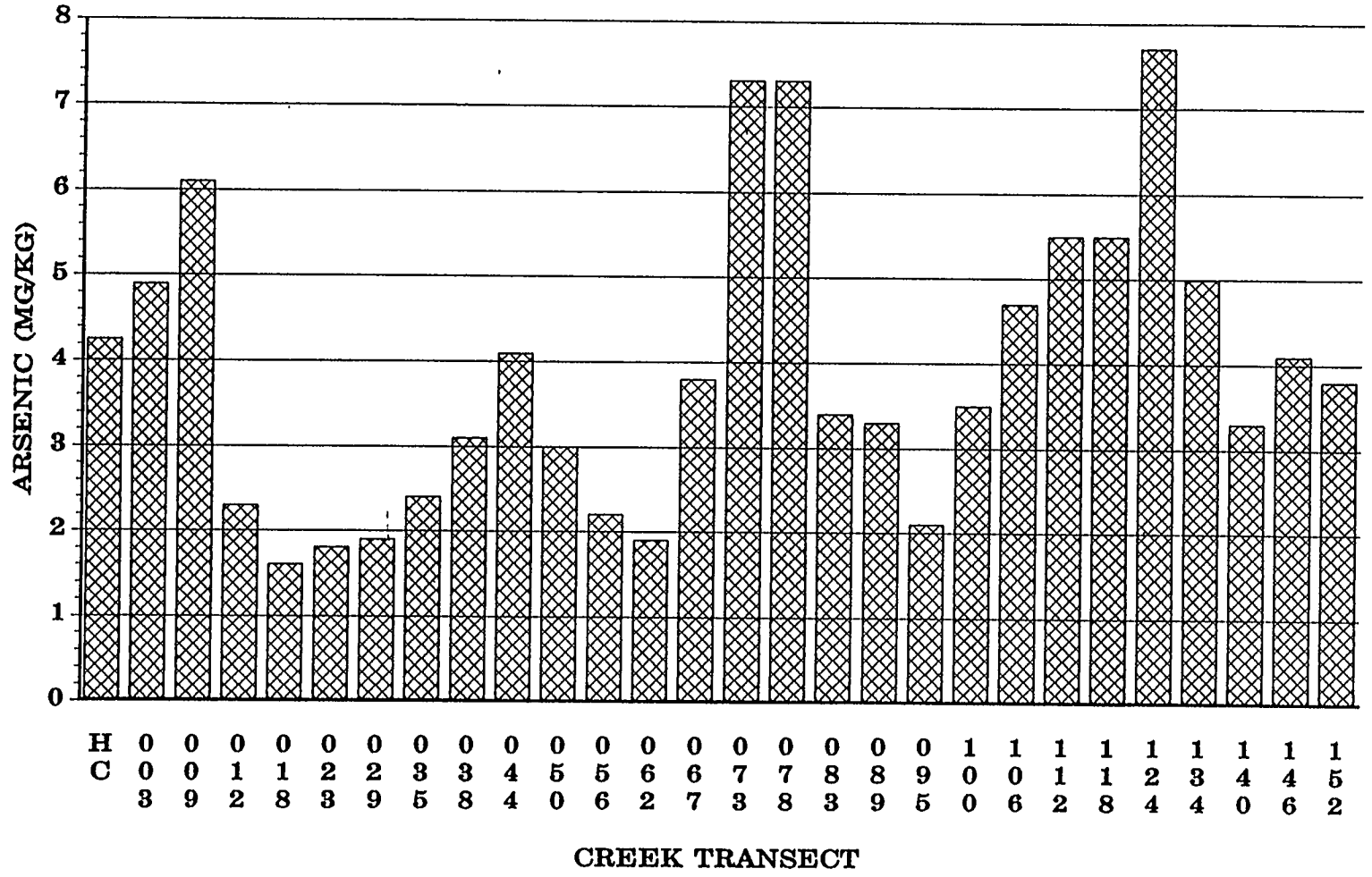

Fig. 3.34b. Arsenic concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

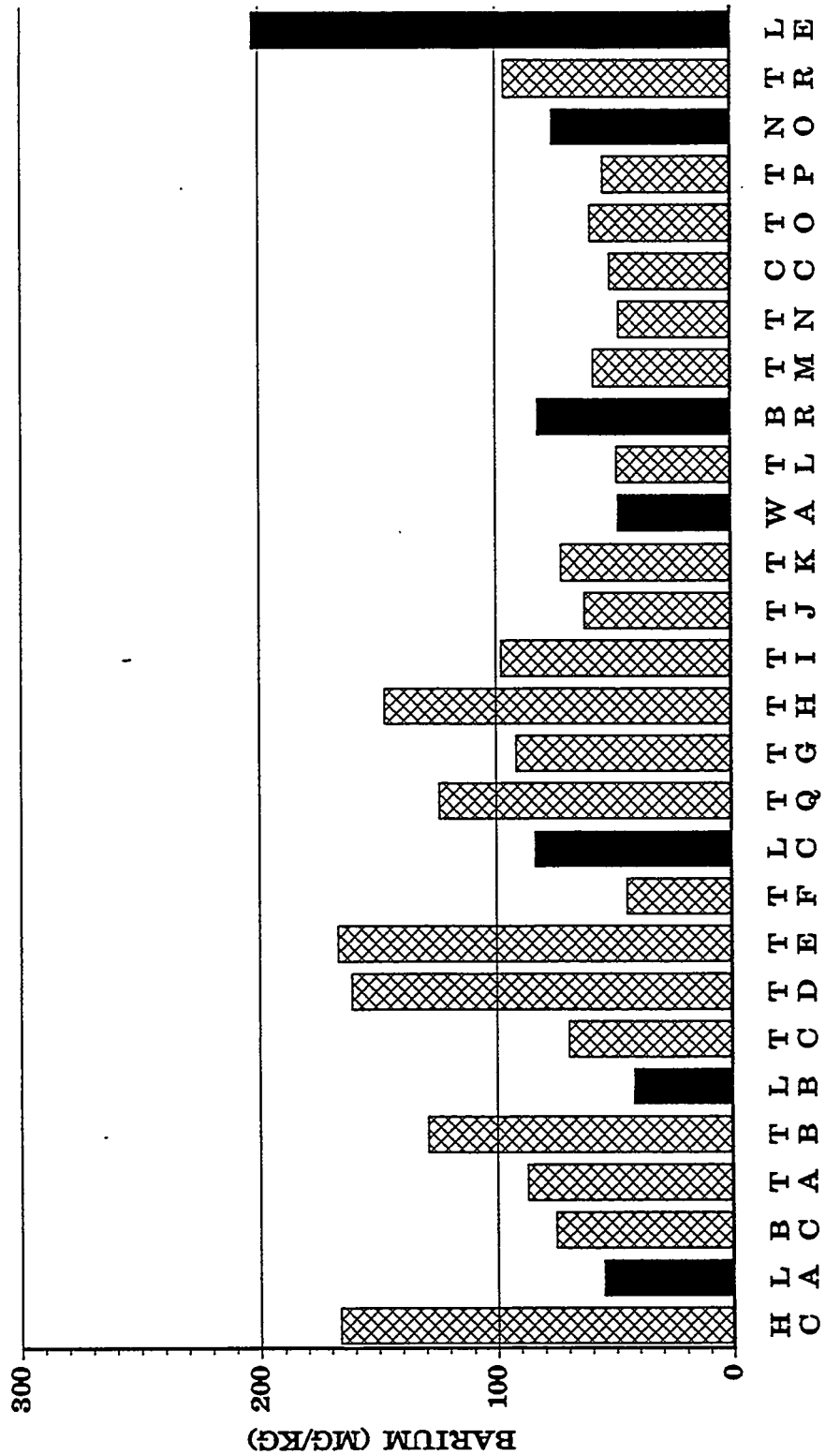

Fig. 3.35a Barium concentrations (mg/kg) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

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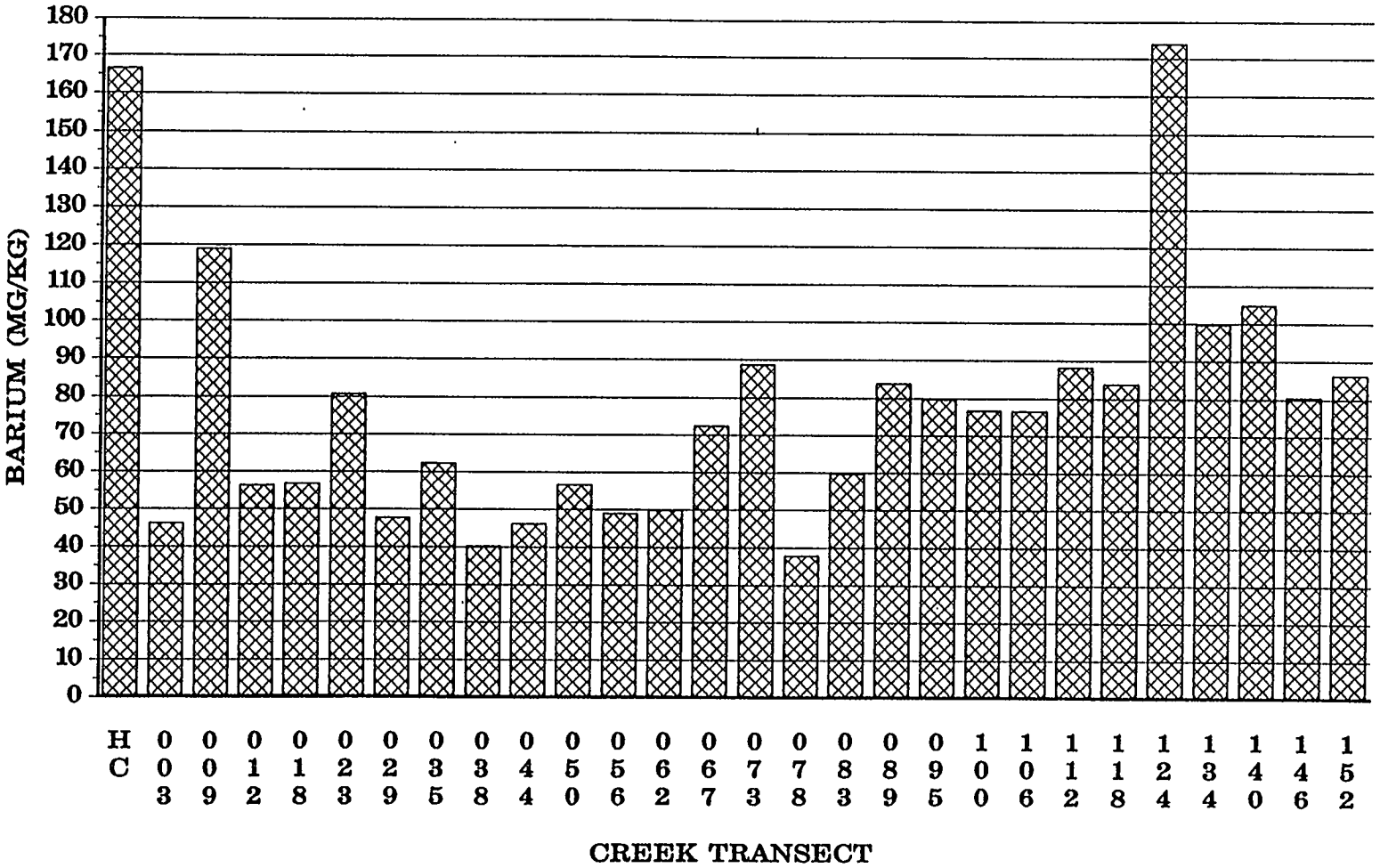


Fig. 3.35b. Barium concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

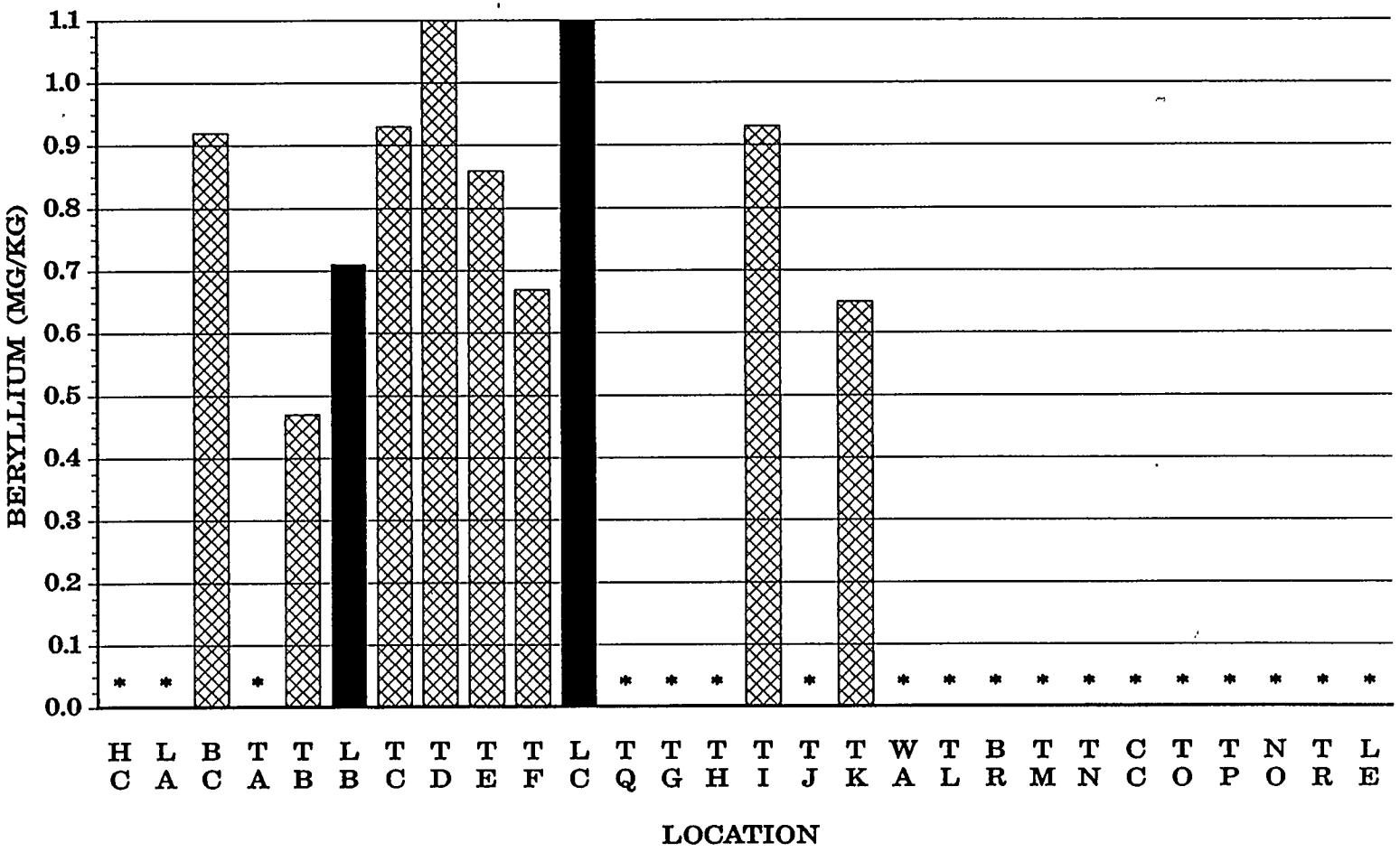


Fig. 3.36a. Beryllium concentrations (mg/kg) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC) (see Map 4). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

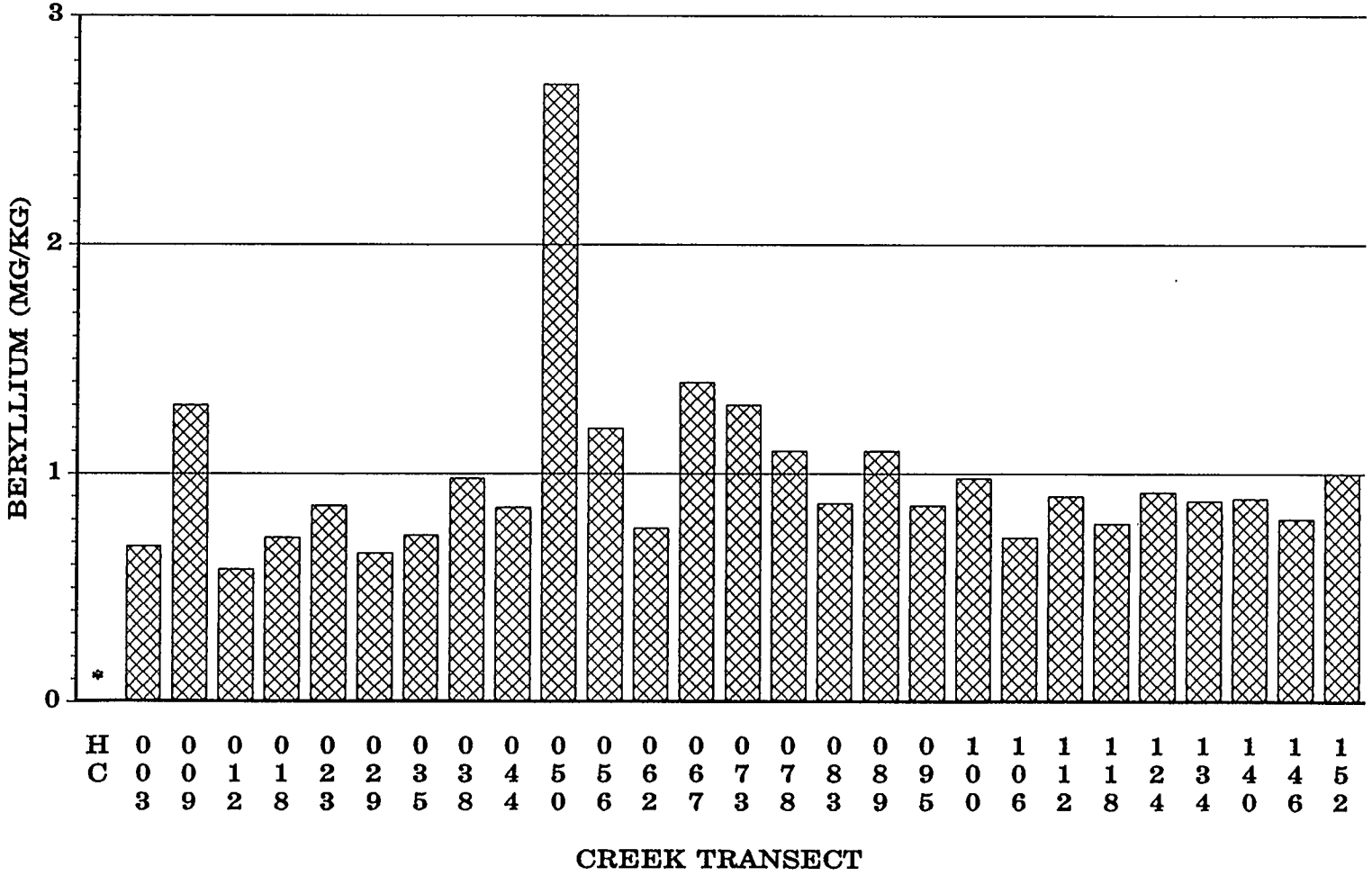


Fig. 3.36b. Beryllium concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

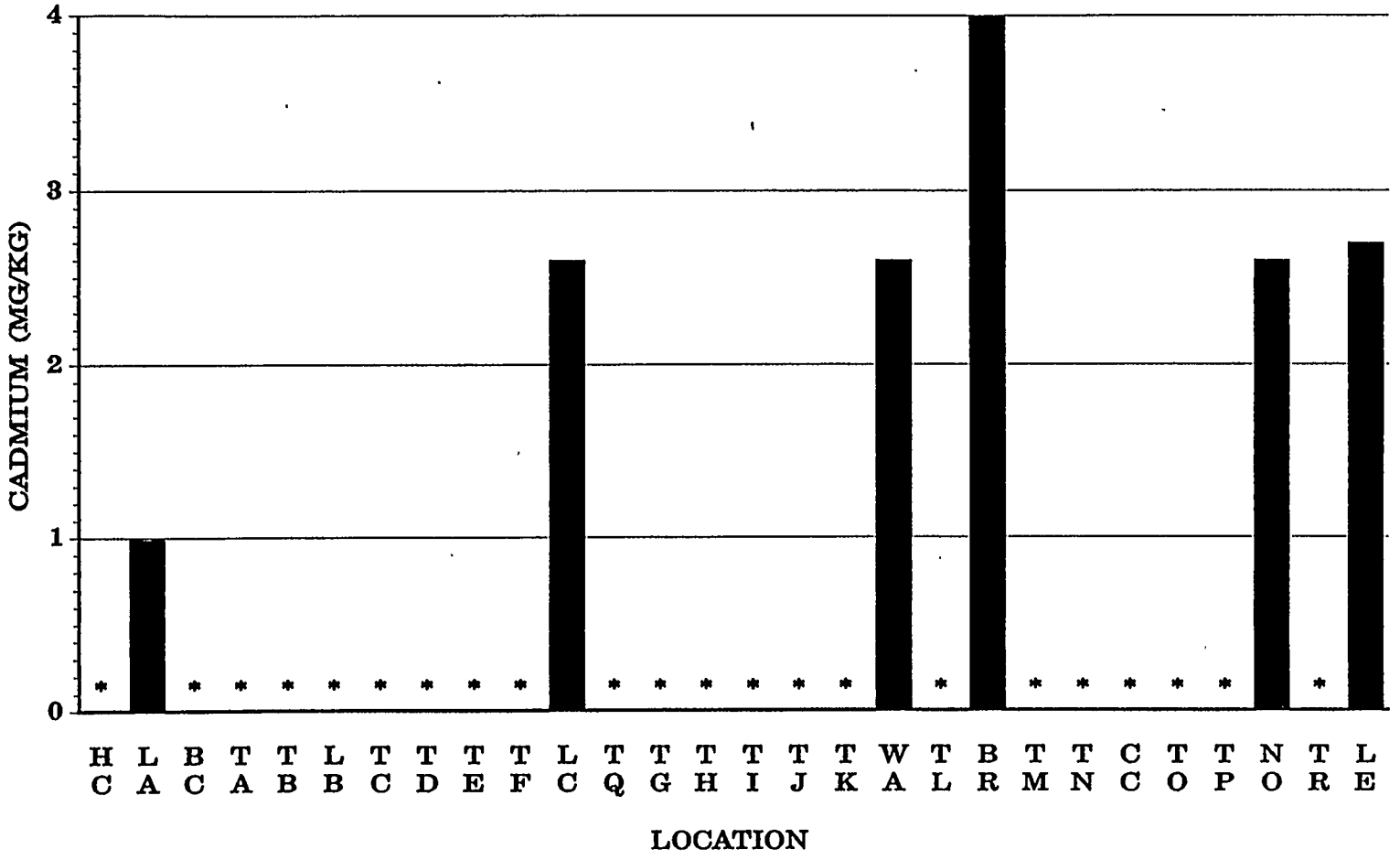


Fig. 3.37a. Cadmium concentrations (mg/kg) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC) (see Map 4). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

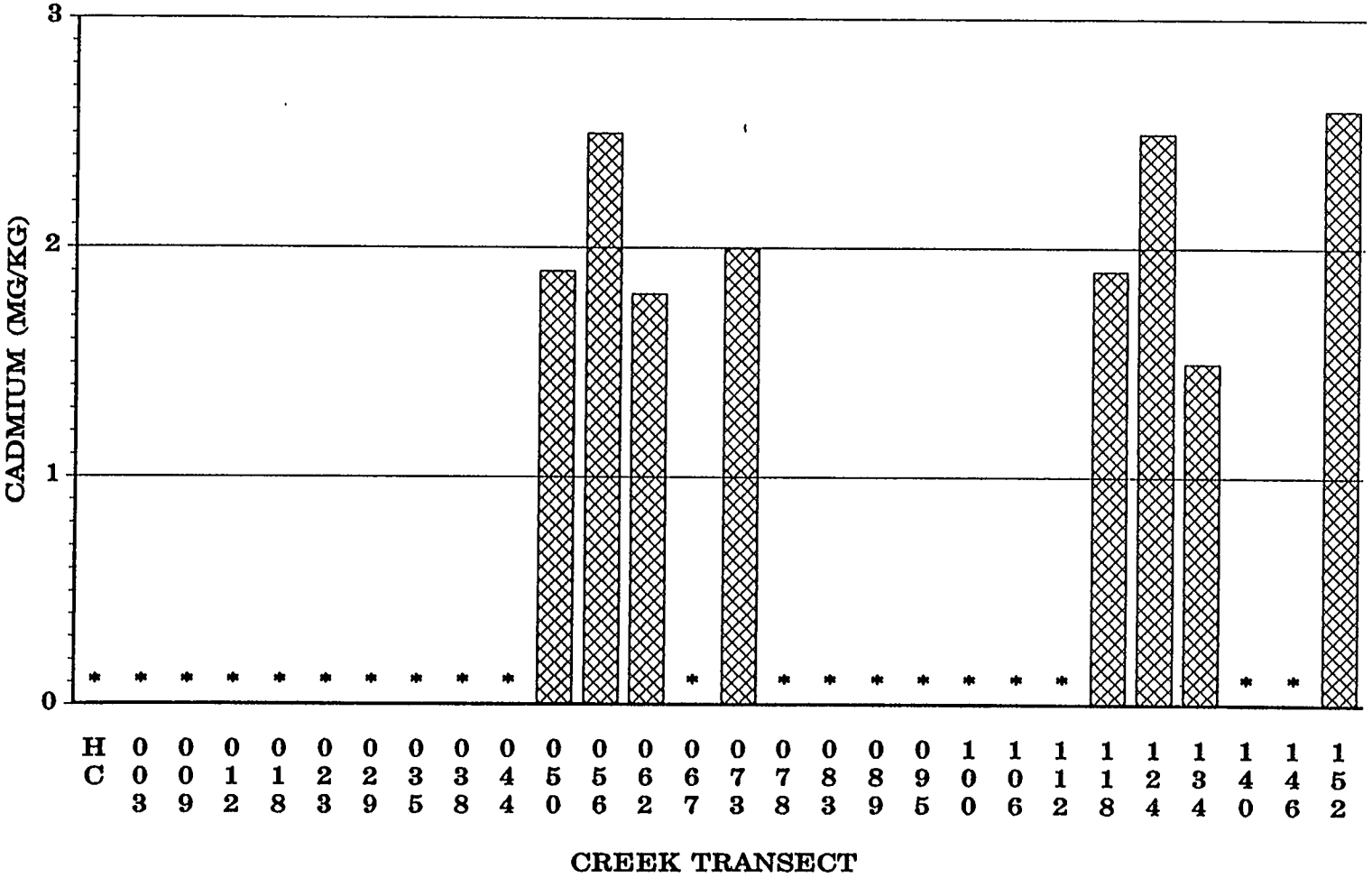


Fig. 3.37b. Cadmium concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

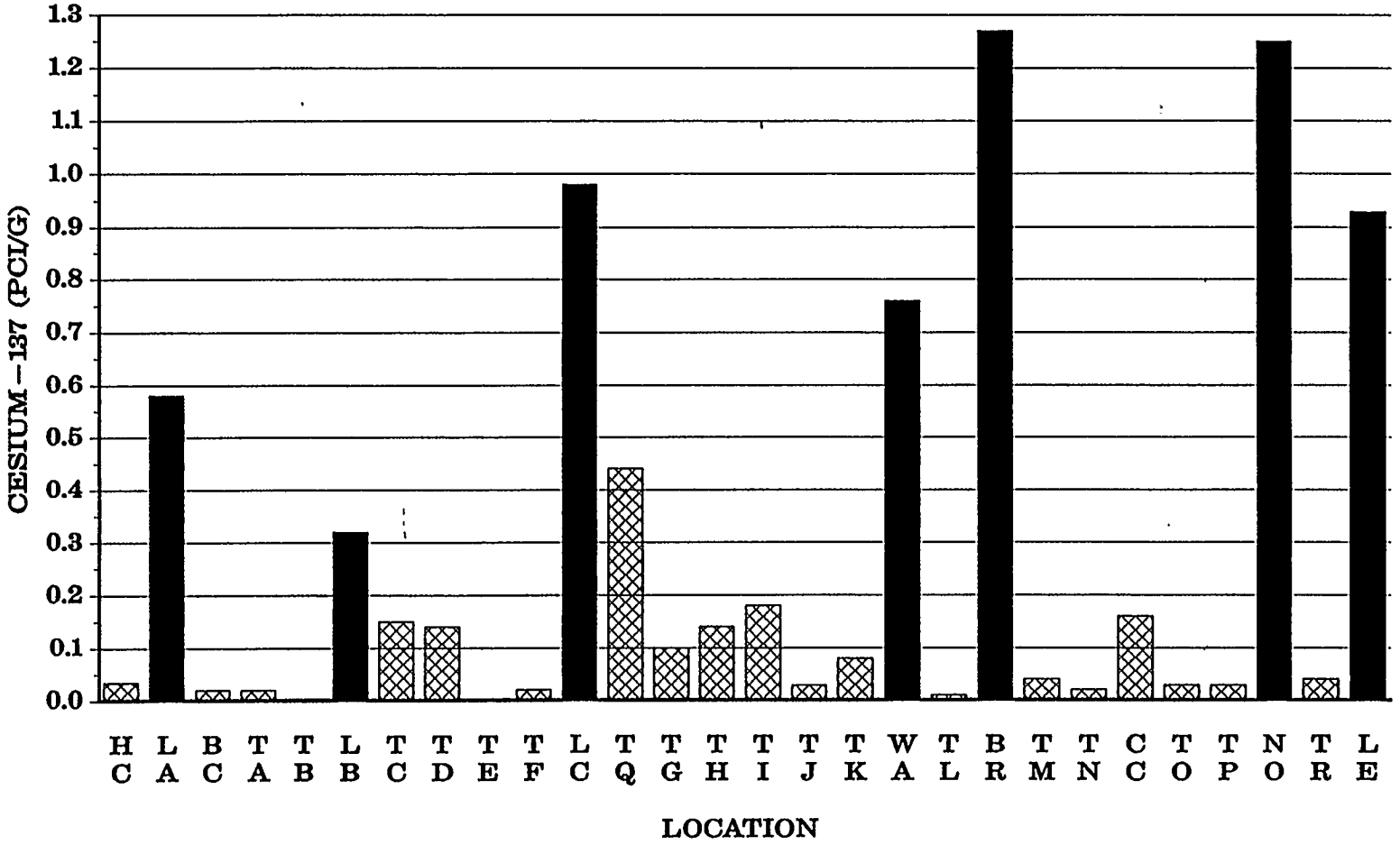


Fig. 3.38a. ^{137}Cs concentrations (pCi/g) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC) (see Map 4). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

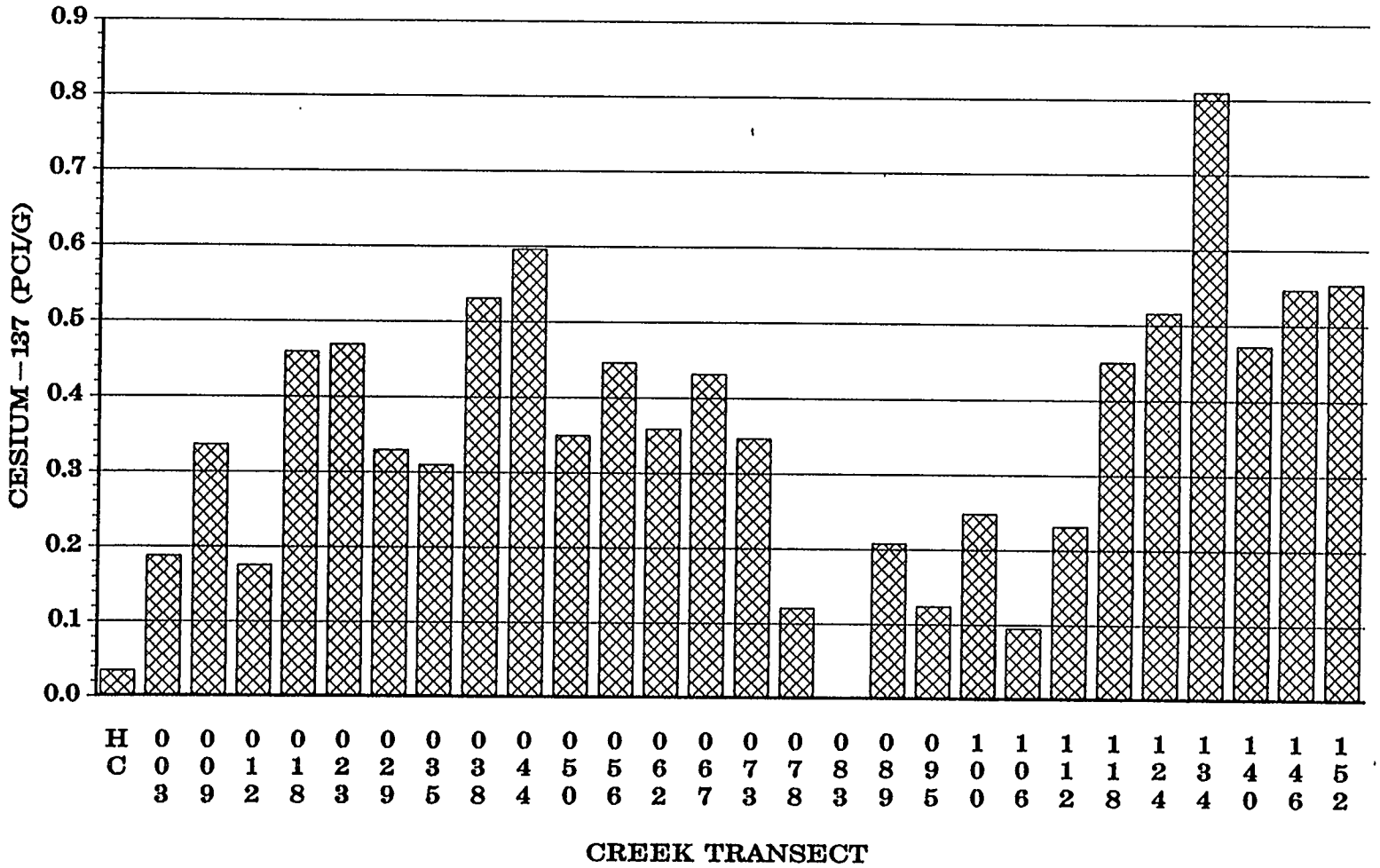


Fig. 3.38b. ^{137}Cs concentrations (pCi/g) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

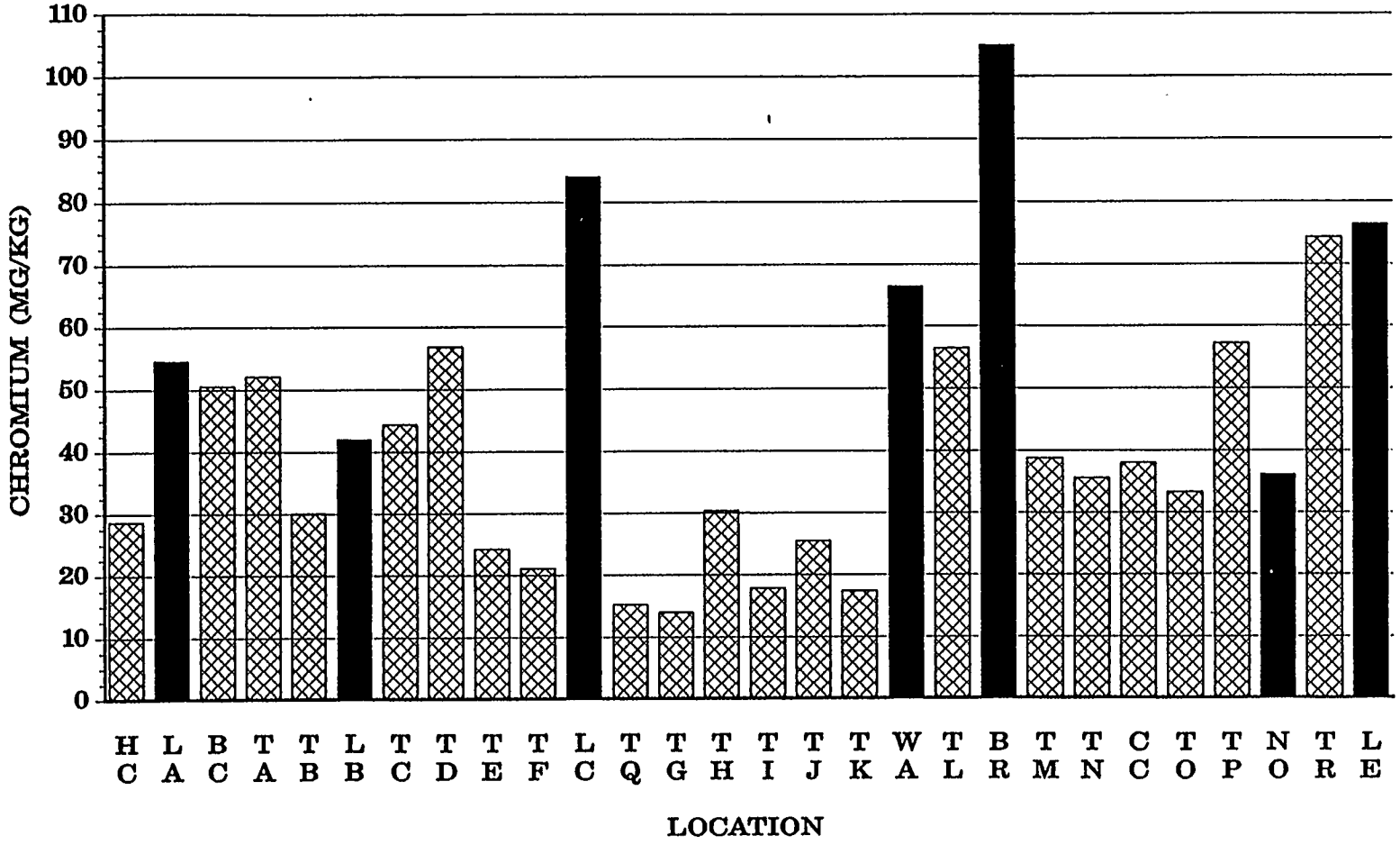


Fig. 3.39a. Chromium concentrations (mg/kg) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC) (see Map 4). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

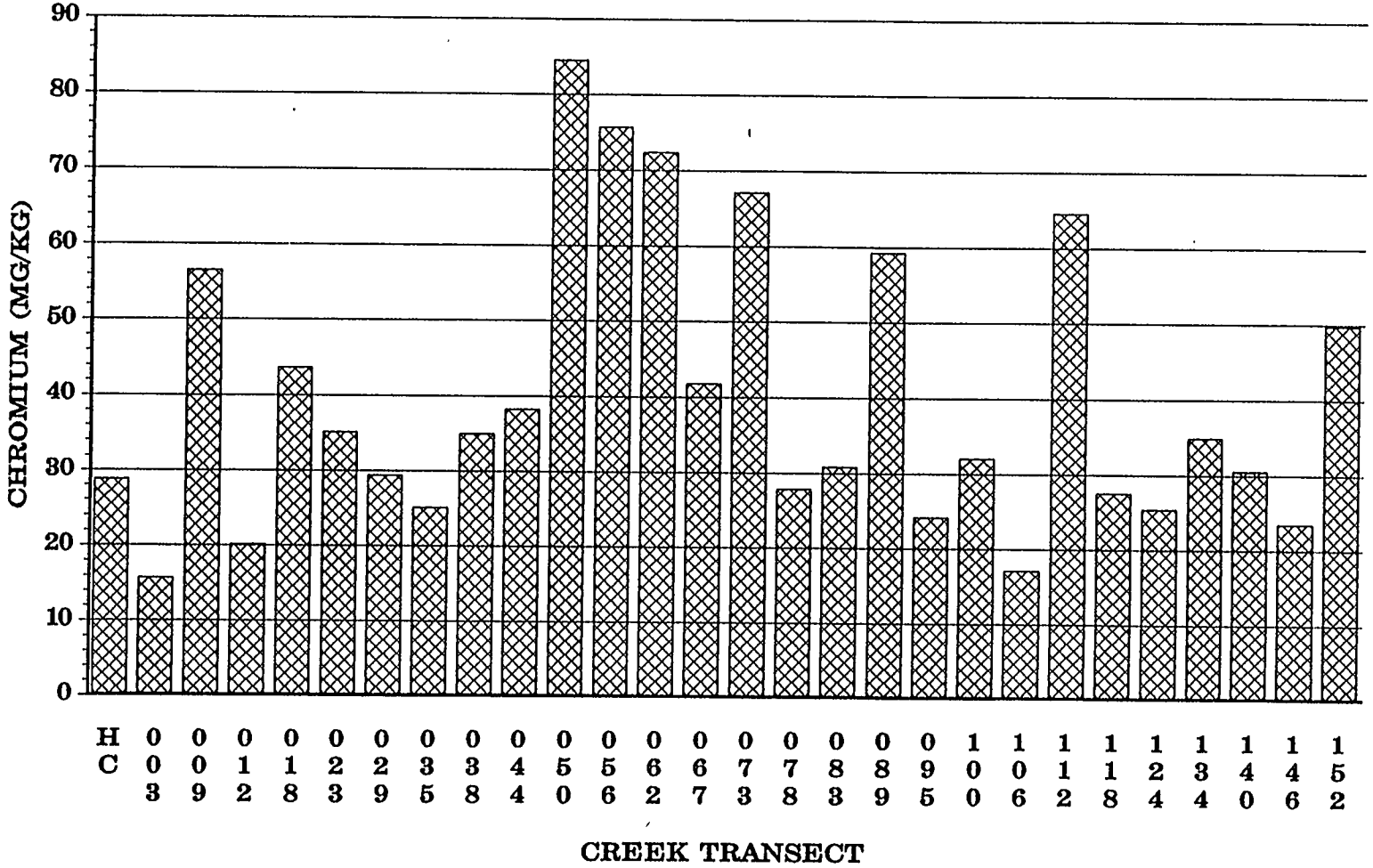


Fig. 3.39b. Chromium concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

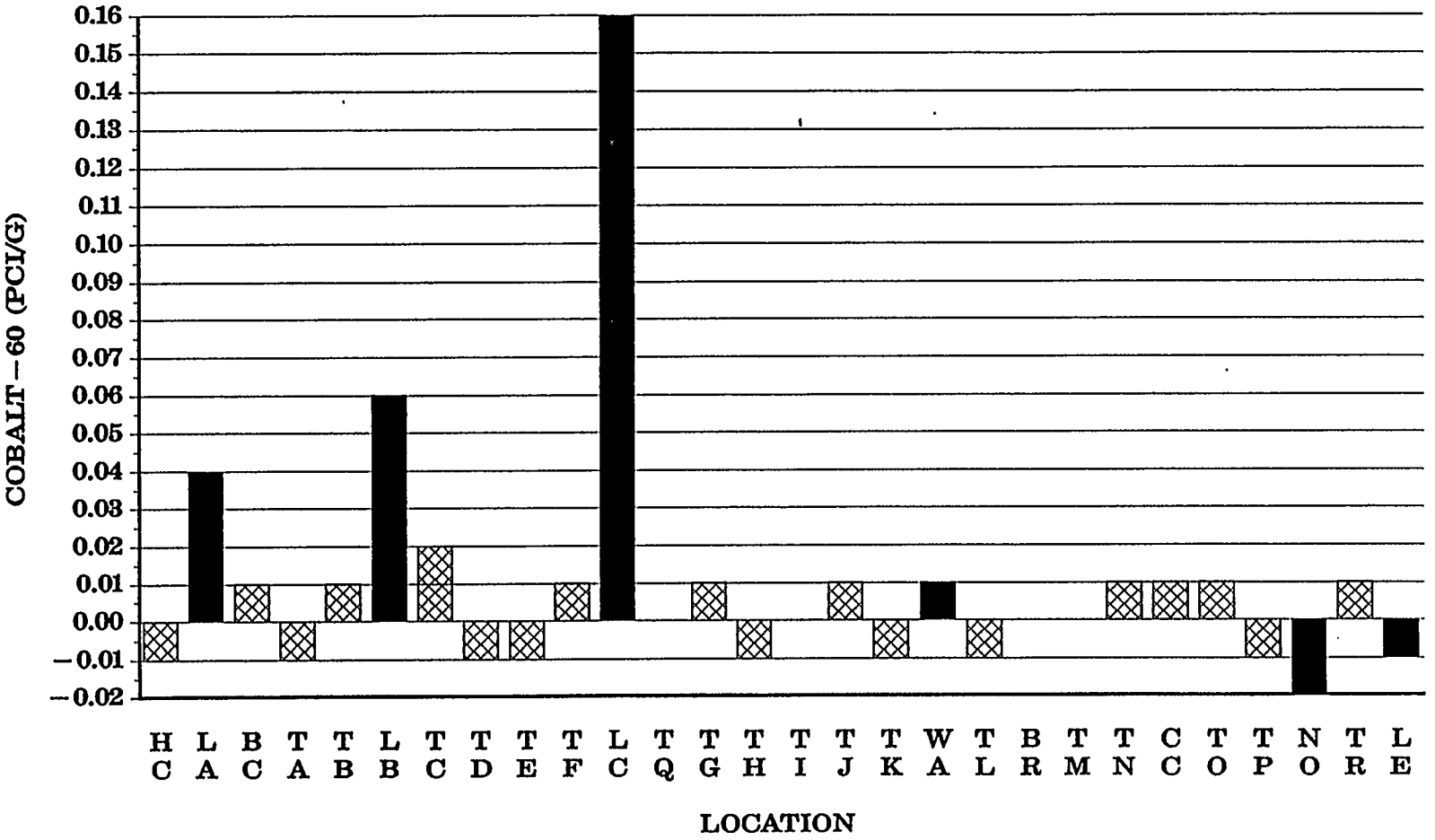


Fig. 3.40a. ^{60}Co concentrations (pCi/g) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC) (see Map 4). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

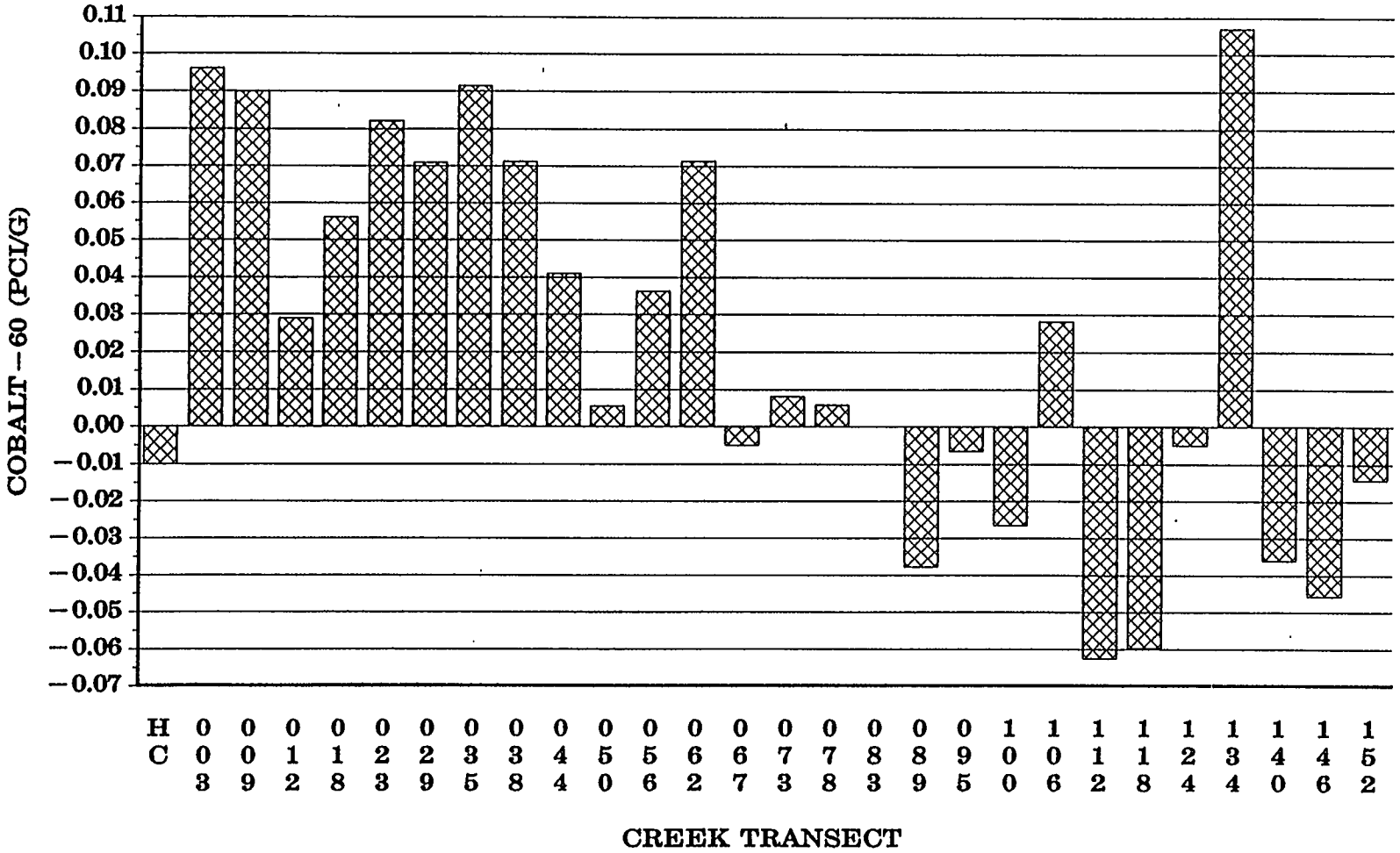


Fig. 3.40b. ^{60}Co concentrations (pCi/g) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

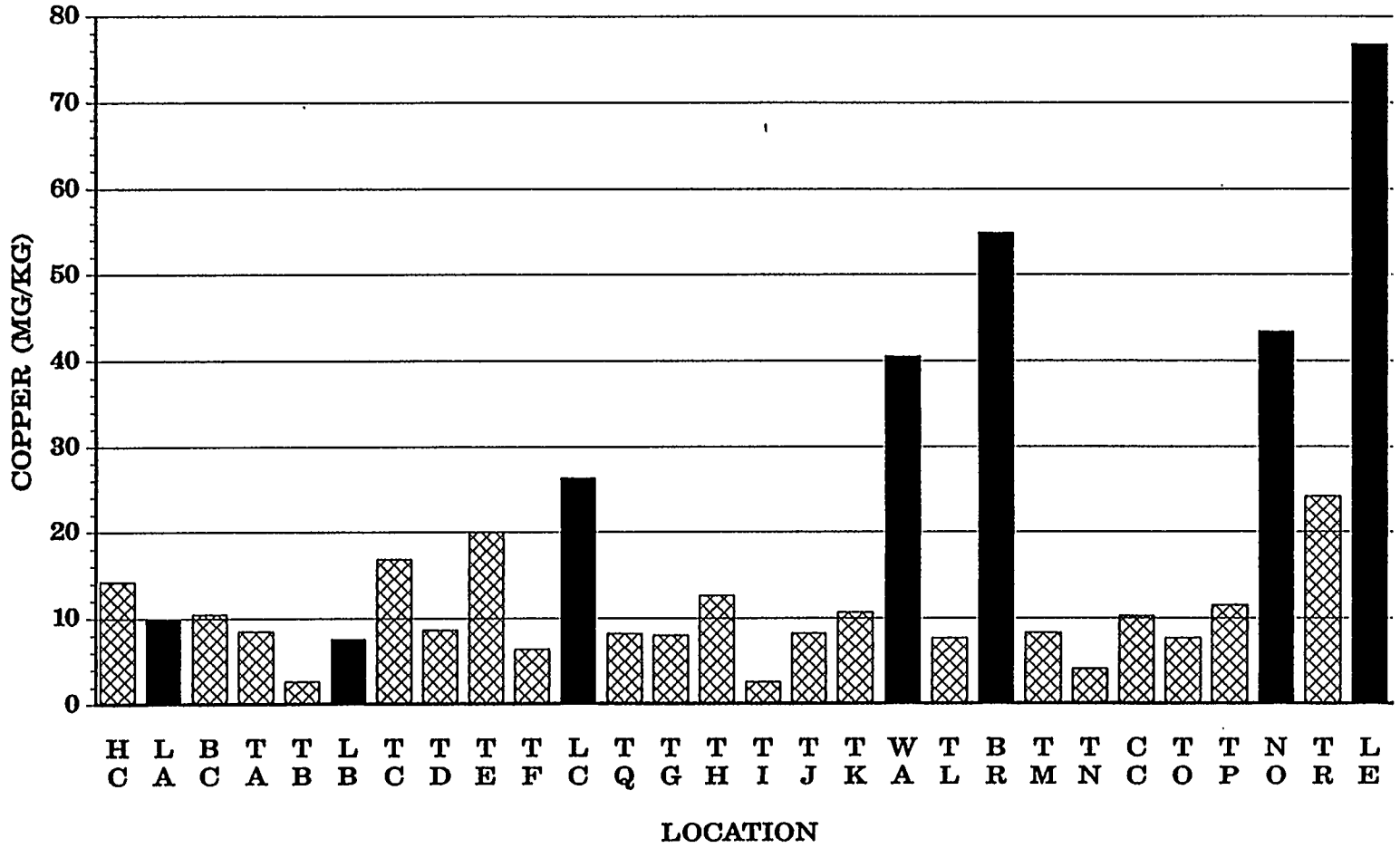


Fig. 3.41a. Copper concentrations (mg/kg) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC) (see Map 4). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

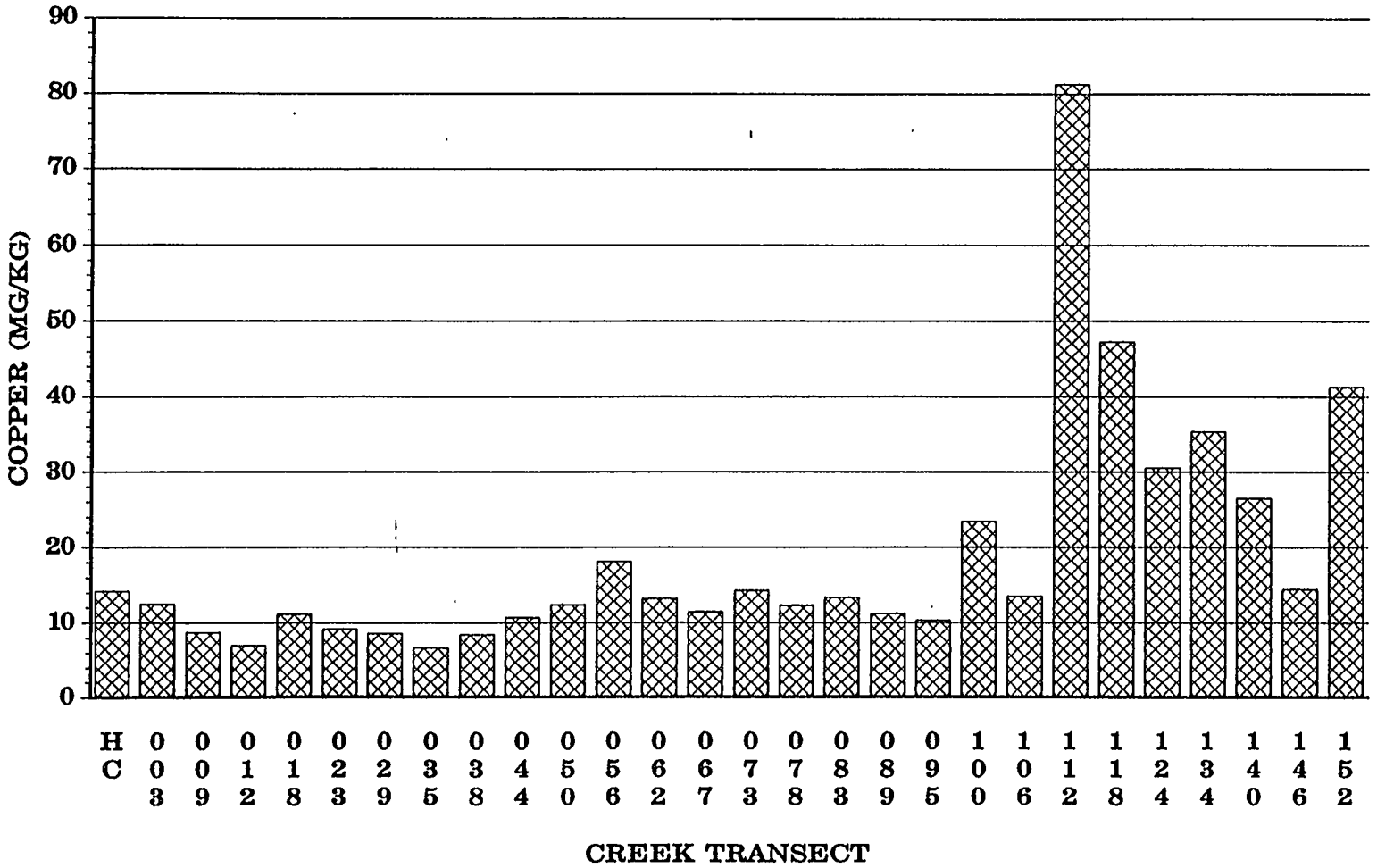


Fig. 3.41b. Copper concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

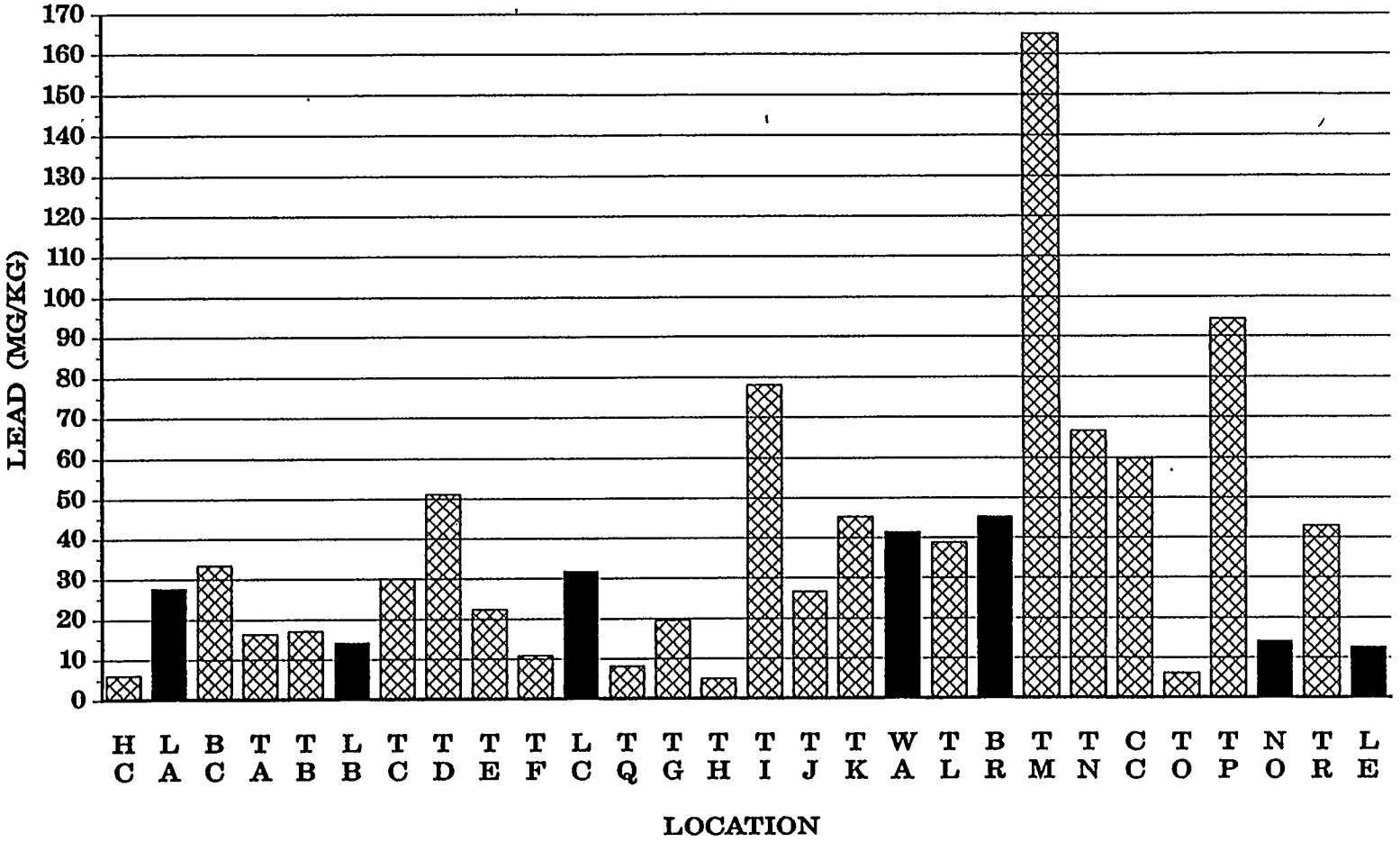


Fig. 3.42a. Lead concentrations (mg/kg) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC) (see Map 4). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

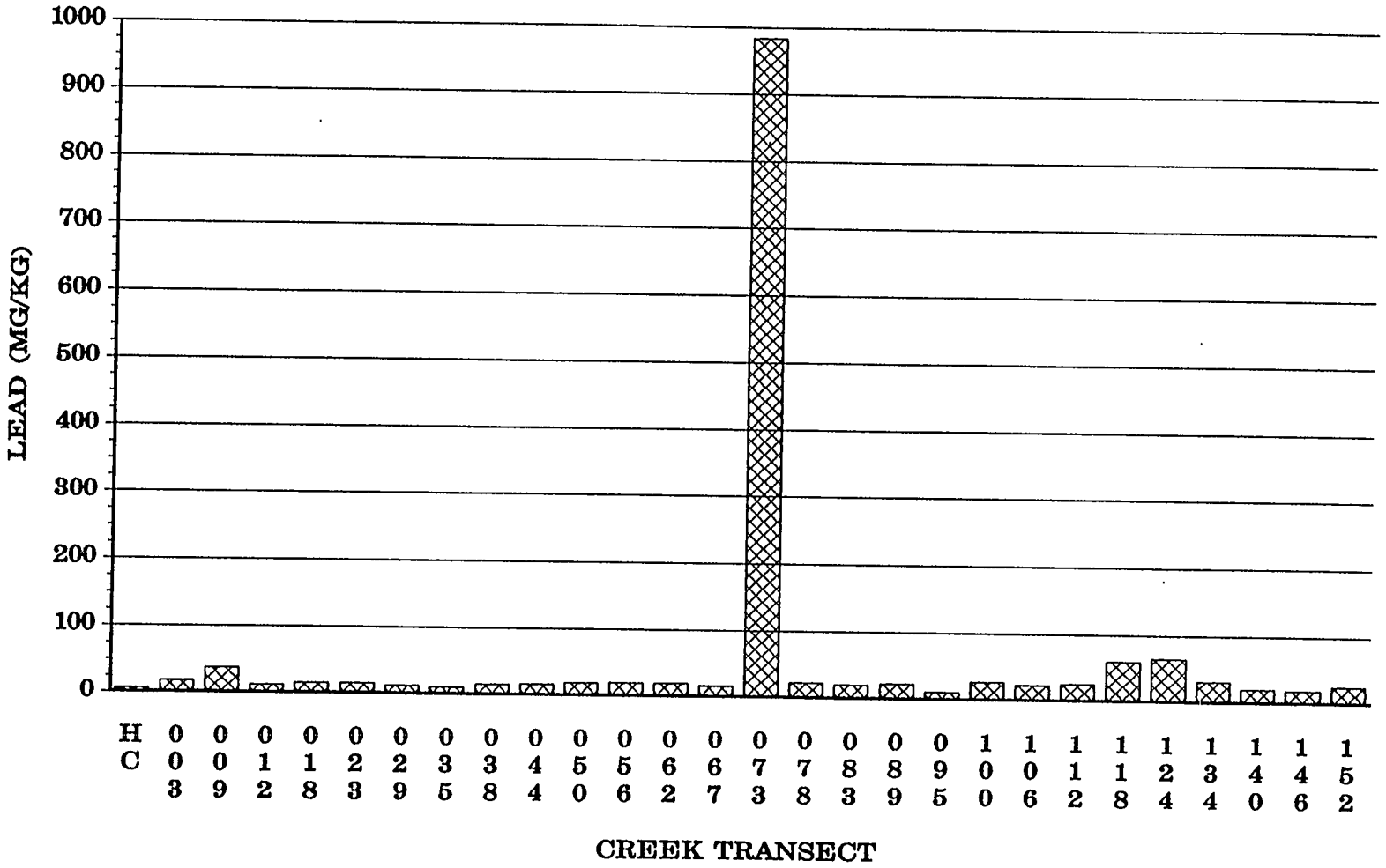


Fig. 3.42b. Lead concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

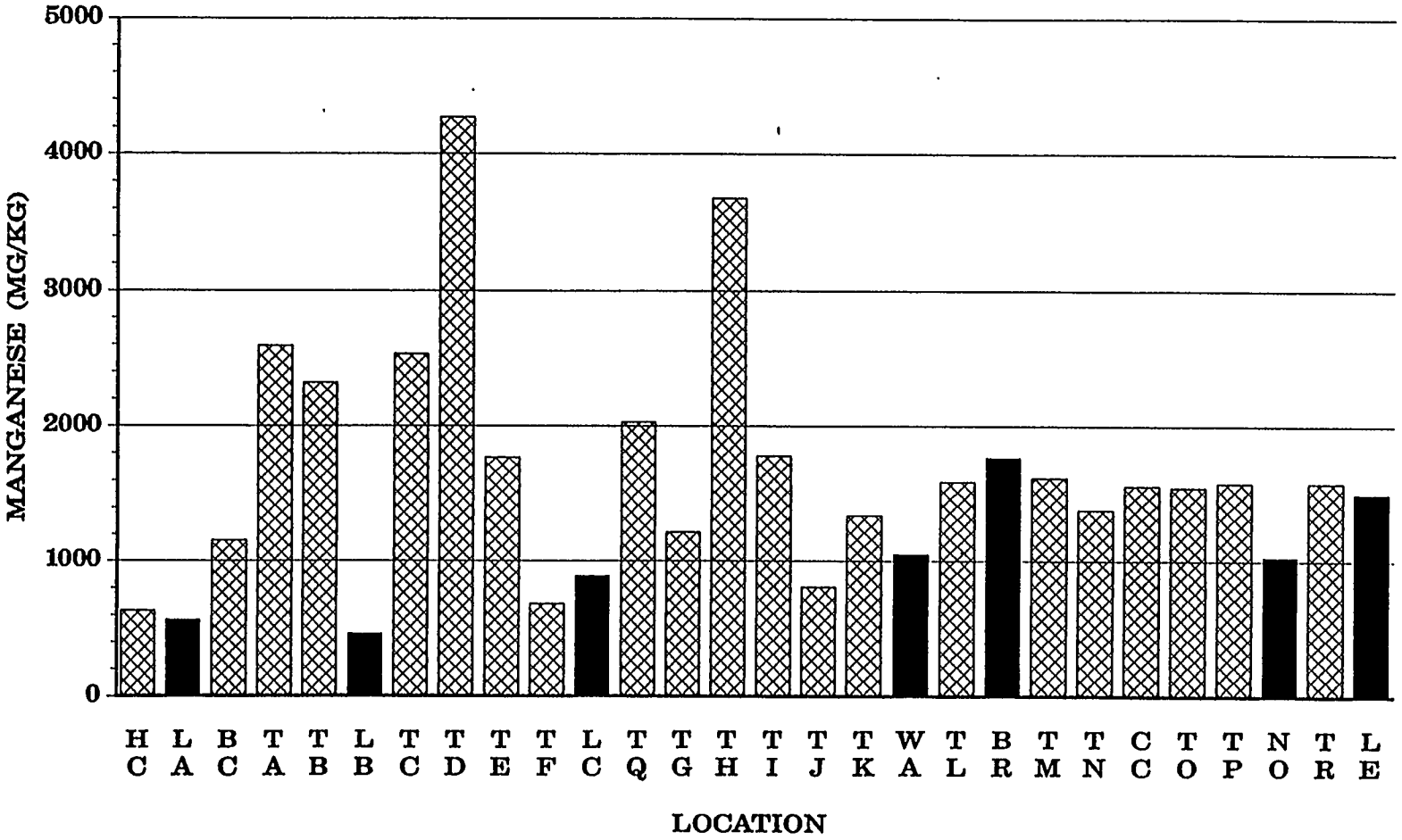


Fig. 3.43a. Manganese concentrations (mg/kg) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC) (see Map 4). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

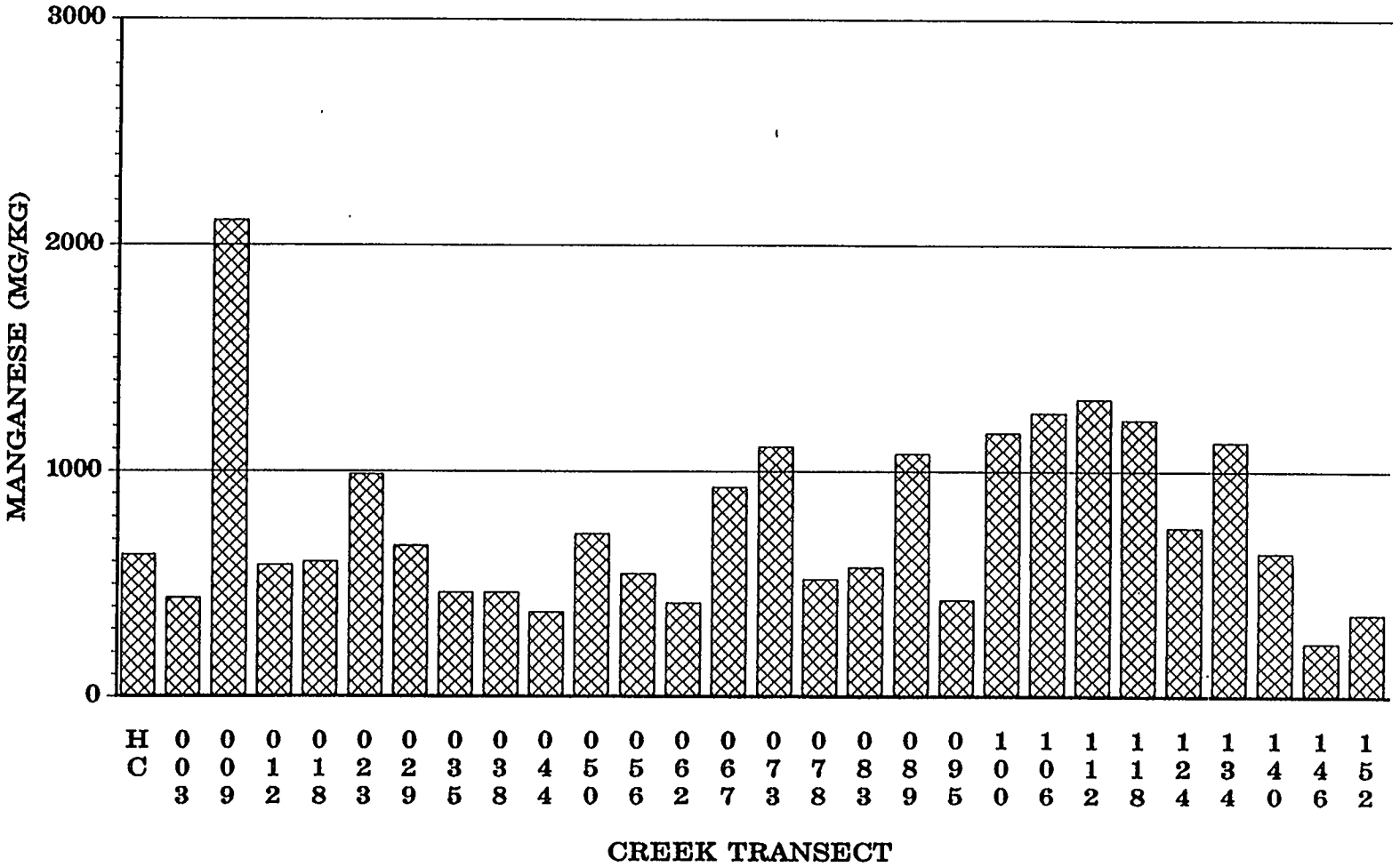


Fig. 3.43b. Manganese concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

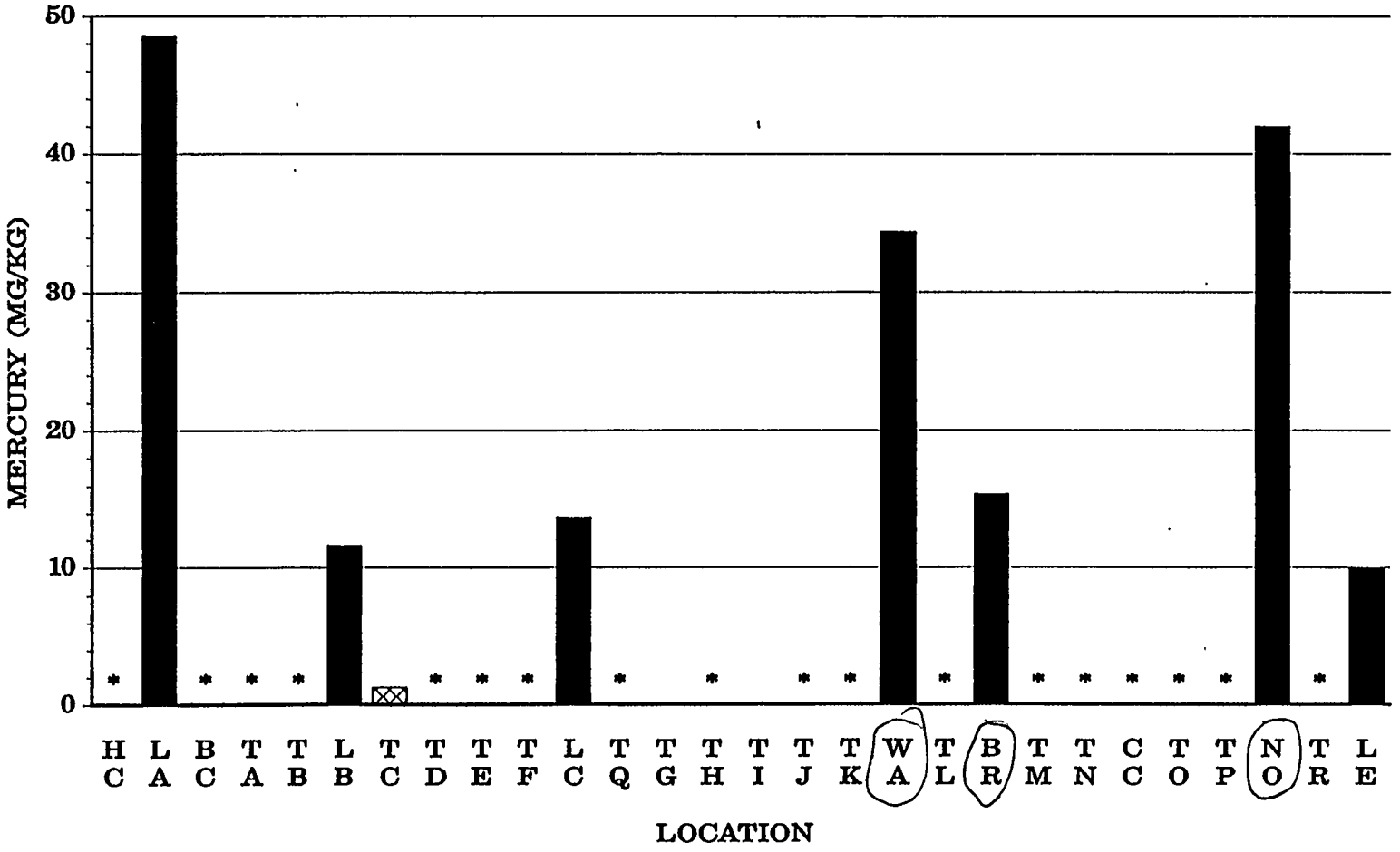


Fig. 3.44a. Mercury concentrations (mg/kg) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC) (see Map 4). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

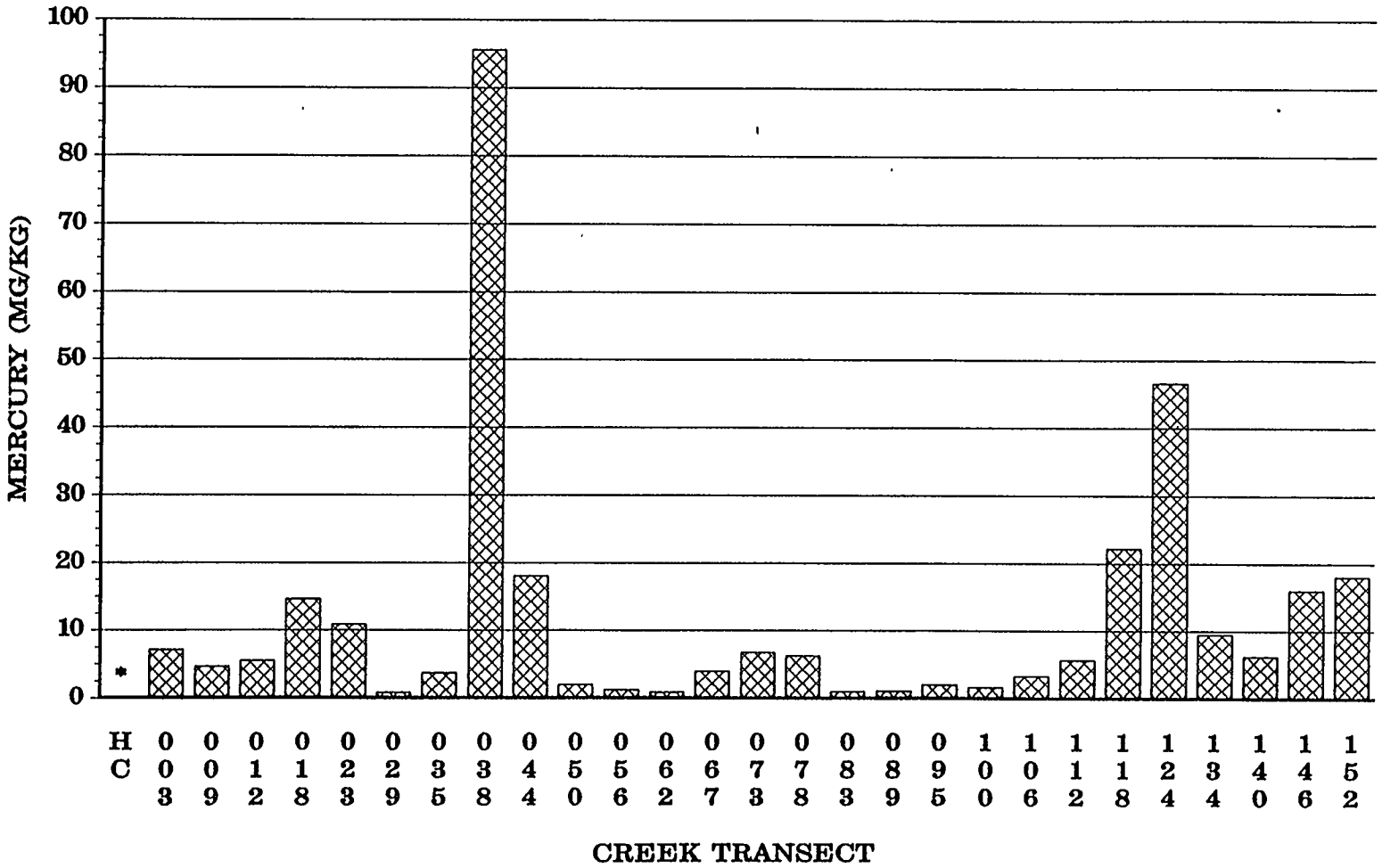


Fig. 3.44b. Mercury concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

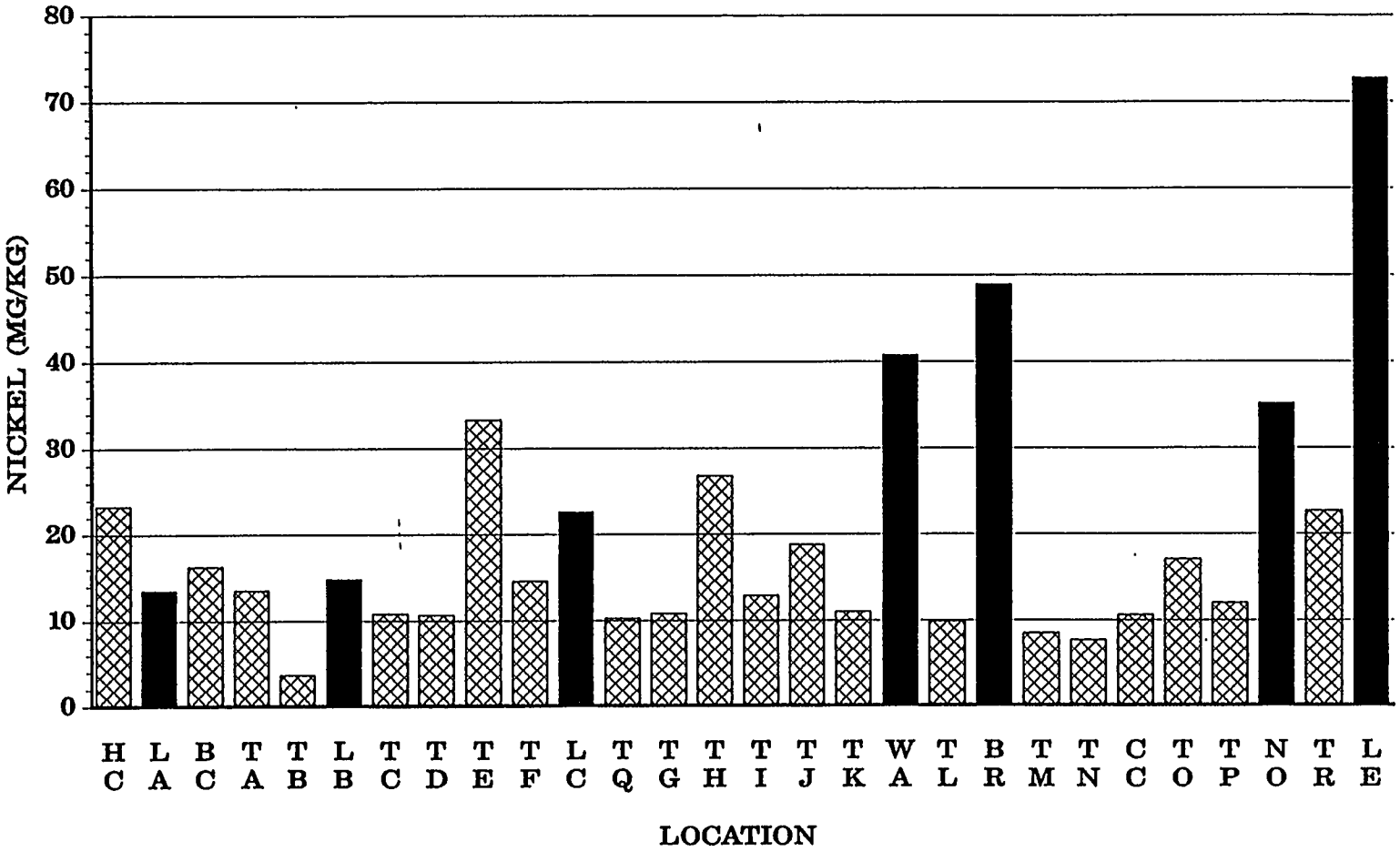


Fig. 3.45a. Nickel concentrations (mg/kg) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC) (see Map 4). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

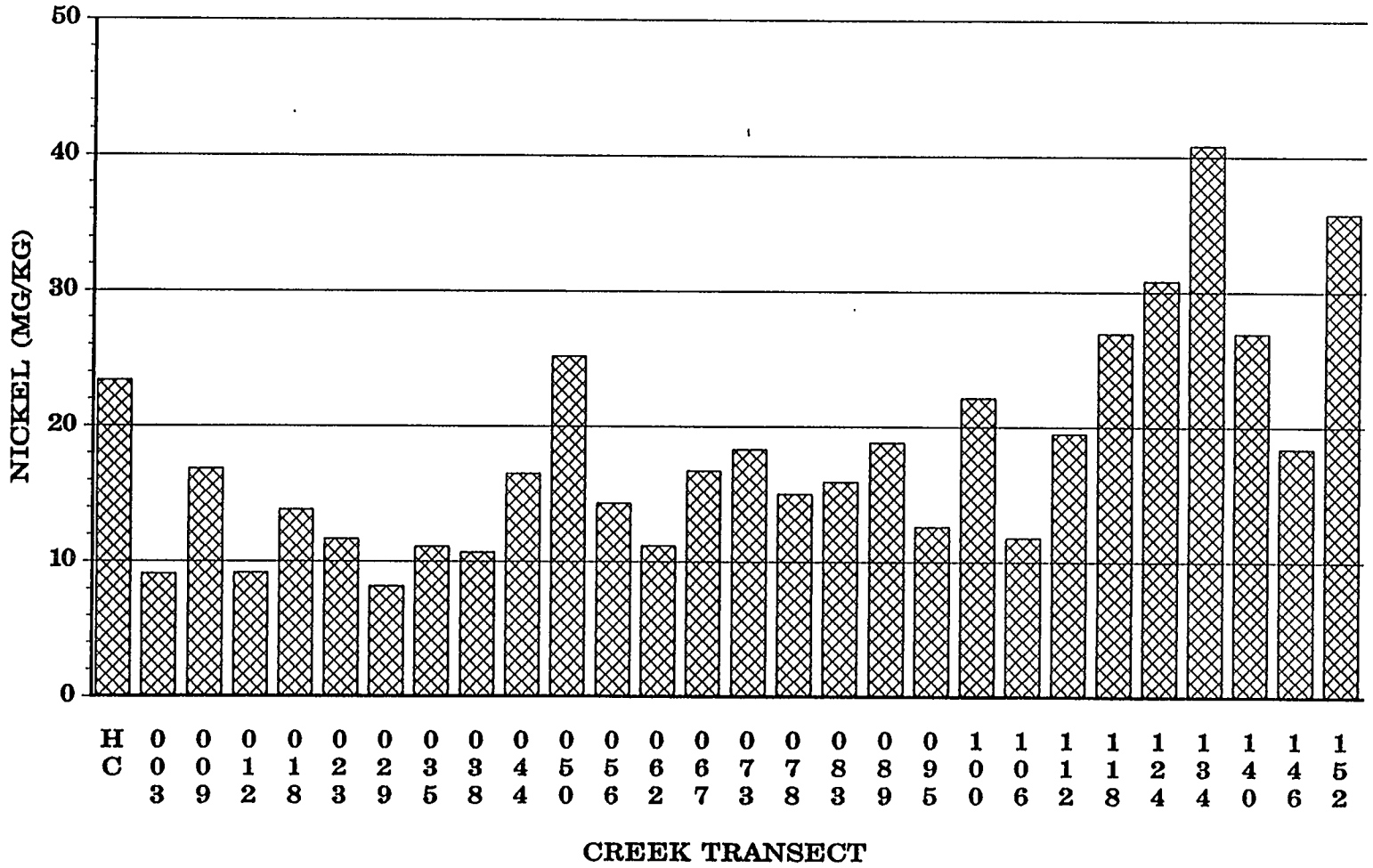


Fig. 3.45b. Nickel concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

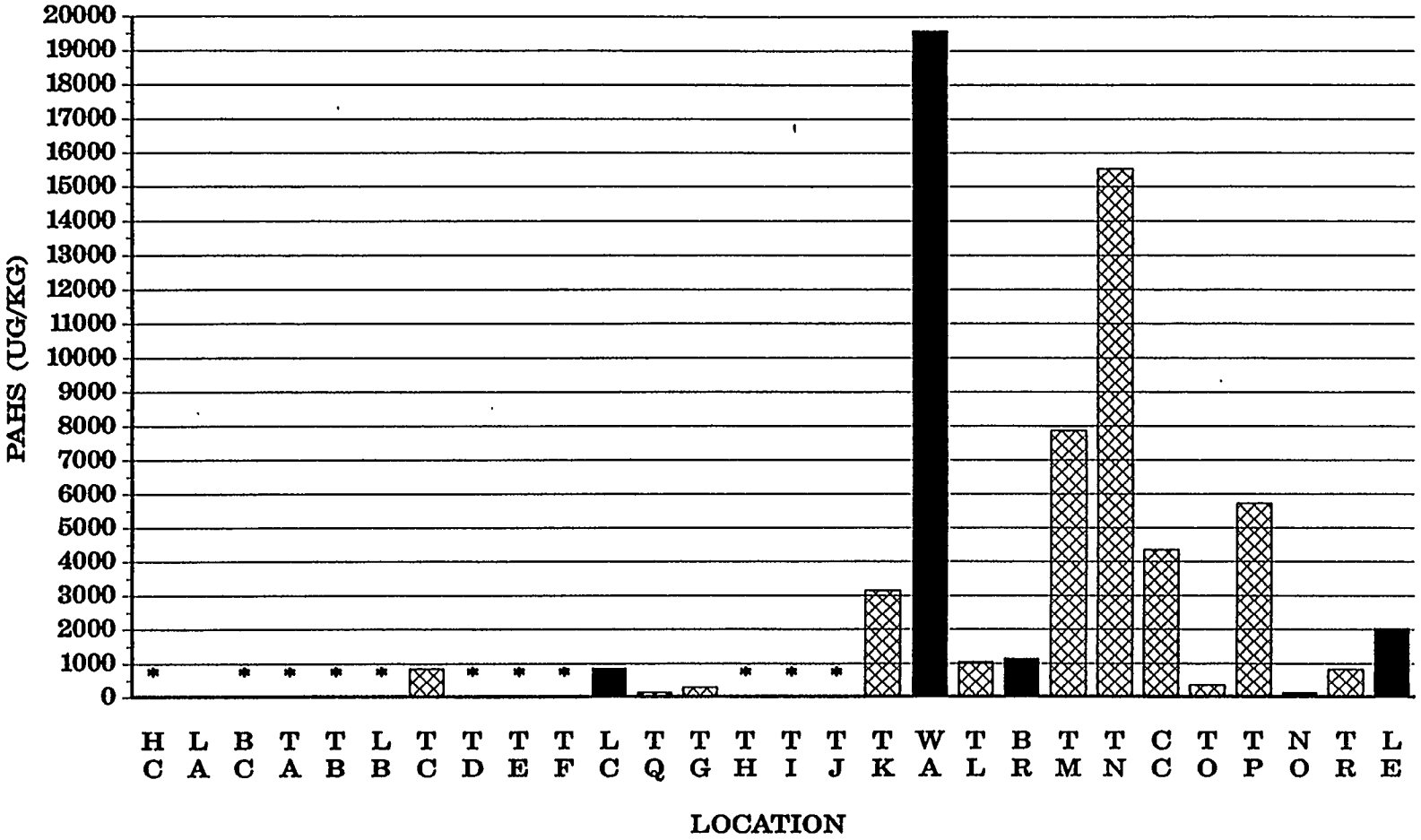


Fig. 3.46a. PAH concentrations (mg/kg) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC) (see Map 4). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

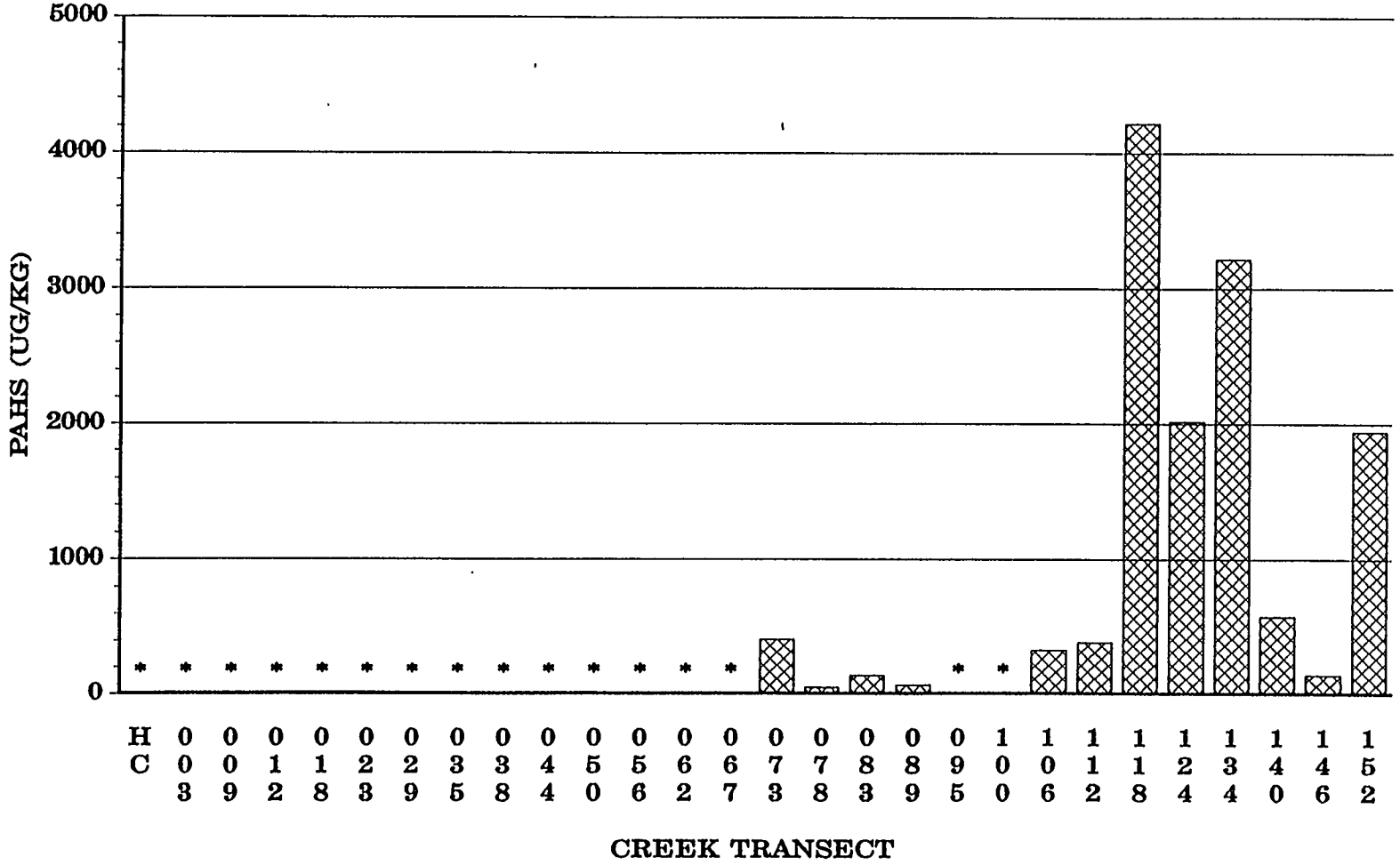


Fig. 3.46b. PAH concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

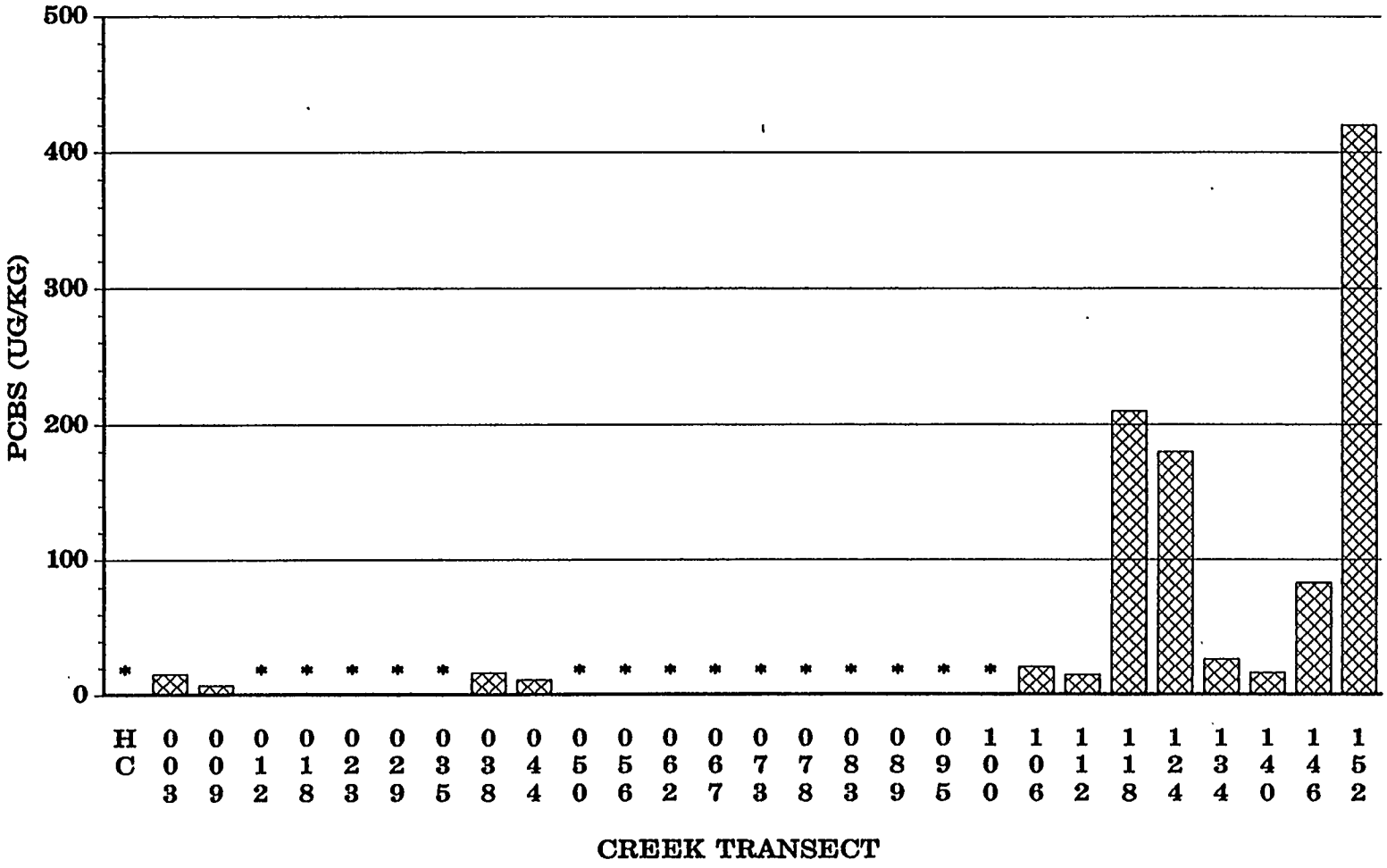


Fig. 3.47. PCB concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

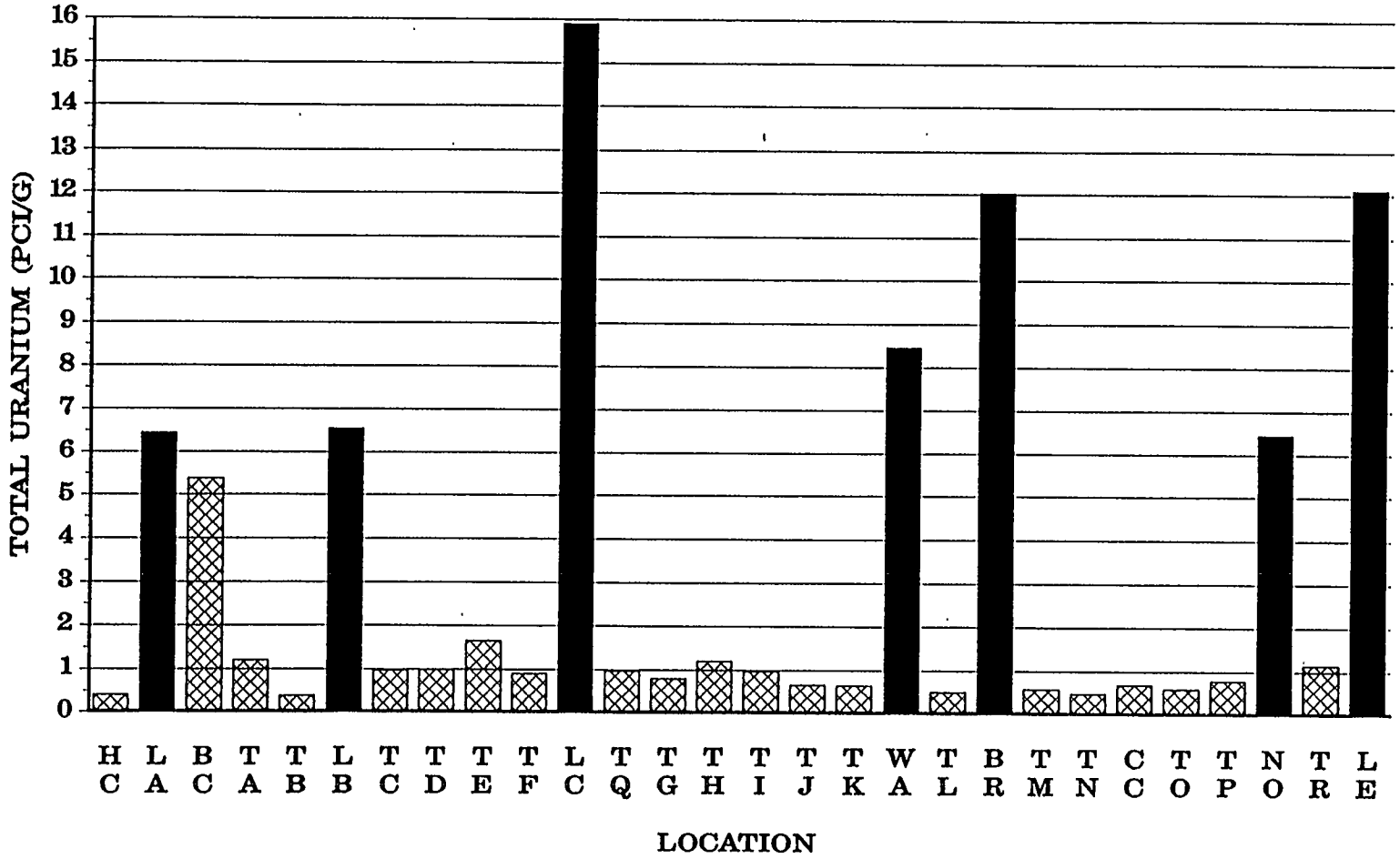


Fig. 3.48a. Total Uranium concentrations (pCi/g) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC) (see Map 4). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

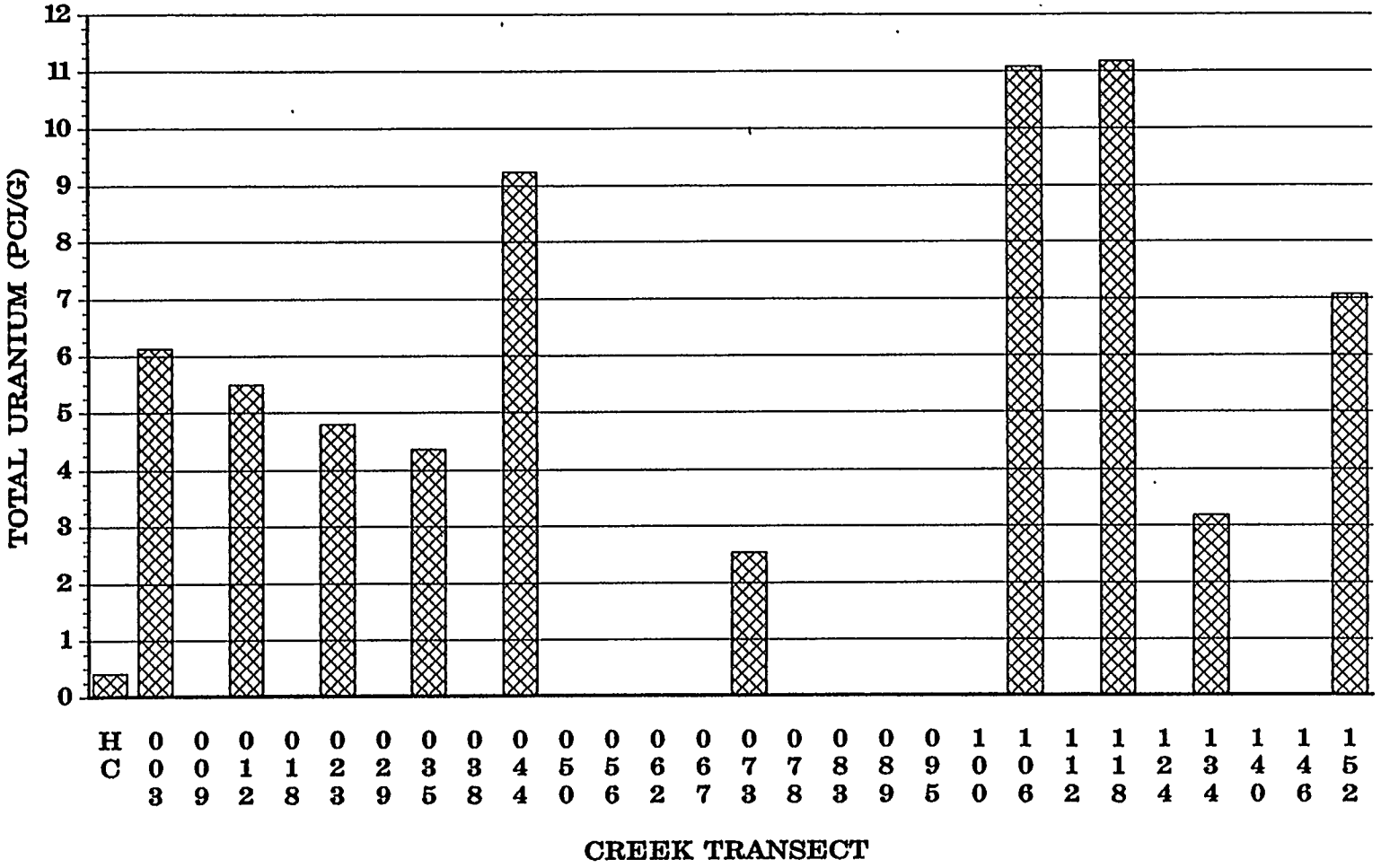


Fig. 3.48b. Total Uranium concentrations (pCi/g) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

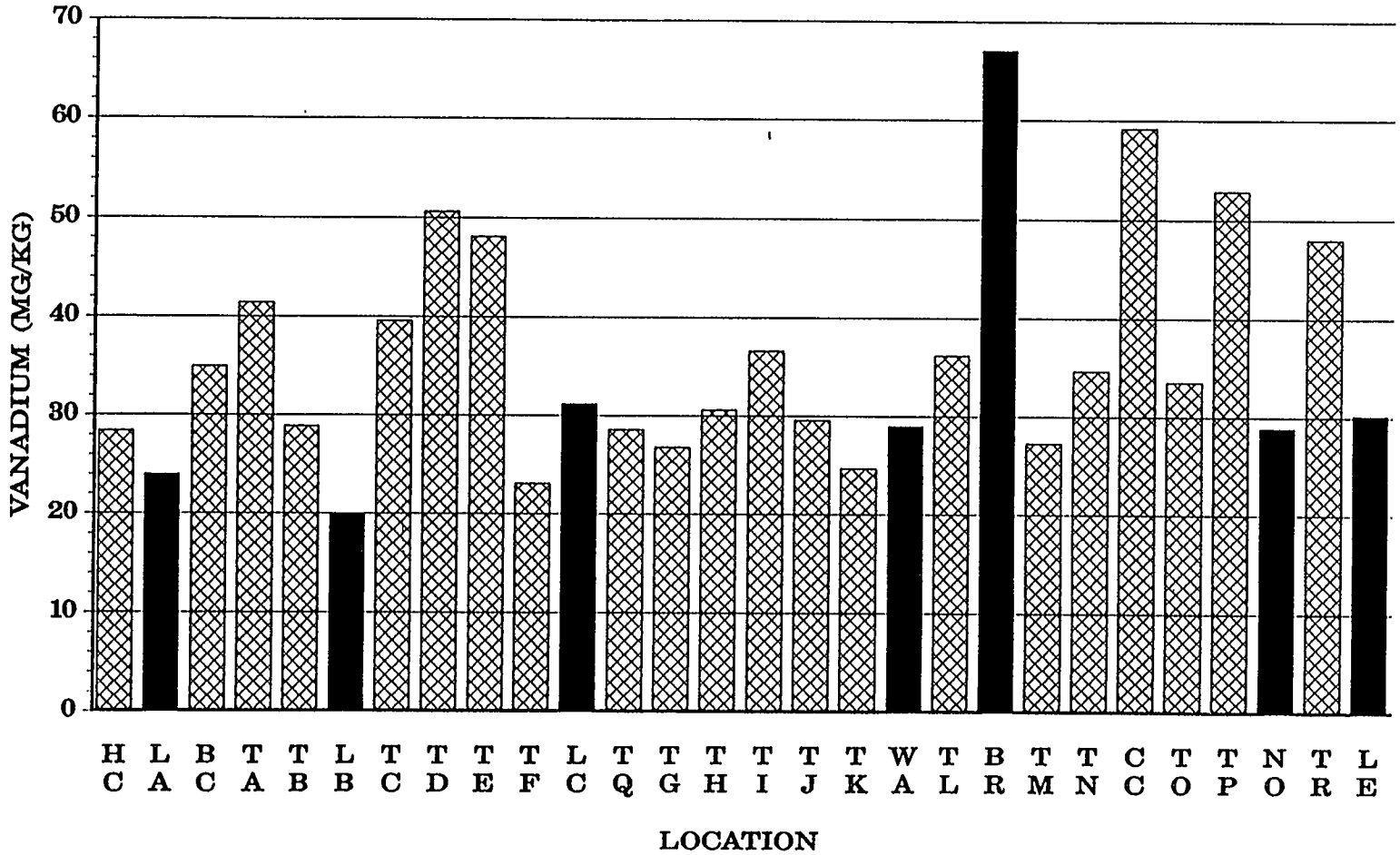


Fig. 3.49a. Vanadium concentrations (mg/kg) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC) (see Map 4). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

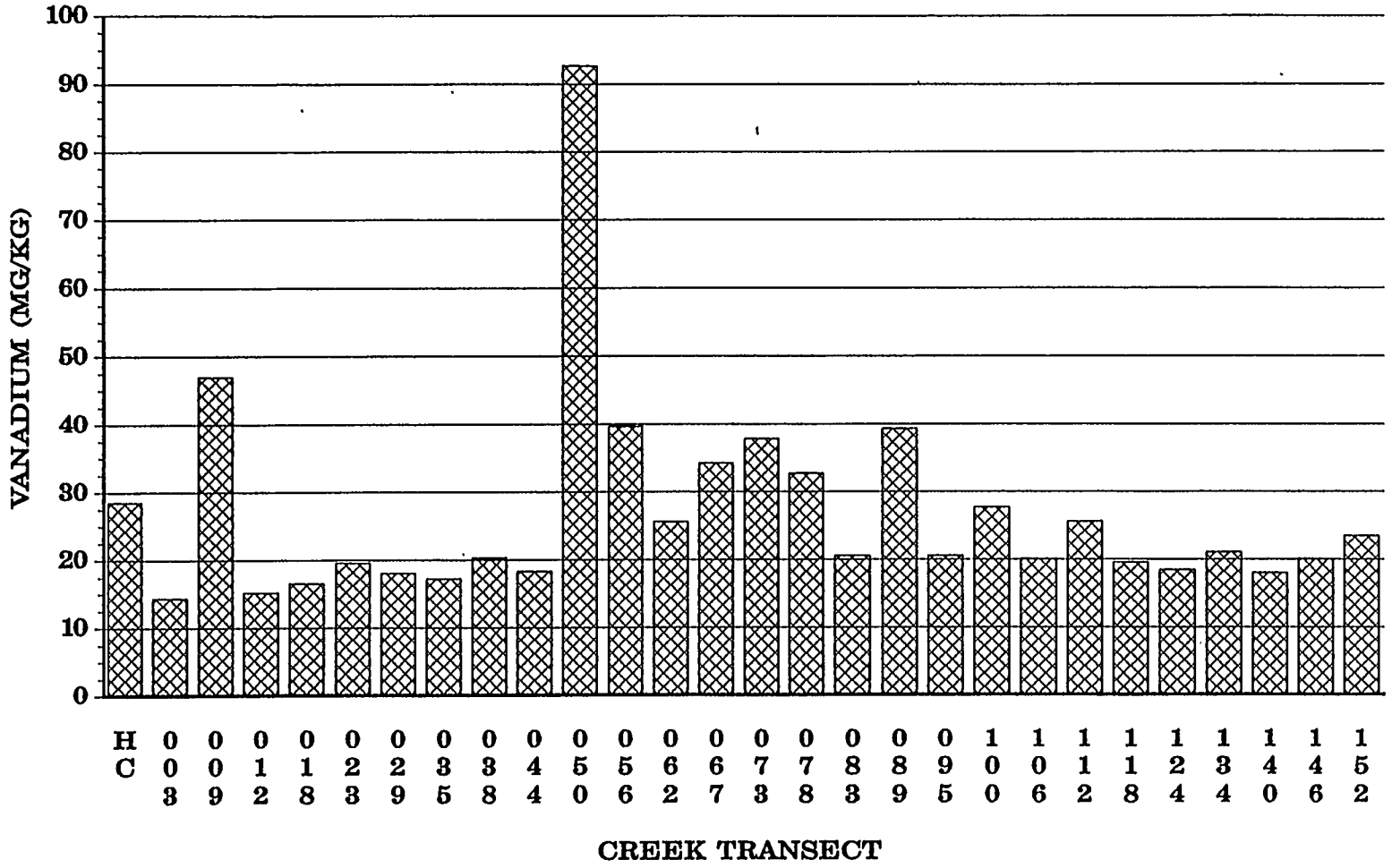


Fig. 3.49b. Vanadium concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

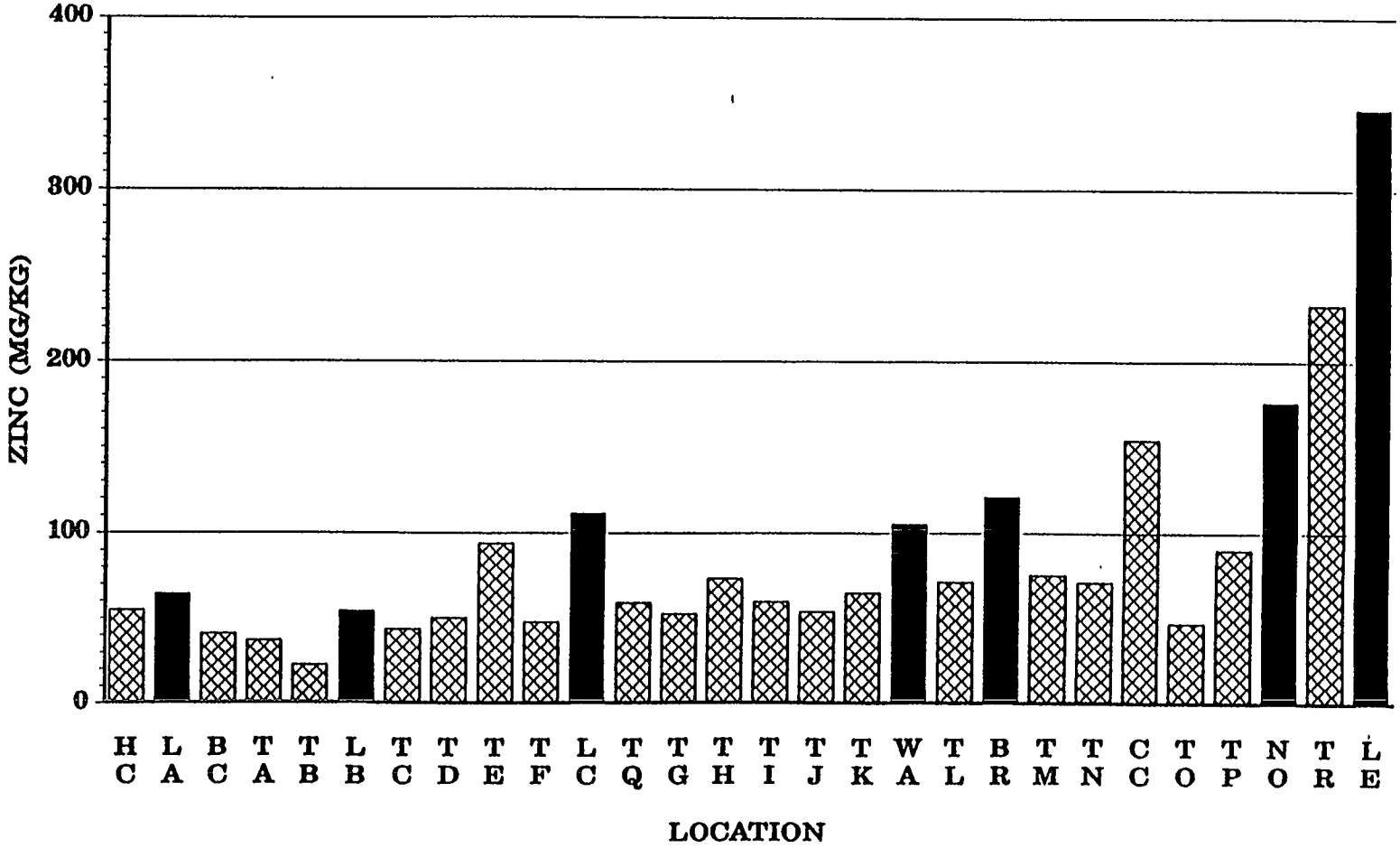


Fig. 3.50a. Zinc concentrations (mg/kg) in creek sediments from EFPC and its tributaries. Each bar represents a grab sample from the instream surface sediment. Solid bars represent samples from EFPC. Shaded bars represent tributaries to EFPC and the Hinds Creek reference site (HC) (see Map 4). Stations are plotted going upstream from left to right (see Map 4). Results less than the detection limit were set to zero and marked with an "*".

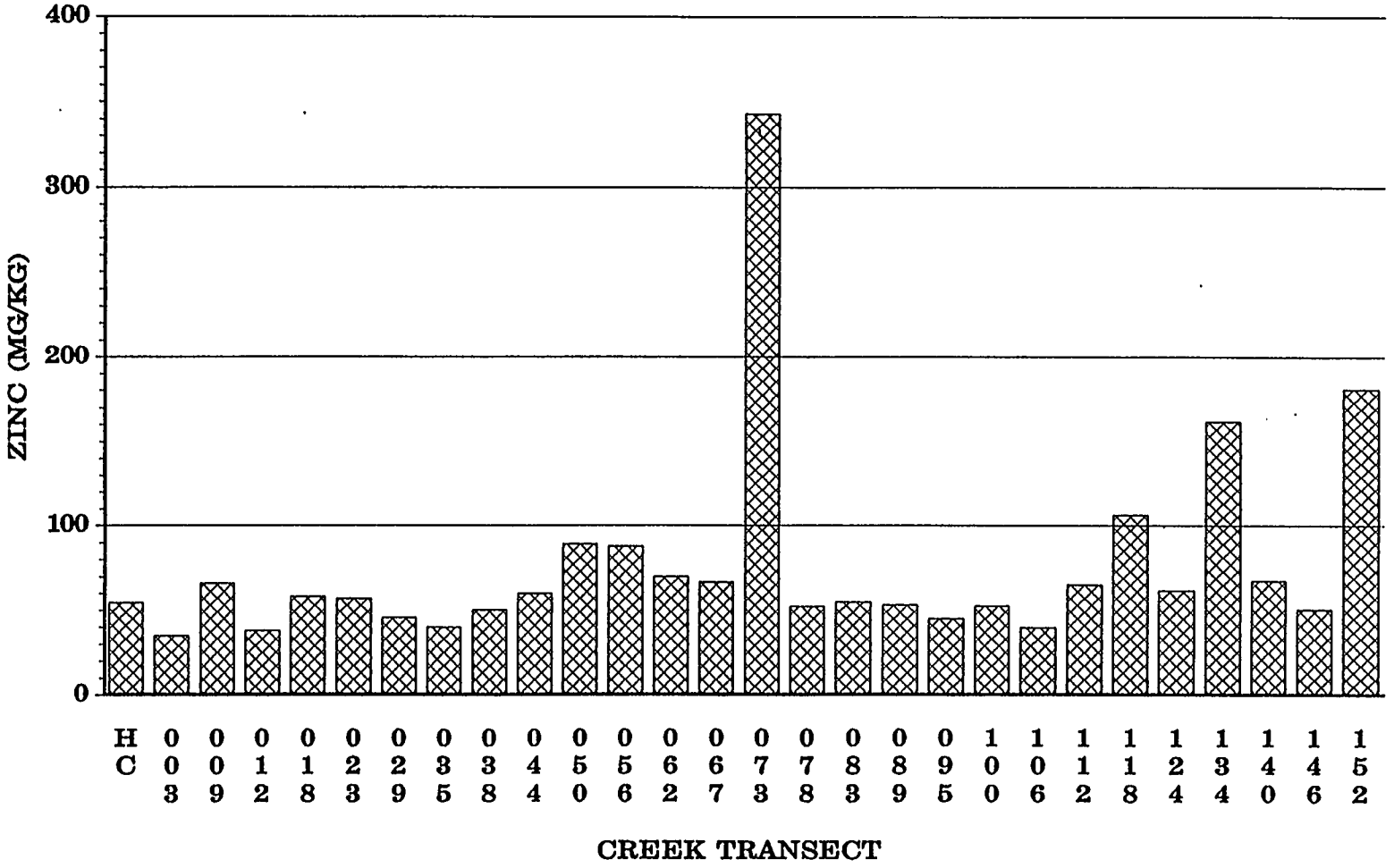


Fig. 3.50b. Zinc concentrations (mg/kg) in EFPC sediments. Each bar represents a composite of three samples taken ~200 meters apart (see Map 4 for exact sample locations). The bar is labeled with the transect number of the central sample of the composite. Transect numbers increase moving upstream (see Map 4). The average of two samples from the reference station are labeled "HC". Results less than the detection limit were set to zero and marked with an "*".

allows a distinction to be made between contaminants derived from Y-12 Plant sources (as observed in the creek sediments) and contaminants with origins other than the Y-12 Plant (as observed in the tributary sediments). The second graph (b) portrays contaminant trends along the length of the creek relative to each other. The concentrations shown by the bar graph for tributary and creek locations represent a single analysis for one sample obtained at a specific location. The concentrations shown by the bar graphs for creek transects represent a single analysis from a composite of three samples taken at three sequential locations along the creek. The two sets of graphs are not strictly comparable because averaging occurs with the composite transect samples. Moreover, the tributary and creek location samples are representative of only a specific location. The contaminant heterogeneity within the sediment also imparts a variance because the aliquot taken for analysis is relatively small compared to the field sample. Each figure allows a comparison to be made with the reference site concentration, which is the average of two samples taken at HC.

Arsenic (Figs. 3.34a and 3.34b) does not appear to be derived from the Y-12 Plant, nor are concentrations anomalously high in EFPC when compared with levels in the reference area. The highest occurrence of arsenic is in the Civic Center (CC) tributary at 25 mg/kg. Other tributaries to the creek display concentrations of arsenic in the 10 to 20 mg/kg range, which is in excess of the reference site and all but one site (BR) within the creek. No general trends or gradients appear to be present within EFPC, and the highest observed arsenic concentrations (at 7 to 8 mg/kg) are within measurement error of the reference area (at 4 to 5 mg/kg).

Barium (Figs. 3.35a and 3.35b), although not a COC, is included for completeness because it was so widely detected. It displays the highest concentration at LE (203 mg/kg), suggesting a Y-12 Plant source, but this is only slightly higher than the maximum concentration observed at the reference site (max. = 184 mg/kg). The levels seen in composite samples or individual EFPC samples are no higher than in samples from the tributaries or the reference site. A general decrease in barium is noted after Transect 089, probably reflecting the change from commercial land use to undeveloped areas. This trend is also observed with other analytes.

Beryllium (Figs. 3.36a and 3.36b) was not detected at the HC reference site (instrumental detection limit = 0.94 mg/kg). For all the composite creek samples (with the exception of Transect 050) and each of the individual creek and tributary location samples (average instrumental detection limits = 1.24 mg/kg), beryllium concentrations are at the detection limit. Beryllium is not observed at individual sampling locations until midway (TR) down the creek. Because beryllium is naturally present in soils and the levels observed within the sediments are near the detection limit, it is difficult to suggest a source (even though process knowledge would implicate the Y-12 Plant).

Cadmium (Figs. 3.37a and 3.37b) is an obvious contaminant from the Y-12 Plant. It is not observed at the reference site or any tributary. Concentrations noted in the creek are significantly higher than the instrumental detection limits of 1.1 to 1.3 mg/kg.

Cesium-137 (Figs. 3.38a and 3.38b) is found in concentrations substantially higher in the creek than in the tributaries or at the reference site. Two sources are thought to be likely as inferred from the bimodal distribution of the creek transects. Elevated levels observed at the outfall of Lake Reality (LE) decrease proportionately downstream until Transect 073. They rise again but generally decrease towards the end of the creek at Transects 012-003. The dual source is postulated because ^{137}Cs is a product of worldwide fallout. Any process that integrates fallout over a wide area is likely to demonstrate increased ^{137}Cs levels. Process water, taken from Melton Hill Lake for use at the Y-12 Plant and subsequently discharged into EFPC, is a suggested cause. Transect 073 is situated in the reach of EFPC downstream from the Oak Ridge Sewage Treatment Plant. The plant is a known source of contamination to EFPC from a spill by Quadrex and possibly through the treatment of sewage from the Y-12 Plant. Water discharged from this plant should also reflect cesium integration over a wide area.

Chromium (Figs. 3.39a and 3.39b) presents a dichotomy in assigning a source. While concentrations at the individual locations are higher than at the reference site, they are not significantly higher than in the tributaries (with the exception of LC). Additionally, only about one-half of the transect composite samples have concentrations higher than the reference site. The BR site is an area with the highest detected soil contaminant levels in the entire floodplain. It appears that creek sediments at this location also reflect this with chromium. The anomalous occurrence at LC is not understood.

Cobalt-60 (Figs. 3.40a and 3.40b) is not observed in any statistically significant quantities until location LC or Transect 062 (except for Transect 134). "Statistically significant" means that due to the uncertainty of the counting error associated with radionuclides, low reported values may be inconsequential. Negative reported values for ^{60}Co are a result of the uncertainty measurement. The presence of ^{60}Co is attributed to discharges at the Oak Ridge Sewage Treatment Plant situated downstream of location TQ and Transect 073. The occurrence of ^{60}Co at Transect 134 and absence of this analyte elsewhere from Transect 152 to 067 is not understood (especially given the location of Transect 134 along Illinois Avenue).

Copper (Figs. 3.41a and 3.41b) is obviously related to the outfall from the Y-12 Plant. The concentrations in the creek sediments leave no doubt of the source; nonetheless, it appears that the solubility of copper decreases greatly after mixing with EFPC water and precipitates out by

Transect 112. Copper concentrations in the sediments reflect background levels downstream of Transect 106.

Lead (Figs. 3.42a and 3.42b) is a common urban contaminant and is observed at relatively higher levels in the tributaries than within the creek. The only significant occurrence within the creek itself is at Transect 073, which corresponds to the Sportsman's Association Target Range. Two aliquots were analyzed from the same sample. The first aliquot demonstrated increased lead concentrations relative to the other transect values, but the levels were not anomalously high. The second aliquot displayed the 984 mg/kg seen on the graph. Lead must exist in this reach of EFPC in discrete particles as a result of lead shot/bullet fragments. This is not considered to be a serious or widespread problem; in fact, lead is not observed in anomalous quantities in Transects 078 or 067, which sampled adjacent portions of the Sportsman's Association property.

Manganese (Figs. 3.43a and 3.43b) is a common element in nature and is abundant in the EFPC watershed. Manganese concentrations are generally higher in both the tributary and the creek sediments than at the reference site, but an identifiable source is not apparent. The one exception is at Transect 009, which is downstream from the confluence of Bear Creek (which drains the west part of the Y-12 Plant). It may be, however, that the manganese and other analytes are flushed upstream to this area when water is impounded in the Watts Bar Reservoir (which creates reverse flow near the EFPC-Poplar Creek confluence). The lack of manganese at Transect 012 (which is adjacent to and immediately downstream of the confluence) supports this hypothesis.

Mercury (Figs. 3.44a and 3.44b) is confirmed by its distribution within the sediments to be a contaminant with the source at the Y-12 Plant. It is surprising that location LA contains mercury concentrations relatively higher than at the other stations, given that a decreasing gradient is generally observed moving down the creek. This may be the result of backflushing, as mentioned in the section on manganese. Transect 038 also displays unusually high mercury levels for an unknown reason.

Nickel (Figs. 3.45a and 3.45b) displays a profile similar to that for copper. The creek sediments support the Y-12 Plant as the source, but nickel concentrations rapidly drop to background levels by Transect 112. Transect 009, again, displays higher concentrations than offsetting locations.

PAHs (Figs. 3.46a and 3.46b) are presented as the sum total of carcinogenic PAHs. A cancer slope factor derived by EPA for benzo(a)pyrene has been attributed to each of the carcinogenic PAHs. Rather than selecting an individual PAH or set of PAHs that may not be

representative of the contamination level, the sum must suffice to characterize their distributions. PAHs, in various combinations, are products of incomplete combustion of hydrocarbons and are present in virtually every urban environment due to the presence of asphalt, coal, oil, flyash, etc. The sediment analyses demonstrate that both the creek and its tributaries contain large amounts of PAHs. In fact, tributaries TM and TN have 4 to 7 times as many PAHs as does the outfall of Lake Reality (LE) or the first tributary encountered downstream (TR). The WA area contains high levels of contaminants in the floodplain soils, but concentrations of PAHs in the creek sediments at this location were not expected. In essence, PAHs are located in the commercial areas along Illinois Avenue and Jefferson Avenue (near the tennis courts) but decrease rapidly thereafter.

PCBs (Fig. 3.47), plotted as sum total of PCBs (1254 and 1260 were the only isomers listed), were not observed at the tributary or creek sediment locations in excess of the contract detection limit (220 μg/kg) but were noted in the composite creek samples from Transects 152 to 106. While several transects had detects noted by the laboratory, the highest detects were at Transect 152 (at 420 μg/kg) and Transects 118 and 124 (both at ~200 μg/kg). It would appear that the Y-12 Plant was the probable source, but PCBs are common contaminants in the urban environment. For example, the noted detects are present in the commercial area along Illinois Avenue, and Transect 124 is downstream of the CC tributary (which drains a large portion of the city of Oak Ridge) and an electrical substation with transformers (at the intersection of Illinois Avenue and the Oak Ridge Turnpike).

Silver (no graph included) was not detected in either the creek or tributary location samples, the creek transect samples, or the reference site. It was listed as a COC because of its presence in a dark ooze that was discharged from the sediments when heavy equipment crossed the creek (discussed previously). Pg 3-95

Uranium (Figs. 3.48a and 3.48b) is displayed as the sum total activity of ^{234}U, ^{235}U, and ^{238}U isotopes in pCi/g. The obvious comparison of creek sediments against the tributaries and reference site indicates a Y-12 Plant source. The profile is somewhat erratic due to missing values rejected in the data validation process.

Vanadium (Figs. 3.49a and 3.49b) commonly occurs within the tributaries at elevated levels relative to the creek sediments. Only the BR location and Transect 050 appear anomalous. BR may reflect the known high contaminant levels seen in the floodplain soils, but the occurrence at the transect is not understood. It cannot be confirmed that the Y-12 Plant is a source for vanadium.

Zinc (Figs. 3.50a and 3.50b) displays anomalously high concentrations in the upper reaches of EFPC, especially at location LE. The overall levels of zinc in the creek sediments appear higher than in the tributaries, but urban sources may also be indicated by the concentrations observed at TR and CC. A high concentration is observed at Transect 073 for probably the same reasons as noted for lead.

Summary. Creek sediments can be used to assess historical contaminant contributions and to distinguish source areas. The COCs identified for EFPC sediment are the same as those identified for the floodplain soil. Overall, the contaminant concentrations are lower in the sediment than in the soil and occur in a less predictable manner. Several analytes are clearly derived from the Y-12 Plant and are not observed in the tributary sediment: cadmium, ^{137}Cs, copper, mercury, nickel, and uranium. Other analytes are likely sourced from the Y-12 Plant but are also naturally occurring in the environment or are typical urban contaminants (barium, chromium, vanadium, and zinc; PAHs and PCBs). The metals are generally found at higher concentrations in the upper portion of the creek than in the lower part, but exceptions do occur. Interestingly, the reach of EFPC consistently showing the highest concentrations for most analytes is located near the intersection of Illinois Avenue and the Oak Ridge Turnpike (Transects 118 to 134). The tributary, CC, which drains a large area of the city of Oak Ridge, may influence this portion of the creek. Chromium, copper, and lead were noted during storm flows for this tributary. PAHs and PCBs are two groups of organic compounds that appear to have both a Y-12 Plant and a commercial source. The first sample (#152) immediately below Lake Reality has relatively higher levels of both compounds, but concentrations significantly decrease until the aforementioned contaminated section of the creek is reached. These compounds are found at very low levels once EFPC enters the undeveloped and wooded areas. In addition, localized contaminated hot spots can be expected to be found that were not discovered during the EFPC RI. The isolated occurrence of high levels of mercury and PCBs as an "oily substance" also may occur elsewhere in the creek and floodplain.

3.2.2.5 Sediment mapping

To determine the location and distribution of sediments within EFPC, mapping was undertaken in the spring of 1992. Field crews traversed the creek from Lake Reality to the confluence of EFPC with Poplar Creek and marked locations of sediment accumulation on a set of 50 topographic maps, at a scale of 1 in.= 50 ft (contour interval = 1 ft), which were compiled for this project. Many reaches of EFPC are barren of sediment and have a bedrock

base. The accumulations of sediments that do exist are primarily coarse-grained in nature. Apparently, the normal stream velocity and frequent storm events carry fine-grained sediments downstream to Poplar Creek.

Ground control for mapping purposes consisted of staked and labeled steel rods every 100 m (328 ft) along the creek. In addition to the natural topography and physical features within the floodplain, the coordinate system that defined the staked locations was also presented on the maps. Depth was established by viewing barren sections of the creek bed adjacent to sediment accumulations and estimating thicknesses or by driving a steel bar into the sediment until refusal. The data derived from this activity are intended to be used as a gross estimation of accumulated sediment locations and thicknesses that represent conditions at that time. Because of the transient nature of sediments within EFPC, a more precise determination is not warranted at this time.

The maps representing field descriptions of sediment locations and thicknesses are too voluminous to be included in this RI report. They will be submitted as part of the Administrative Record for permanent storage, and a computer aided design (CAD) map with less detail will be available for review. Table 3.22 shows the estimated volume of sediments by easting (parallel to the Turnpike) or northing (parallel to Illinois Ave.) administrative coordinates. An estimated 53,800 m^3 (1.9 mil ft^3) of sediment are present within EFPC; however, the volumes that require remediation are considerably less. It is likely that resampling and remapping of the creek will be required concurrently with the remedial actions if these actions require sediment removal.

3.2.3 Sediment Geotechnical Data

3.2.3.1 Scope of investigation

Historical data reported a correlation between mercury content and particle size classes of sediments/soils (<500μm) in the EFPC floodplain (TVA 1985) but did not explore this relationship for other potential contaminants. As part of the Phase Ia RI, the relationship between particle size and content of other potential contaminants was determined through geotechnical investigation.

3.2.3.2 Sample collection

Sediment samples were collected from the stream channel at each of the three study sites (NO, BR, WA) and at each of the surface water monitoring locations. Samples were extracted with stainless steel Shelby tubes or bucket augers (where necessary). The sediment samples were

Table 3.22. Sediment volume within EFPC

Administrative coordinates	Surface area (sq.ft)	Depth (ft)	Volume (cubic ft)
E18582-18730	11250	5.5	61875
E18730-19055	21500	4.45	95675
E19055-19546	26500	3.6	95400
E19546-19774	26250	3.46	90825
E19774-19824	5250	2.5	13125
E19824-20268	33500	2.67	89445
E20268-20681	31000	2.54	78740
E20681-21292	24500	3.41	83545
E21292-21390	31750	2.4	76200
E21390-21310	5000	2.03	10150
Tributary			
E21325-21269	1000	0.625	625
E21262-21355	10750	0.94	10105
E21355-21843	14000	1.412	19768
E21843-22747	17000	1.02	17340
E22797-23080	8750	1.11	9712.5
E23070-23293	10750	0.68	7310
E23293-23681	10750	1.08	11610
E23706-23915	16250	0.9	14625
E23915-23910	750	1.17	877.5
E23935-24306	6250	1.19	7437.5
E24434-24994	14250	1.51	21517.5
E25172-25685	15000	1.3	19500
E25795-26068	5250	1.06	5565
E26116-26139	500	0.5	250
E26226-26276	1250	1.27	1587.5
E26301-26347	500	1	500
E26416-26562	2000	0.82	1640
E26689-26814	750	0.7	525
E26843-26922	3250	0.76	2470
E26972-27007	500	0.67	335
E27300-27365	500	0.67	335
E27265-27290	250	0.67	167.5
E27342-27405	500	1	500
E27508-27550	250	1.5	375
E27660-27662	500	1	500
E27703-27733	500	1	500
E27890-27911	250	0.67	167.5
E27896-27914	250	0.74	185
E28036-28056	250	0.5	125
E28195-28235	250	0.33	82.5
E28453-28563	2750	0.69	1897.5

Table 3.22 (continued)

Administrative coordinates	Surface area (sq.ft)	Depth (ft)	Volume (cubic ft)
E28693-28833	750	0.52	390
E28841-28951	3750	0.74	2775
E28939-29370	16000	0.875	14000
E29477-29437	6750	0.84	5670
E29437-29667	5500	0.73	4015
E30153-30223	250	1	250
E30333-30541	4250	0.75	3187.5
E30461-31089	27750	0.98	27195
E30611-31029	15000	0.69	10350
E31077-31337	1000	3	3000
E31302-31397	1500	0.95	1425
E31475-31565	1750	0.75	1312.5
E31655-31710	3500	0.92	3220
E31703-31908	7250	1.28	9280
E31973-32073	3000	1.22	3660
E32312-32342	250	1.17	292.5
E32340-32570	3250	0.95	3087.5
E32590-33030	4750	1.35	6412.5
E32490-32560	5250	1	5250
E32485-32620	2250	0.53	1192.5
E32650-33196	26250	1.63	42787.5
E33206-33436	5500	1.44	7920
E33464-33767	22500	1.63	36675
E33767-34063	12500	1.75	21875
Tributary			
E34095-34150	750	1.25	937.5
E34293-34478	9500	1.22	11590
E34538-35332	24500	1.18	28910
E35552-35602	11500	1.29	14835
E35562-35597	500	0.5	250
E35670-35840	4950	1.81	8959.5
E35880-36447	32000	1.45	46400
E36513-36945	29750	1.45	43137.5
E37013-37606	15750	1.41	22207.5
E37606-38147	9750	2.05	19987.5
E38255-38455	8000	1.24	9920
E38485-38565	3000	1.29	3870
E38573-38713	4500	1.25	5625
E38713-39111	13750	1.63	22412.5
E39161-39540	11000	1.325	14575
E39540-39955	13750	1.17	16087.5
E40045-40165	4750	0.76	3610

Table 3.22 (continued)

Administrative coordinates	Surface area (sq.ft)	Depth (ft)	Volume (cubic ft)
E40165-40364	14750	1.44	21240
E40374-40732	9750	0.965	9408.75
E40747-40802	250	1.75	437.5
E40832-41020	3500	1.4	4900
E41035-41288	14000	1.53	21420
E41298-41418	1500	1.5	2250
E41526-41706	4750	2.03	9642.5
E41736-41916	1750	1.33	2327.5
E42009-42094	750	1.5	1125
E42064-42094	750	1.5	1125
E42134-42322	7250	1.44	10440
E42322-42462	2500	0.61	1525
E42432-42282	8500	1.25	10625
E42044-42154	8250	1.14	9405
E42154-42670	11250	1.06	11925
E42665-42750	500	1	500
E42730-42900	1750	1	1750
E42998-43138	4000	1	4000
E43163-43148	1500	1.5	2250
E43241-43366	1000	0.5	500
E44746-44906	4000	1.5	6000
E44971-45206	2000	1.5	3000
E45255-45295	1000	0.5	500
E45285-45335	750	0.67	502.5
E45355-45295	500	0.625	312.5
E45245-45175	1500	1.5	2250
E45162-45175	500	1	500
E45205-45255	2000	2.17	4340
E45235-45270	750	1.39	1042.5
E45315-45355	250	0.5	125
E45375-45505	7500	0.44	3300
E45533-45603	500	0.375	187.5
E45653-45853	4000	1.32	5280
E45901-46439	8000	1.19	9520
E46439-46637	7250	1	7250
E46687-46915	7750	0.67	5192.5
E46945-47378	10250	1.41	14452.5
E47511-47561	500	1.75	875
E47571-47631	1250	0.95	1187.5
E47761-47899	2500	1.22	3050
E48030-48070	250	1.5	375
E48127-48187	750	0.83	622.5

Table 3.22 (continued)

Administrative coordinates	Surface area (sq.ft)	Depth (ft)	Volume (cubic ft)
E48396-48466	1000	0.35	350
E48466-48904	6500	1.29	8385
E48172-48192	250	0.5	125
E49380-49470	750	1	750
E49708-49778	500	2.83	1415
E49948-50196	6250	0.99	6187.5
E50364-50366	11750	1.19	13982.5
E50366-50494	15000	1.32	19800
E50600-50752	3500	0.92	3220
E50832-51160	9000	1.75	15750
E41230-51388	3500	1.18	4130
E51726-51856	1750	2.58	4515
E52030-52174	3250	2.125	6906.25
E52194-52582	8750	1.57	13737.5
E52861-52981	3500	1.78	6230
E53029-53417	9500	2.37	22515
E53642-54348	19250	2.24	43120
E54531-54681	4500	2.61	11745
E54817-55475	21750	2.11	45892.5
E55515-56051	20500	1.43	29315
E56061-56459	16750	0.9	15075
E56489-56617	2250	0.97	2182.5
E56628-56818	3000	1	3000
E56986-57176	3750	1.89	7087.5
E57592-58010	10750	1.33	14297.5
E58190-58378	4750	0.65	3087.5
N39658-39770	3500	1.28	4480
E59054-59583	11250	1.32	14850
E59620-59670	750	1.17	877.5
E59711-59771	4500	1.29	5805
N38673-38883	3250	0.39	1267.5
N38523-38633	1500	0.67	1005
Civic Center			
N37709-38217	10250	1.16	11890
N37344-37360	1250	0.72	900
N37238-37344	1500	0.85	1275
N36913-36993	1250	0.835	1043.75
N36595-36855	3000	1.04	3120
N36497-36557	500	0.83	415
Tributary			
N35277-35377	3500	0.33	1155
N35563-35643	3500	1.085	3797.5

Table 3.22 (continued)

Administrative coordinates	Surface area (sq.ft)	Depth (ft)	Volume (cubic ft)
N35264-35314	500	0.5	250
N35174-35214	250	0.5	125
N34608-34648	750	1	750
N34463-34518	250	1.25	312.5
N33852-33942	500	0.625	312.5
N33852-33892	250	1	250
N33464-33832	7250	1.98	14355
N33196-33444	7500	0.95	7125
N33136-33176	750	0.83	622.5
N33010-33050	250	1.5	375
N32948-32988	250	0.5	125
N32480-32530	250	0.5	125
N32282-32362	750	0.5	375
TOTAL SEDIMENT VOLUME			1,918,099

shipped to Singleton Laboratories, where they were dry-sieved and separated into three fractions in accordance with ASTM D421 and ASTM 2217 Rev. 1985. The samples were segregated into three particle-size classes:

Fine grain: < 75 μm (passed through a # 200 sieve)
Medium grain: 75 μm - 425 μm (retained on # 200 sieve)
Coarse grain: > 425 μm (retained on # 40 sieve)

Each size fraction for a given site was transferred to CompuChem Laboratory and analyzed for mercury, uranium, and PCBs. Figures 3.51 through 3.53 show the results of each contaminant analysis for the three particle-size classes at the seven instream EFPC sites. Difficulty was encountered in obtaining sufficient volume of the fine size fraction to perform complete analyses. The analytical priority was established as mercury, uranium, and then PCBs. Where insufficient volume precluded sample analysis, an "NA" is included in the graph.

3.2.3.3 Evaluation

Results from this part of the EFPC RI do not support the contention that contaminants are preferentially concentrated in the finer size fractions for instream sediments. Fine-grained sediments are generally less abundant than coarser-grained sediments, and this may inhibit partitioning to a degree. In the lower third of the creek (LC, LB, LA), some contaminant partitioning may be represented. Absolute differences are observed for each contaminant at the lower three creek stations; however, only the fine-size fraction for mercury and PCBs at LB exhibit a significant difference from the medium and coarse classes.

3.2.4 Groundwater Data

Groundwater was investigated as a potential pathway for contaminant migration within the EFPC floodplain. The conceptual model for groundwater indicates that the EFPC valley is comprised of an alluvial aquifer receiving surface water from Bear Creek Valley and recharge from the watersheds along Black Oak and East Fork Ridges. Deep groundwater flows paths are not postulated to cross these surface water divides. Most of the groundwater transport within the LEFPC floodplain is assumed to take place within the alluvium. Subsurface migration routes for water and contaminants associated with the alluvium include the following:

- downward migration of water and contaminants into the floodplain alluvium;

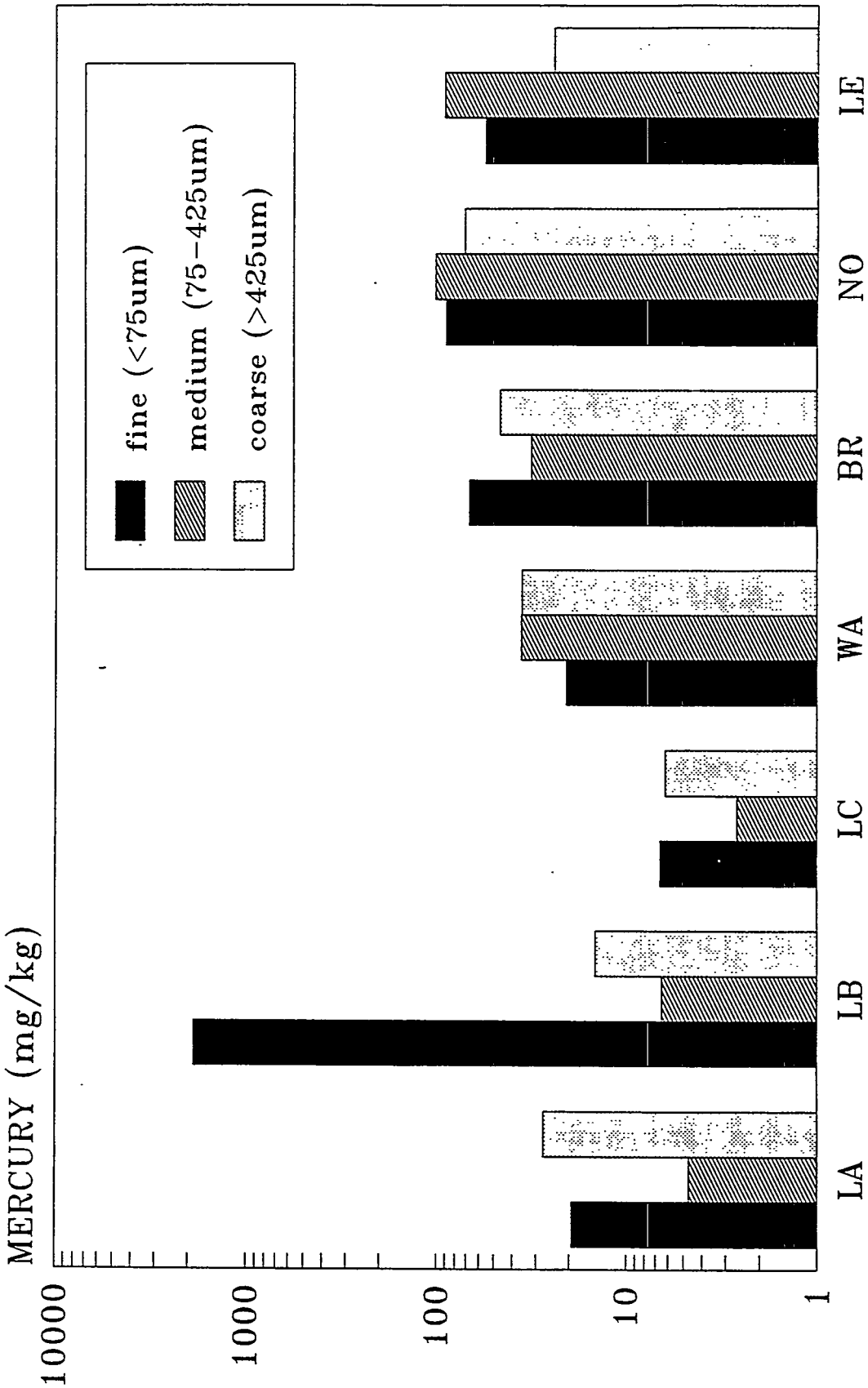


Fig. 3.51. Mercury concentrations (mg/kg) by size fractions in sediments. Sediment sampling stations are moving upstream from left to right.

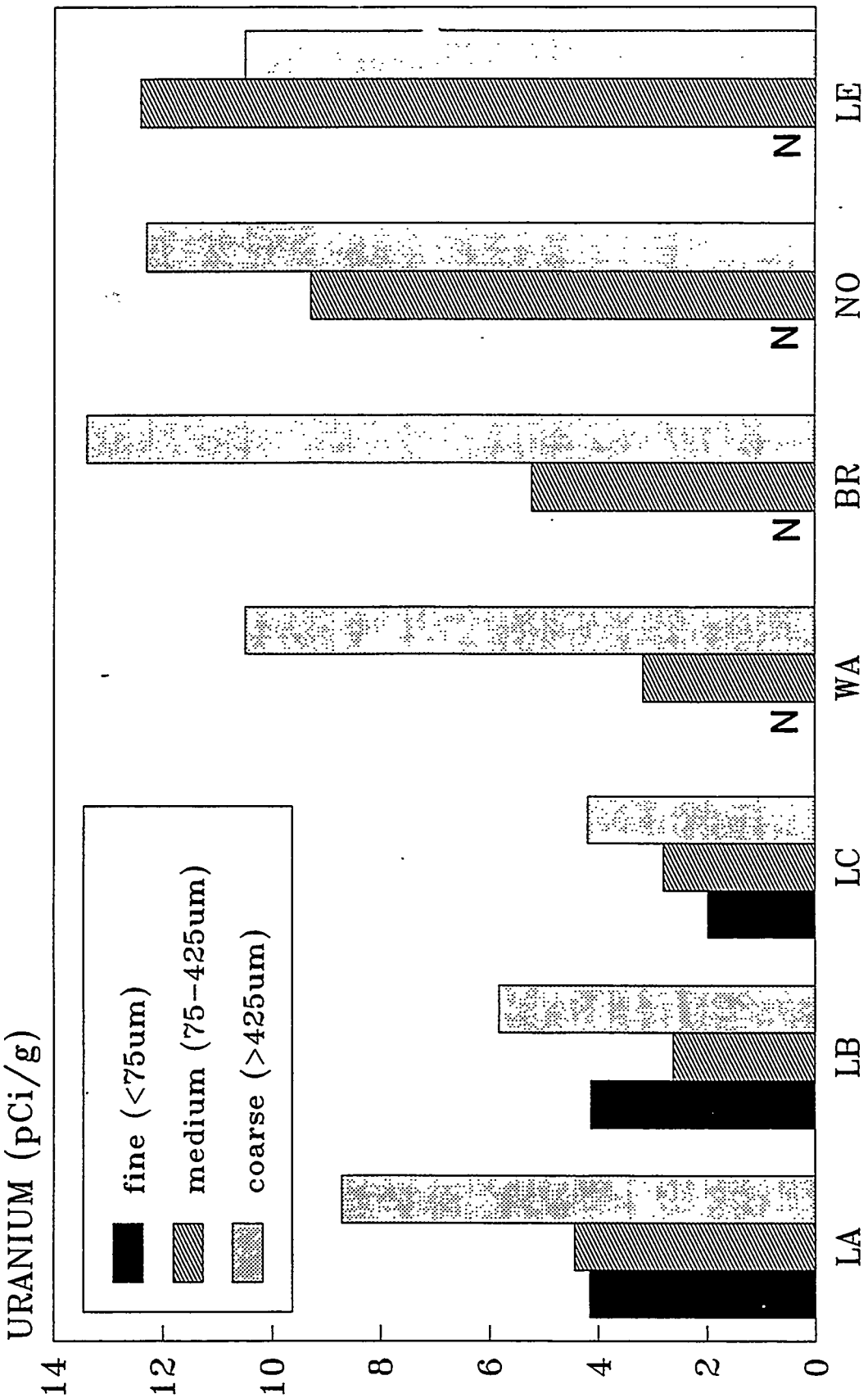


Fig. 3.52. Total isotopic uranium activity (pCi/gm) by size fraction in sediments. Sediment sampling stations are moving upstream from left to right. Size fractions noted with "N" were not analyzed due to insufficient sample.

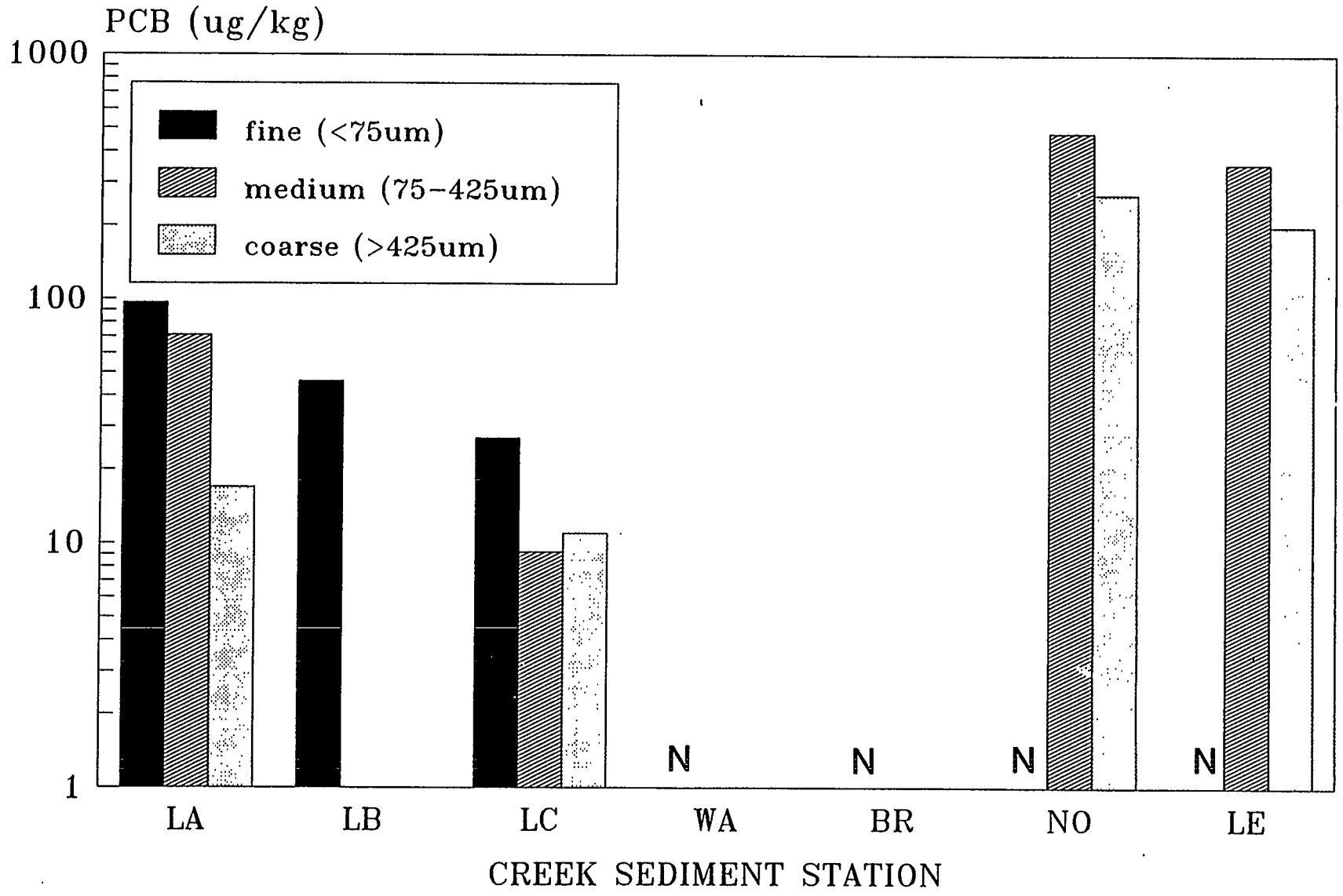


Fig. 3.53. **Total PCB concentration (μg/kg) by size fraction in sediments. Sediment sampling stations are moving upstream from left to right. Size fractions noted with "N" were not analyzed due to insufficient sample. Some size fractions were below detection limit.**

- lateral transport of water and contaminants between the alluvium and the surface water/sediment system; and

- fluxes between the bedrock and surface water/sediment, which are assumed to be quantitatively small, to be two-way, and to account for "gaining" and "losing" stream reaches within the drainage system.

The first two of these migration routes constitute the major mode of alluvium-surface water interaction in the floodplain subsystem under normal flow conditions.

Twenty-two wells were sampled for the complete suite of analytes for 4 consecutive quarters (1 year). Monitoring wells were distributed along the upper half of the creek's length. The wells were situated to maximize detection of contaminants within the floodplain (i.e., downstream of Lake Reality), in areas of known floodplain contamination, and immediately adjacent to the creek bank. The sampling design allowed groundwater to be evaluated on a temporal as well as a spatial basis.

Four of the 22 wells were deep wells screened in the bedrock. Groundwater field parameters and analytical results were examined to ascertain whether a deep aquifer should be evaluated separately as part of the site model. Examination of the lithologic logs did not support the contention of the presence of an aquitard between the alluvium and bedrock. Hydrogeochemical modeling concluded that no difference could be discerned between shallow and deep groundwaters. More importantly, the modeling indicated that the geochemistry of the EFPC groundwater is such that mercury is not likely to persist in a dissolved phase.

COCs for groundwater include the metals and radionuclides listed for soils but none of the organic compounds. Total analyses (unfiltered) contained much higher contaminant concentrations than the filtered analyses. In fact, many of the filtered analyses were below the analytical detection limits, which indicates that the majority of contamination is due to suspended sedimentation within the water column and not within the groundwater medium itself.

No spatial or temporal gradient or plume of contamination was observed from the groundwater monitoring results. Higher levels of most contaminants (including mercury) were noted in the wells located in the upper reaches of the floodplain, which also have elevated levels of soil contamination.

3.2.4.1 Scope of investigation

Historical Data. Energy Systems has ongoing groundwater monitoring for the presence of metals, uranium, and organics in three wells below Lake Reality (Energy Systems 1991). The USGS has analyzed groundwater for metals, radionuclides, and organics in 16 shallow-aquifer wells at sites of known mercury contamination along the floodplain and in two background wells installed at separate sites in the floodplains along two small streams in the greater Knoxville area. These sites were sampled at two separate times (Carmichael 1989).

The Energy Systems monitoring of three wells in EFPC below Lake Reality failed to detect VOCs. Dissolved mercury at these sites was below the limits of detection. The USGS survey of shallow wells in the EFPC floodplain (Carmichael 1989) produced similar results but indicated the presence of dissolved uranium in the groundwater.

Water samples collected from the USGS observation wells in 1987 were analyzed for a wide range of substances included on the EPA's Priority Pollutant and Superfund Contract Laboratory Hazardous Substance lists. Unfiltered samples collected from several of the wells in the EFPC floodplain contained total and/or total-recoverable concentrations of one or more of several constituents (antimony, chromium, lead, mercury, selenium, total phenols, or ^{90}Sr) that exceeded drinking water standards specified by TDEC and/or EPA. Other substances identified in one or more of the survey wells include trichloroethene, trans-1,2-dichloroethene, benzo(a)anthracene, benzo(b)fluoranthene, chrysene, 3,3'-dichlorobenzidine, di-n-butylphthalate, pyrene, and N-nitrosodiphenylamine. Both total and dissolved concentrations of uranium exceeded 1.0 μg/L in samples from nearly 70% of the wells examined in the EFPC floodplain. Comparison of the results of total and dissolved uranium indicates that dissolved uranium composed the bulk of the total concentration in the majority of the samples where both total and dissolved concentrations were detected.

Comparison of the results of total and/or total recoverable trace-metal fractions with those from the dissolved fractions indicates that with the exception of uranium, all trace metals identified in the samples were associated principally with silt and clay particles suspended in the water samples and not with the water itself. Thus, the USGS investigation indicated that, except for uranium, shallow aquifer water near EFPC does not appear to contain trace metals in concentrations exceeding the TDEC and/or EPA drinking-water standards.

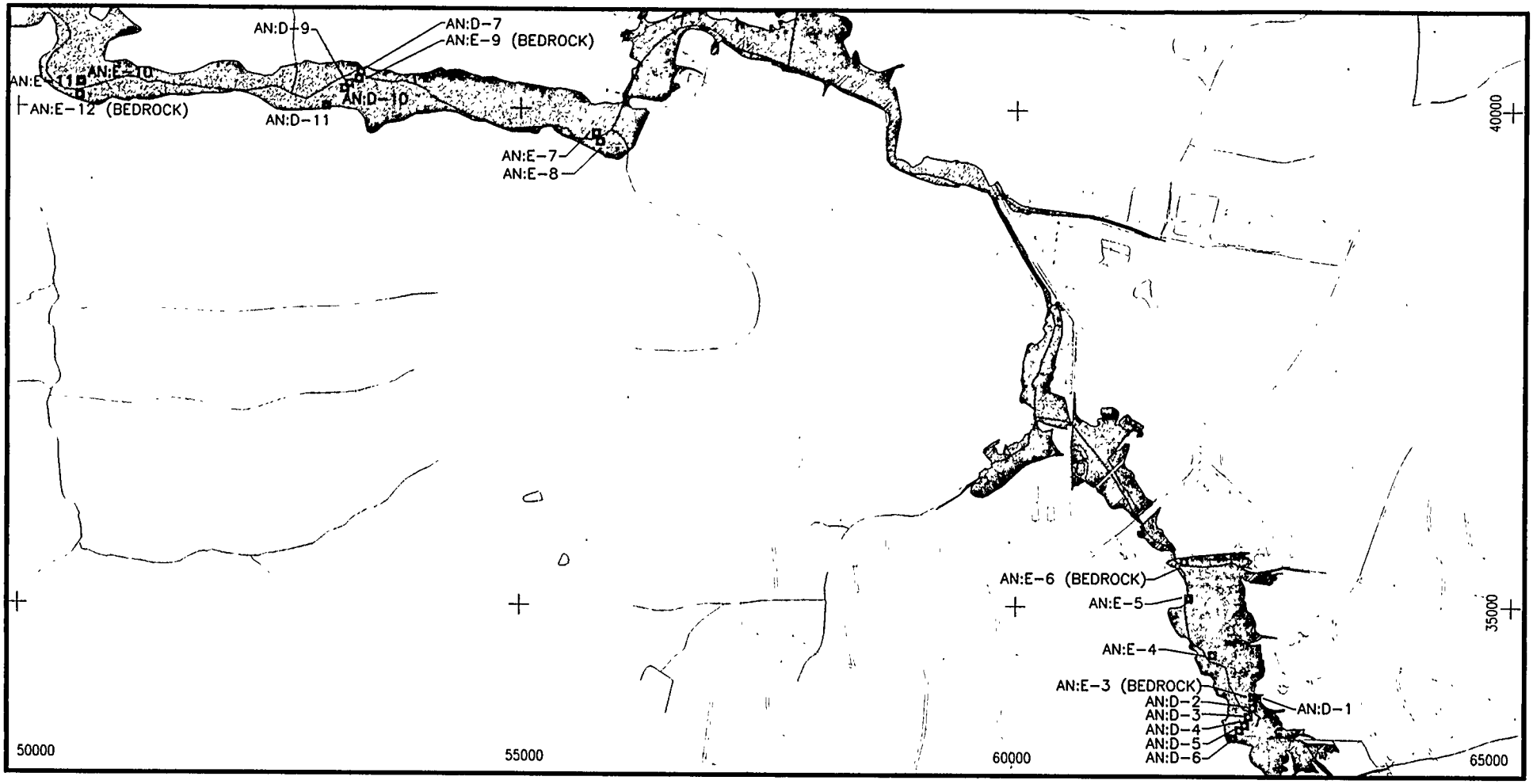
Elevated concentrations of total and/or total-recoverable trace-metals in water samples from several wells were suspected to be the result of borehole contamination during well installation. Additional factors that might also have affected the results of water-quality analyses include:

matrix effects between sample constituents, relatively high pH values measured in water samples from a few of the wells, relatively high laboratory detection limits for many of the organic compounds, and possible delays in filtration and preservation of dissolved trace-metal samples.

EFPC RI Groundwater Data. Groundwater monitoring wells were used to characterize the groundwater quality associated with the EFPC watershed during the EFPC RI Phase Ia assessment. Eleven wells, AN:D-1 through AN:D-11, were installed in 1986 for the USGS investigation of shallow groundwater quality near EFPC. Twelve additional wells, AN:E-1 through AN:E-12, were installed by Energy Systems in 1990-1991 for the Phase Ia assessment to augment and substantiate data collected from the USGS wells. The locations of the monitoring wells are illustrated on Fig. 3.54 (and Map 4), and a summary of the monitoring well construction data is presented in Table 3.23.

3.2.4.2 Monitoring well installation

USGS Groundwater Monitoring Wells. Ten of 11 USGS wells were employed for the RI and are located in areas where historically elevated levels of mercury concentrations (BR and NO sites) were identified within EFPC floodplain soils. Boreholes for USGS monitoring wells AN:D-1 through AN:D-6, and AN:D-9 through AN:D-11 were installed using a portable, gasoline-powered auger with solid-stem auger flights. Boreholes AN:D-9 through AN:D-11 were not completed to bedrock because the portable auger rig was unable to penetrate the entire thickness of the soil horizon. The boreholes for USGS wells AN:D-7 and AN:D-8 (not used) were installed with a trailer-mounted auger rig with hollow-stem auger flights. Initially, a 12-in.-diameter borehole was augered to a predetermined depth based on identified zones of contamination. An 8-in.-diameter steel casing was then cemented into the borehole to seal the upper contaminated soil zones from the screened interval. After the cement had hardened, each borehole was completed to bedrock by drilling through the surface casing with a 6-in.-diameter auger. Upon completing the 6-in.-diameter boreholes, 2-in.-diameter screen and casing were installed. A high purity silica sand filter pack was placed in the annular space around the well screen. A 6-in.-thick bentonite seal was placed above the sand pack. The remainder of the annular space was then filled to land surface with Portland cement and a protective casing with locking cap installed over the height of the well casing above land surface. After installation was completed, the elevation of the ground surface was surveyed, and the height of the well casing above ground surface was recorded to establish a reference point for groundwater measurements. The borehole lithologic and well construction logs are included in Appendix C.



EAST FORK POPLAR CREEK

PLOTTING INFORMATION:		PEN CONFIGURATION
PROJECT NO: Z-0001	XREFS Z-0001B/BASWTR, Z-0001B/FLOODPLN, Z-0001B/TRIBS, Z-0001B/BASRDS	1 5 RED
DWG. FILE./Z-0001/DWGS/333GWWEL		2
		3
		4
DATE: 04-13-93	PLOT FILES: /Z-0001P/333GWWEL.PLT	5 5 BLUE
PLOTTED BY: R. BEELER		6
SHEET 1 OF 1		7 5 BLACK
		8 25 BLACK

LEGEND: SCALE: 1" = 1000'

- .....CREEKS & TRIBUTARIES
- .....FLOOD PLAIN
- .....ROADS
- +.....OAK RIDGE ADMIN. GRID (IN FT.)
- TA.....TRIBUTARY SAMPLE
- □..... GROUND WATER WELLS

TITLE:

Figure 3.54 Groundwater Wells
AN:D – U.S.G.S.
AN:E – Energy Systems

SAIC
Science Applications International Corporation

Table 3.23. Summary of EFPC Phase Ia monitoring well construction data

Well identification[a]	Well completion date	Well casing diameter (in.)	Well casing type	Total well depth (ft, BLS)	Screen interval (ft, BLS)	Elevation	
						Ground surface (ft, MSL)	Measuring point[b] (ft, MSL)
AN:D—1	1986	2.0	SS	4.90	1.90—4.90	861.49	863.29
AN:D—2	1986	2.0	SS	8.20	4.20—8.20	862.70	865.30
AN:D—3	1986	2.0	SS	9.70	4.70—9.70	863.19	865.29
AN:D—4	1986	2.0	SS	4.90	2.90—4.90	862.10	864.80
AN:D—5	1986	2.0	SS	6.10	3.10—6.10	862.74	865.24
AN:D—6	1986	2.0	SS	3.80	1.80—3.80	863.37	865.17
AN:D—7	1986	2.0	SS	8.00	5.00—8.00	835.80	837.60
AN:D—8	1986	2.0	SS	8.40	4.40—8.40	834.60	837.00
AN:D—9	1986	2.0	SS	7.00	3.00—7.00	834.30	836.20
AN:D—10	1986	2.0	SS	9.30	5.30—9.30	833.70	835.90
AN:D—11	1986	2.0	SS	8.40	5.40—8.40	834.10	836.50
AN:E—1	10/24/90	2.0	SS	10.40	8.40—10.40	877.69	878.21[d]
AN:E—2	10/25/90	2.0	SS	7.30	4.80—7.30	879.22	880.94
AN:E—3[c]	11/08/90	2.0	SS	15.00	10.00—15.00	860.83	865.75[d]
AN:E—4	10/18/90	2.0	SS	4.00	3.00—4.00	861.54	863.64
AN:E—5	10/22/90	2.0	SS	5.90	4.90—5.90	860.97	862.44[d]
AN:E—6[c]	01/09/91	2.0	SS	29.70	19.70—29.70	857.92	862.52[d]
AN:E—7	10/22/90	2.0	SS	7.40	4.90—7.40	837.83	840.86[d]
AN:E—8	10/15/90	2.0	SS	7.80	5.80—7.80	836.71	840.10
AN:E—9[c]	10/26/90	4.0	SS	23.10	13.10—23.10	838.00	839.14[d]
AN:E—10	10/10/90	2.0	SS	6.80	5.70—6.80	832.89	833.36[d]
AN:E—11[c]	10/25/90	4.0	SS	20.00	10.00—20.00	830.81	833.76[d]
AN:E—12	10/16/90	2.0	SS	7.60	5.60—7.60	830.25	832.62

[a]Data obtained from Hazardous Waste Remedial Actions Program (HAZWRAP) and USGS construction logs and field notes.
[b]The elevation of the measuring points was obtained by adding the value of the reported "stick—up" to the surveyed ground surface elevation.
[c]Bedrock groundwater monitoring wells.
[d]These elevations do not represent the actual height of the measuring point above ground surface because the "stick—up" recorded was only measured to the top of the concrete pad and not to ground surface.
SS = stainless steel

The AN:D monitoring wells were developed after installation to remove fine formation sediment from the well casing and the aquifer zone adjacent to the screened intervals. In January 1987, the wells were developed by USGS using the pump-and-surge method. Initially, all standing water and sediment from inside the well casings was purged with a small centrifugal pump. The water within the wells was allowed to recover, and a stainless-steel bailer was lowered below the water column to surge the sandpack and borehole wall. The bailer was then withdrawn, and the well was repumped to remove the agitated water and sediment. This procedure was repeated until the water from each well became clear. The estimated maximum yield or rate of recovery for the monitoring wells was relatively low ranging from < 0.9 to 2.8 L/min (0.25 to 0.75 gal/min).

The wells were redeveloped in October and November 1990 as part of the EFPC RI Phase Ia using the surge-and-bail method in association with water quality field measurements. A bailer was used to surge/remove all the water from the wells, and field measurements for temperature, specific conductivity, and pH were then taken on the removed water. Development was completed when the water was clear and the field measurements were stable. Low recovery rates were also observed during this development effort. However, all wells were evacuated to dryness three times, except for AN:D-5 and AN:D-6 (due to slow recharge rates) and AN:D-8 (not used because of an obstruction in the well). Consequently, monitoring well AN:D-8 was removed from the monitoring program.

Energy Systems Groundwater Monitoring Wells. The 12 Phase Ia wells were located in relation to the USGS wells at the BR and NO sites to maximize the head and gradient data and chemical data in each of the stream reaches around the sites. During this phase, eight alluvium (shallow) and four bedrock (deep) wells were installed by HAZWRAP, a division of Energy Systems. Total well installation depths ranged from 1.2 to 3.12 m (4 to 10.4 ft) for shallow wells and 4.5 to 8.9 m (15 to 29.7 ft) for deep wells.

Two different construction designs were used. Wells installed in the soil horizon were constructed with a 2-in.-diameter stainless-steel well casing with threaded top cap, and 0.010 in. slot, continuous wire wrapped, stainless-steel screens of various lengths. A 7-in.-diameter cast iron protective casing with a locking cap was installed over the well casing. Wells installed into bedrock were constructed with either 11- or 7-in.-diameter cast iron surface casing with a locking cap, 2- or 4-in.-diameter, stainless-steel well casing with threaded top cap, and 0.010-in. slot, continuous wire wrapped, stainless-steel screen of 5- or 10-ft lengths. In all monitoring wells, *Morie Industrial* sand with a 20/40 grain size distribution was used to pack the screened intervals and 0.25-in.-diameter bentonite pellets were used to form a seal above the sand pack. The

remaining annular space above the bentonite was filled with Portland cement. The surface casing installed for the bedrock wells was also grouted into place with Portland cement. The borehole lithologic logs, well construction logs, and well development forms for all the Energy Systems wells are included in Appendix D.

Two types of drilling methods were used to install the boreholes for the Phase Ia monitoring wells. The shallow boreholes, AN:E-1, AN:E-2, AN:E-4, AN:E-5, AN:E-7, AN:E-8, AN:E-10, and AN:E-12, were installed to total depth using a backhoe-driven auger with 8.75-in.-diameter hollow-stem auger flights. The boreholes were installed by pushing a 1.5- or 2-ft-long, 2-in.-diameter, stainless-steel, splitspoon soil sampler 60 cm (2 ft) into the soil and then overdrilling the splitspooned borehole to the same depth with the augers. The borehole was advanced to total depth using this alternating process. A 3-in.-diameter splitspoon sampler was used to collect samples. When drilling was completed, 2-in.-diameter screen and casing were placed into the boreholes. A sand filter pack was installed in the annular space around the well screen. A bentonite seal was then place above the sand pack. The remainder of the annular space was then filled to land surface with cement and a 7-in. cast iron protective casing with locking cap installed over the height of the well casing above land surface. A 0.5-ft-thick concrete pad with 2- by 2-ft dimensions was then formed around the casing. The elevation of the ground surface was surveyed and the height of the well casing above ground surface recorded to establish a reference point for groundwater measurements.

The installation of the boreholes completed into bedrock (AN:E-3, AN:E-6, AN:E-9, and AN:E-11) was completed in three phases using a combination of two separate drilling techniques. The initial phase of the borehole installation was completed using the same sample/auger technique described for the shallow borings. After reaching the top of the bedrock, the borehole was overdrilled using a 10.6- or 16.0-in.-diameter auger depending on the specified diameter (7 or 11 in.) of the surface casing. The cast iron surface casing was then cemented into the borehole to seal the upper contaminated soil zones from the screened interval. An air rotary drilling rig with a 10.625 or a 6.25 tricone roller bit was used to complete the final phase by drilling through the surface casing and into bedrock to total depth. Upon completing the borehole, a 2-in. (AN:E-3 and AN:E-6) or 4-in. (AN:E-9 and AN:E-11) screen and casing were placed into the borehole. A sand filter pack was installed in the annular space around the well screen, and bentonite seal was placed above the sand pack. The remainder of the annular space was filled to land surface with cement, and a locking cap was installed on the protective casing.

The wells were finished by pouring a 0.5-ft-thick, 2- by 2-ft concrete pad around the casing. The elevation of the ground surface was also surveyed, and the height for the well casing above ground surface was recorded.

The AN:E wells were also developed to remove the sediment from the well casing and the borehole walls adjacent to the screened intervals. Well development was completed by HAZWRAP between October 1990 and January 1991 using the bail method in association with water quality field measurements. A disposable 1-in.-diameter, 2-ft-long clear PVC bailer was used to evacuate the well. Field measurements for temperature, specific conductivity, and pH were taken on the purged water. Development was completed when the field measurements were stable. At least five well volumes were removed from all wells except AN:E-10. Only two volumes of water were removed from AN:E-10 due to the low recharge rate. Wells AN:E-1, AN:E-4, and AN:E-12 also demonstrated low recharge rates. The maximum yield or rate of recovery was estimated to be < 3.7 L/min (1 gal/min).

3.2.4.3 Groundwater monitoring

Water Level Data. As part of the EFPC RI Phase Ia sampling design plan, water level data were collected from the 23 groundwater monitoring wells quarterly for 1 year from November 1990 to October 1991. Precipitation data were also acquired for the same period from NOAA in Oak Ridge. A summary of the water level data in tabular and graphic form for each well is presented in Appendix E. Graphs of the water elevations grouped by wells in a common area with corresponding precipitation data are presented in Figs. 3.55 through 3.59.

Water levels were obtained by measuring the depth to the water table surface from the top of the 2- or 4-in. well casing with elevations of the water table surface obtained by adding the height of the reference point recorded on the well construction logs to the ground surface elevation. During the monitor well installation, errors were made by the oversight geologist in recording the correct reference point height for the AN:E wells. However, the errors were not discovered until the monitoring period was complete, resulting in inaccurate calculations of the true water table surface. In most cases, a 0.5-ft error was translated to each water level measurement, producing a somewhat deeper water table surface. The relative difference of the water level measurements between quarters within any given well is correct, and the true absolute water table should parallel the calculated surface, but at a higher elevation. The exact recording errors have not been resolved; therefore, the data presented in this report represent the actual data collected in the field.

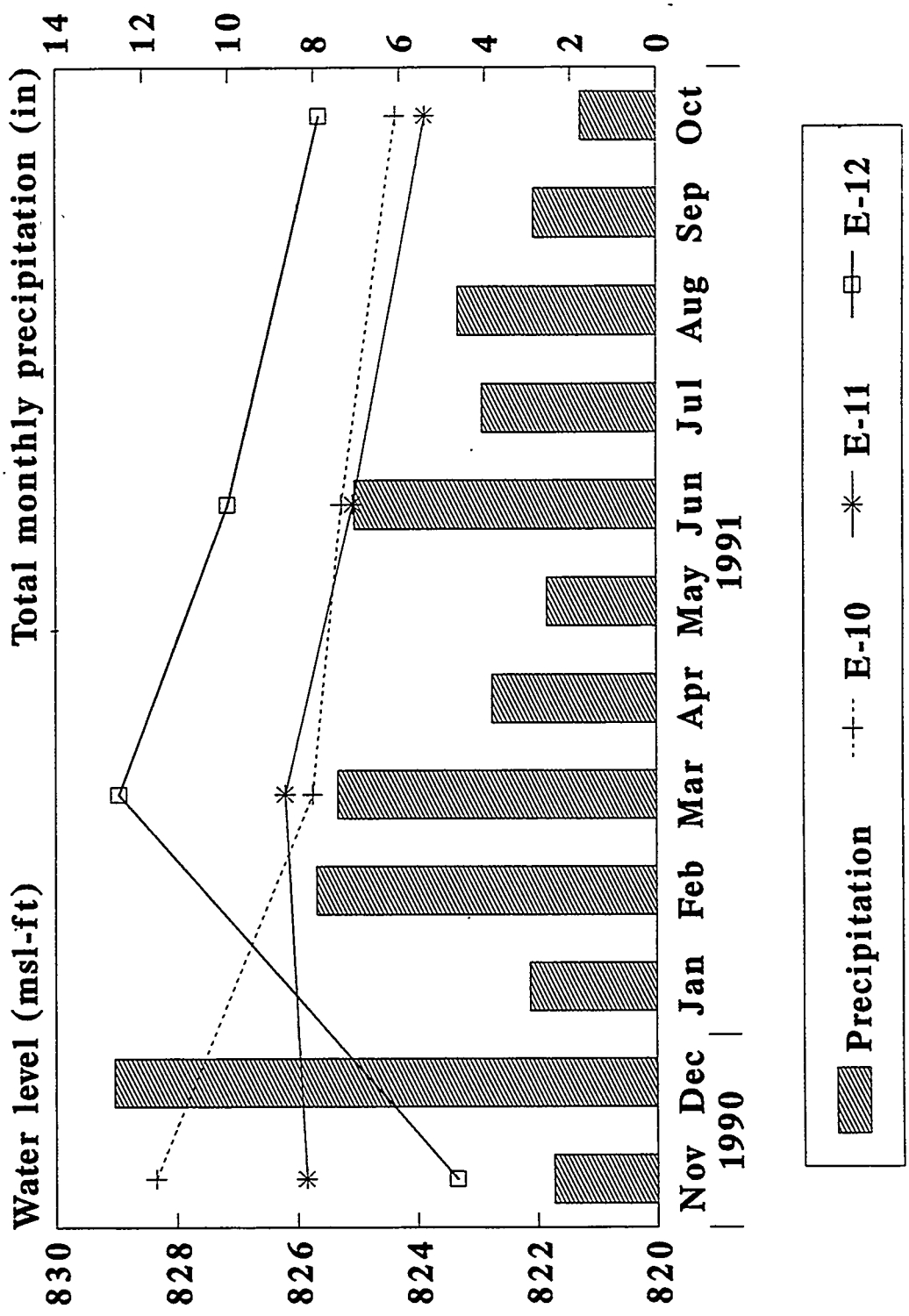


Fig. 3.55. Water level and precipitation data - middle reach of EFPC (downstream of WA site).

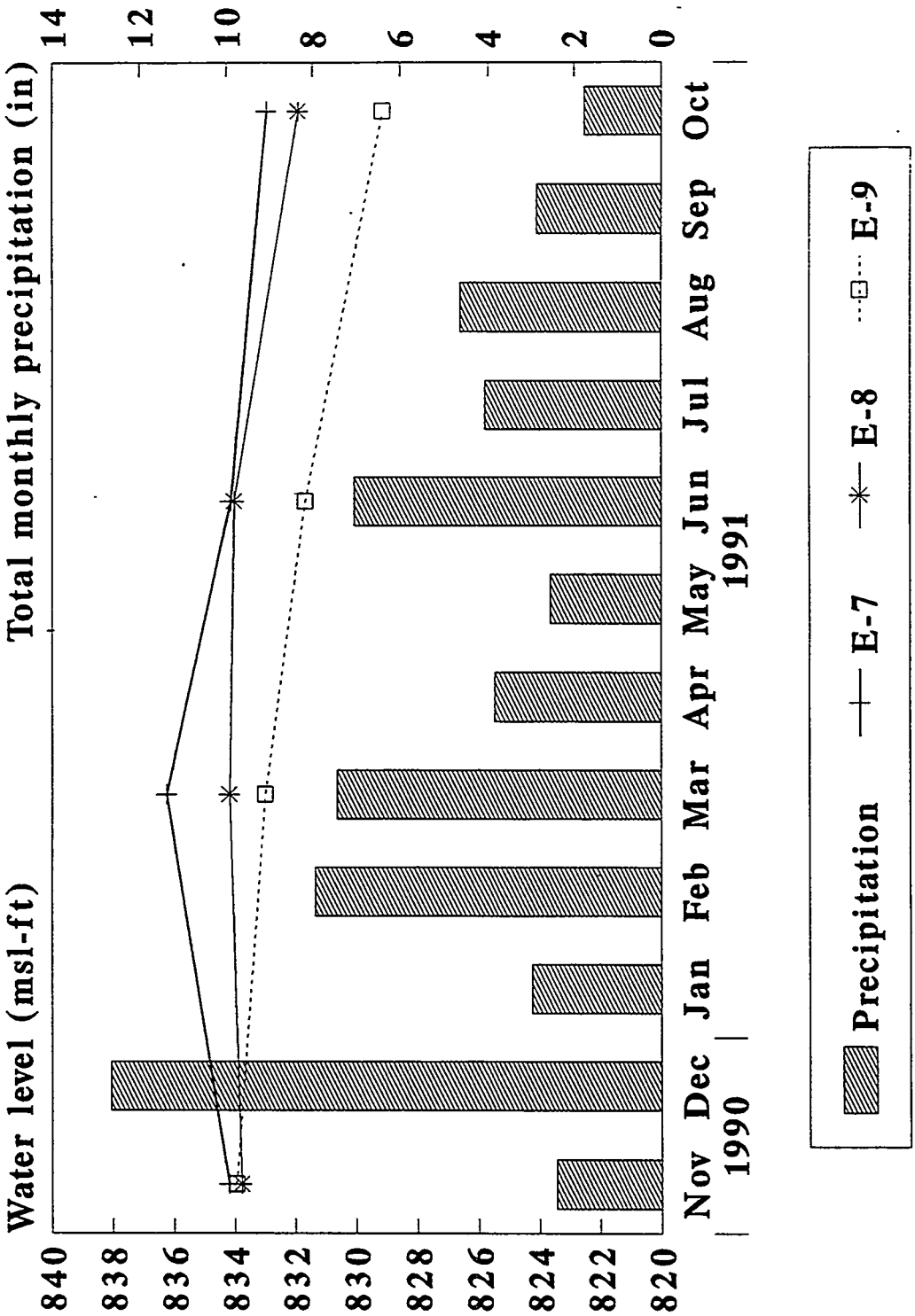


Fig. 3.56. Water level and precipitation data - middle reach of EFPC (BR & tennis courts).

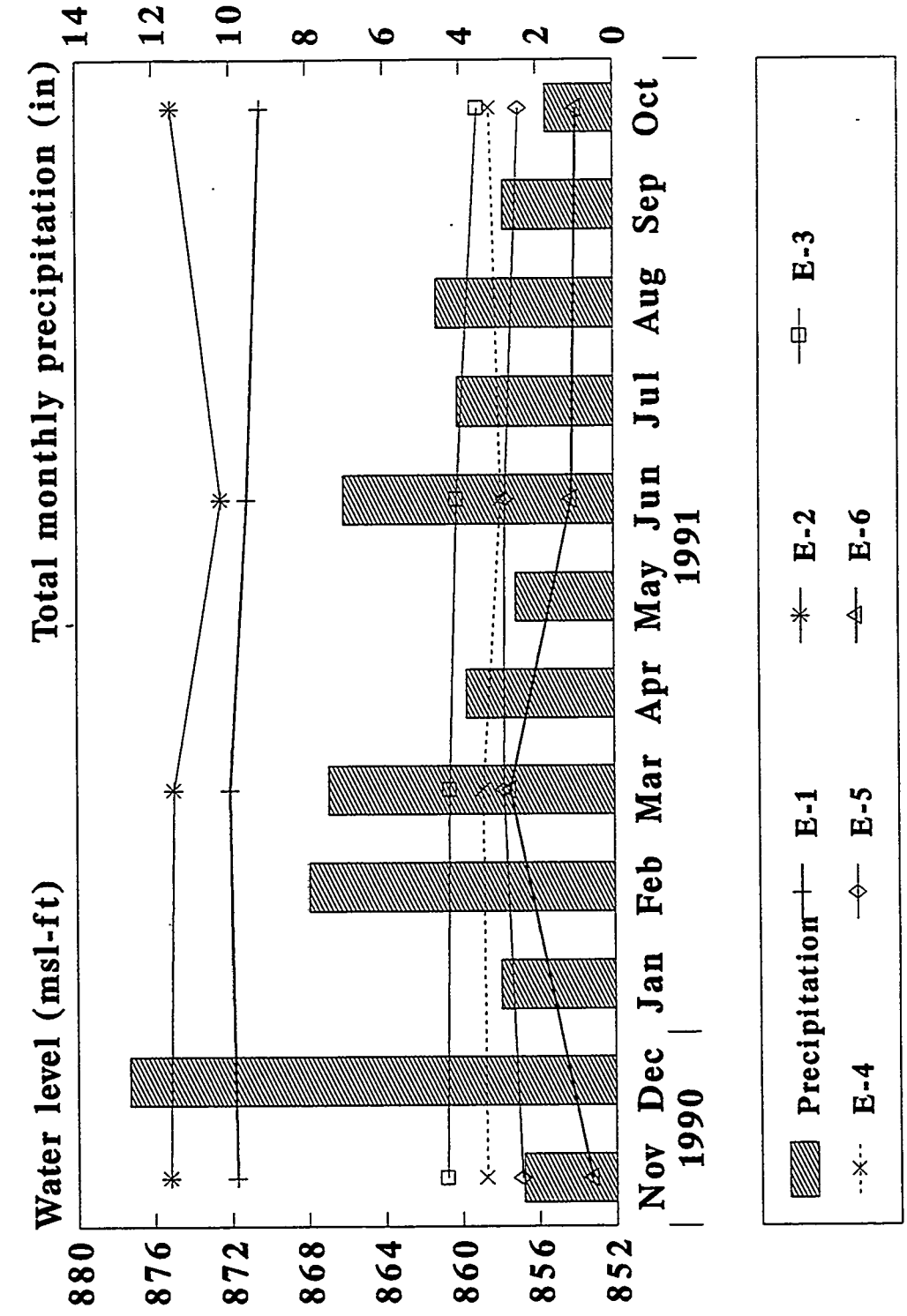


Fig. 3.57. Water level and precipitation data - upper reach of EFPC (along Illinois Avenue).

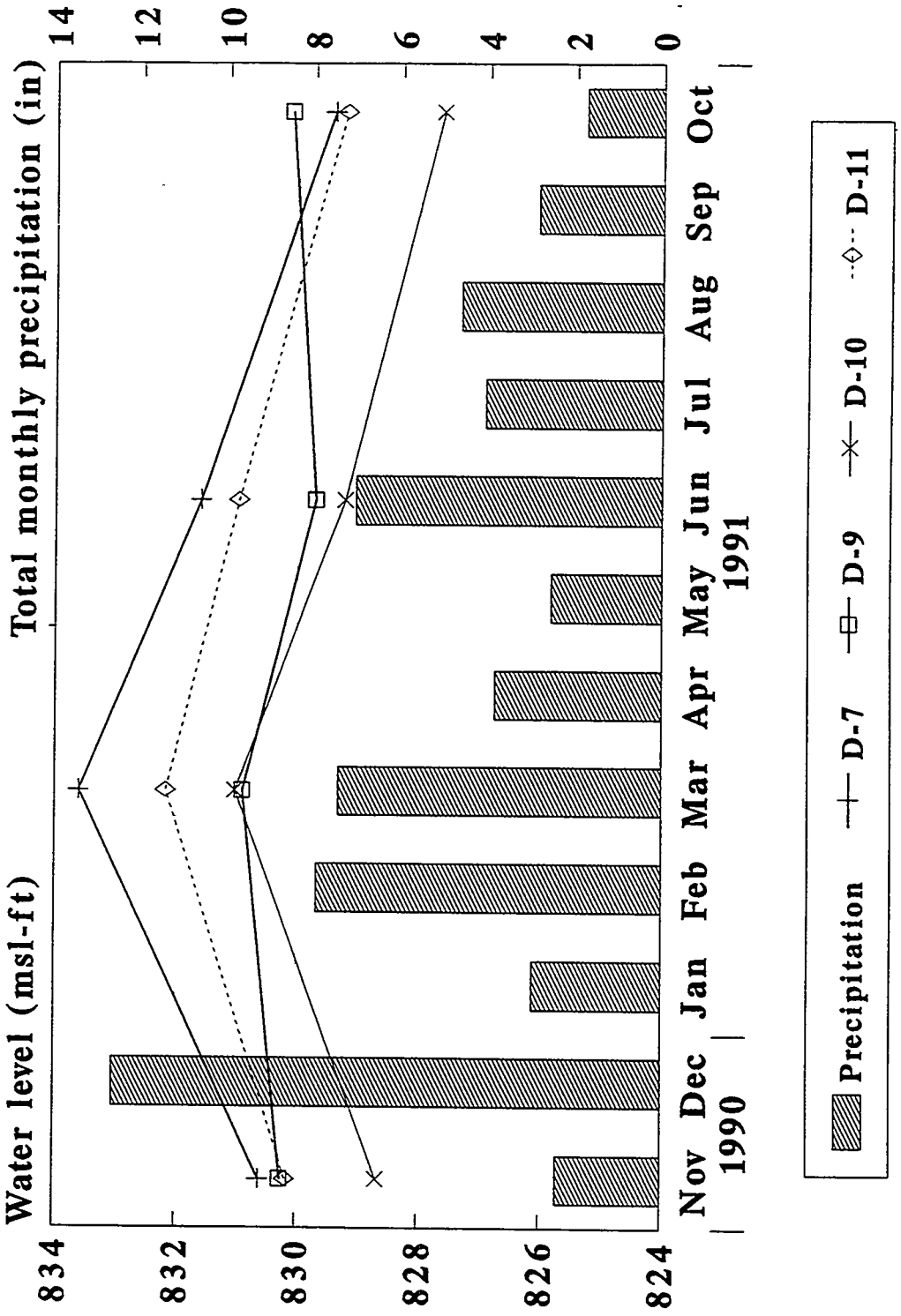


Fig. 3.58. Water level and precipitation data - (BR Site).

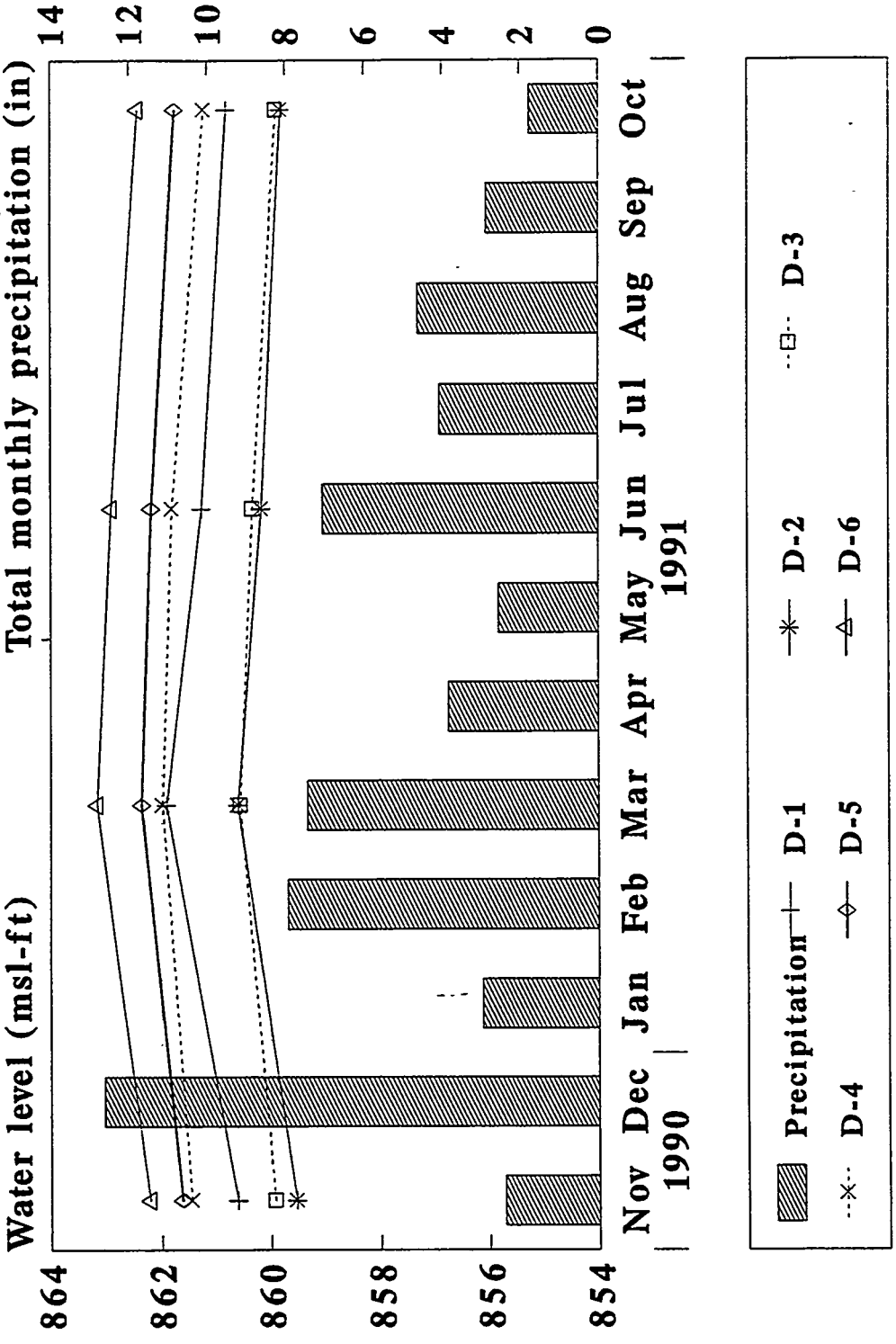


Fig. 3.59. Water level and precipitation data - (NO site).

During the monitoring period, depth to water table surface varied with highest levels recorded in seasonal peak precipitation periods and lowest levels during periods of low rainfall. In March 1991, rainfall was near its peak, with a total of 18.8 cm (7.44 in.) of rain measured in the area. During this month, the water table surface was measured at its highest level in all wells except for AN:E-2, AN:E-9, and AN:E-10. Depths ranged from 3 cm (0.1 ft) (AN:D-1) to 1.5 m (4.92 ft) (AN:E-1) BLS or at elevations of 861.39 to 872.51 ft MSL. The highest measurements for wells AN:E-2, AN:E-9, and AN:E-10 were recorded in November 1990 at depths ranging from 1 to 1.2 m (3.55 to 4.04 ft) BLS or 834.45 to 828.55 ft MSL. In November 1990 and October 1991, rainfall was near its lowest levels, with 6 cm and 3.7 cm (2.40 and 1.76 in.) of rain measured in the area, respectively. In these months, water table measurements were recorded at their lowest levels in all monitoring wells except AN:D-9, AN:E-2, and AN:E-4. Depths ranged from 27 cm (0.89 ft)(AN:D-1) to 2.5 m (8.36 ft) (AN:E-9) BLS or 860.60 to 829.14 ft MSL. The lowest measurements for well AN:D-9, AN:E-2, and AN:E-4 were recorded in June 1991 with depths ranging from 1.12 to 2 m (3.68 to 6.75 ft) BLS or 857.86 to 872.47 ft MSL.

Groundwater Hydrology. EFPC and its associated floodplain below Pine Ridge Gap lie along the axis of East Fork/Oak Ridge Valley and provide the principal groundwater discharge area for the underlying shallow aquifer. The EFPC floodplain is a typical alluvial valley unconsolidated aquifer recharged from the bounding ridge slopes and upland portions of the valley floor. Shallow groundwater flow for areas within East Fork Valley but above the EFPC floodplain is predominantly toward the creek. Within the EFPC floodplain, shallow groundwater flow has two components of movement, toward EFPC and along valley strike towards Poplar Creek.

Groundwater elevations within the shallow aquifer vary significantly with rainfall, as does base flow within EFPC. Seasonal variations produce localized changes in the hydrologic balance between EFPC and the alluvial aquifer. During the wet season, EFPC is a gaining stream (groundwater discharge); conversely, during the dry season, portions of the creek may experience a net loss (groundwater recharge). However, even under low flow conditions, the overall movement of shallow groundwater across the valley (from ridge to ridge) is toward the confluence of EFPC and Poplar Creek. The approximate piezometric surface of the EFPC alluvial aquifer (in relation to MSL - taken from the hydrographs) is at about 875 to 870 ft in the upper reach, sloping to 862 to 860 ft in the vicinity of the NO study area and gradually dropping from 861 to 853 ft along the creek segment parallel to Illinois Ave. Farther downstream near the tennis courts, the piezometric surface lies at about 836 to 834 ft but drops only slightly to 833

to 829 ft near the BR study area. The western-most monitoring wells behind the city of Oak Ridge fire station show the piezometric surface to be in the 828- to 824-ft range.

Groundwater in communication with EFPC is restricted to the unconfined shallow aquifer within the floodplain and portions of the adjoining bedrock aquifer. While the RI did not investigate deep groundwater flow paths within the bedrock zone, no significant groundwater movement across the divides is postulated between the East Fork and adjacent valleys. The fate and transport of contaminants in groundwater within the EFPC floodplain are considered to be the same as the surface waters of EFPC.

Even if this conceptualization was incorrect and EFPC does provide groundwater recharge to deep flow paths within the bedrock aquifer, no significant impact is anticipated. First, groundwater velocities in the deep surface are relatively slow (with notable exceptions in well-developed karst regions), and any impact from recharge would be minimal. Second, the majority of contamination within the groundwater medium is related to particle-bound metals, which would not be transported in large quantities into the deep subsurface. Empirical evidence for this conclusion has been noted in the groundwater monitoring results. Wells AN:E-10 and AN:E-11 are a nested well cluster with screened intervals in the alluvium (5.7 to 6.8 ft BLS) and bedrock (10 to 20 ft BLS), respectively. Well AN:E-12 is located immediately across the creek at the same site. It is also a shallow well screened in the alluvium (5.6 to 7.6 ft BLS). A comparison of three total (dissolved and particle-bound, i.e., not filtered) metal analyses between the three wells shows that the bedrock wells have significantly lower contaminant concentrations (or in many cases nondetects). Accordingly, the deep bedrock aquifer is not included in the site conceptual model.

Groundwater Geochemistry. Groundwater samples from wells screened in floodplain soils and shallow bedrock were collected and analyzed to identify any association between COCs and the groundwater pathway.

Before analyzing the groundwater data, several data quality screens were applied to eliminate any geochemically unreasonable data. Duplicate samples within each sampling round were not usually analyzed for the full suite of analytes, and in many cases anions were not analyzed. For the purposes of analyzing the major element geochemistry, those samples were deleted. Field measurements were reviewed to determine any discrepancies noted while obtaining the sample.

The last pH measurement taken during well purging, prior to sampling, is reported in the data base. Shallow groundwater pH is a dynamic balance between acid-producing (and pH-lowering) processes (e.g., biological oxidation of soil organic matter) and acid-consuming (and

pH-raising) processes (e.g., carbonate mineral dissolution reactions). Shallow groundwater samples in the Oak Ridge area range from fairly acidic (pH < 4.5) in shallow soil zones to slightly basic (7.0 < pH < 8.5) in shallow carbonate bedrock. In general, pH values will rarely range below 4.0 or above 8.9 in the absence of unusual geology or contamination. Groundwater samples from EFPC that fell outside this acceptable range were identified and examined in detail. Several samples exhibited a final field pH (the final pH measurement during well purging) greater than 8.9, which is considered a generous upper bound for naturally occurring groundwater in the region. As a result of these uncertainties, those samples were deleted from further consideration. This condition resulted in only four samples being deleted from the analyses. All of the samples deleted were collected during the initial sampling round in NOAA transect wells, with the highest pH (12.7) in a new well (AN:E-3), which suggests, in this case, incomplete well development and possible contamination from grout. Subsequent pH measurements in these wells were consistently lower and comparable to values measured throughout the floodplain.

Specific conductivity is a measure of the total ionic content of a sample. Fluctuations in specific conductivity, for an individual well, may occur following periods of freshwater throughput (e.g., during a spring thaw) or during periods of drought. Changes in specific conductivity should be accompanied by complementary changes in the concentrations of major cations and anions. Several samples exhibited unusually low field-measured specific conductivity (e.g. 9.5 μS/cm in AN:D-9, 114 μS/cm in AN:E-6). See Fig. 3.60 for the range of conductivities. Despite some question about the validity of the field measurement, the results of major element analyses suggest that the sample composition is consistent with other samples from that location, and the sample was not deleted from further analysis.

In most shallow groundwater systems that are not directly impacted by unusual geologic conditions or contaminants, the dominant anion in solution (and a major component of anionic charge balance) is bicarbonate (HCO_3^-). The concentration of bicarbonate ion and the relative distribution of dissolved carbon species in solution among carbonic acid (H_2CO_3), bicarbonate ion, and carbonate ion (CO_3^{2-}) are calculated from the results of an alkalinity analysis and the solution pH.

Alkalinity was not measured for any of the groundwater samples; therefore, bicarbonate and carbonate ion contributions to the charge balance must be calculated. For the purposes of this analysis, it was assumed that the calculated charge imbalance was due to missing alkalinity and that the alkalinity was distributed between bicarbonate and carbonate ions based on sample pH. To check this assumption, the augmented sample analyses (sample analyses with the addition of calculated concentrations of bicarbonate and carbonate ions) were used to calculate the saturation

state of the sample with respect to calcite. A further check of the validity of calculating alkalinity for charge balance includes a comparison of Piper plots of data from EFPC and the Y-12 groundwater program. Figure 3.60 is a Piper plot of all EFPC groundwater analyses. This type of plot is useful in classifying groundwater types into broad classes based on the major element composition. Figure 3.61 illustrates the fields for classification of broad water types. Figure 3.62 is a Piper plot of groundwater data from the Y-12 Plant groundwater monitoring program in unconsolidated materials in Upper EFPC. Comparisons of Figs. 3.60 through 3.62 reveal that the EFPC and Y-12 groundwater fall into the calcium-magnesium-bicarbonate water type, with a few samples enriched in sodium, chloride, and sulfate.

All sample analyses should be electrically neutral as indicated by charge balance between the sums of major cations (calcium, magnesium, sodium, potassium) and anions (chloride, sulfate, bicarbonate). Recognizing that there will be uncertainty in individual analyses, a common rule of thumb is that the difference between cationic charges and anionic charges should be no greater than 10%.

The thermodynamic saturation state of each sample with respect to simple minerals may be represented by the sample saturation index (SI). The SI is a measure of the thermodynamic state of a solution and its tendency to either dissolve or precipitate a specific mineral phase. The calculation of the SI begins with the assumption of a simple precipitation or dissolution reaction, e.g., calcite dissolution:

$$CaCO_3 = Ca^{2+} + CO_3^{2-}.$$

For this chemical reaction, an ion activity product (IAP) can be defined as:

$$IAP = (Ca^{2+})(CO_3^{2-}),$$

where species concentrations are in units of mol/L. The saturation state of the solution is a comparison of the IAP measured in solution with the theoretical value of that product at thermodynamic equilibrium, K_{eq}:

$$SI = \log(IAP/K_{eq}).$$

The total salt content of the groundwater is sufficiently low that complex formation is not significant, and molar concentrations were used instead of activities in calculations of IAP and K_{eq}. Carbon speciation, i.e., the relative amounts of carbonate and bicarbonate ions, was

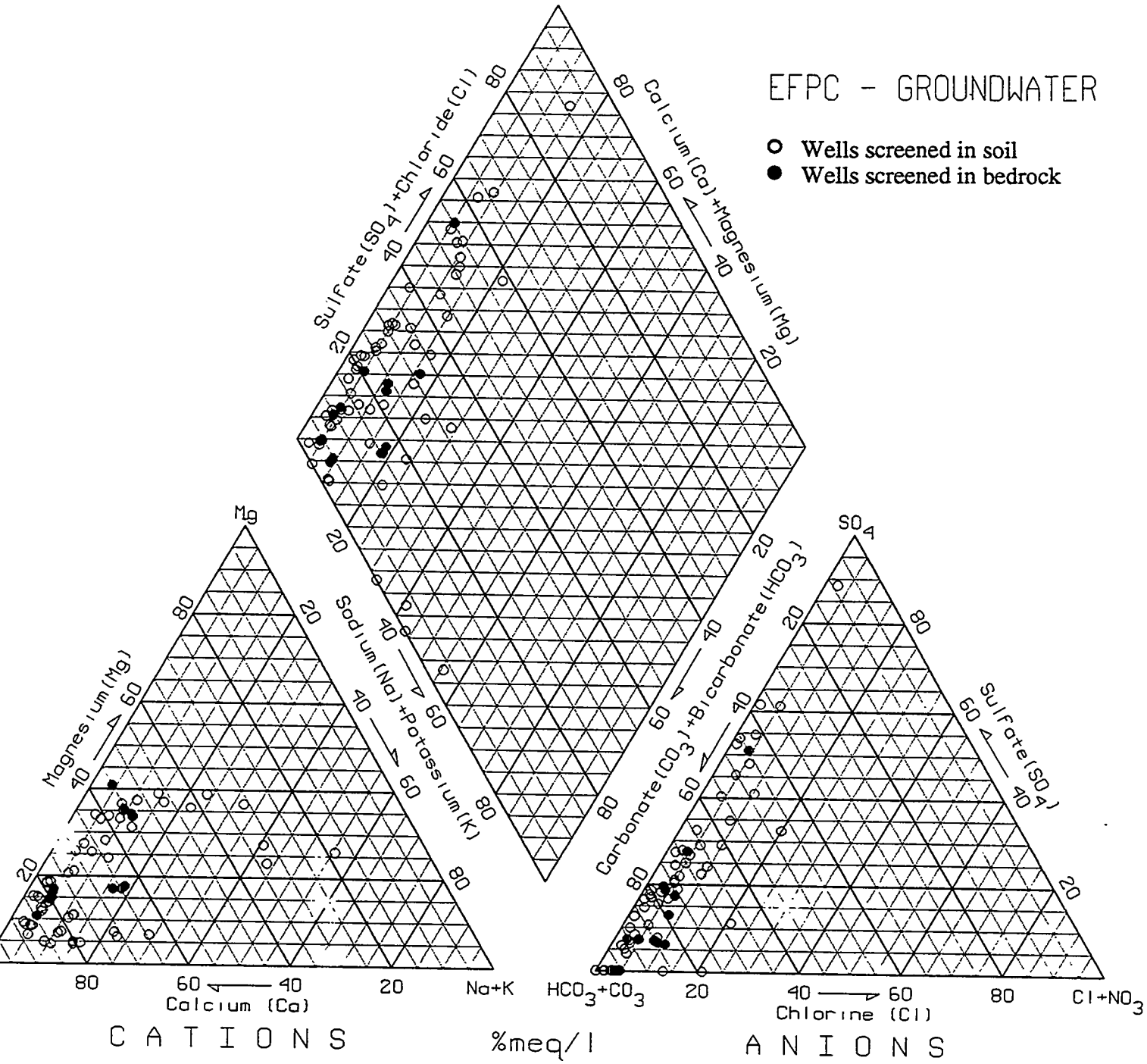


Fig. 3.60. Piper plot of groundwater analyses.

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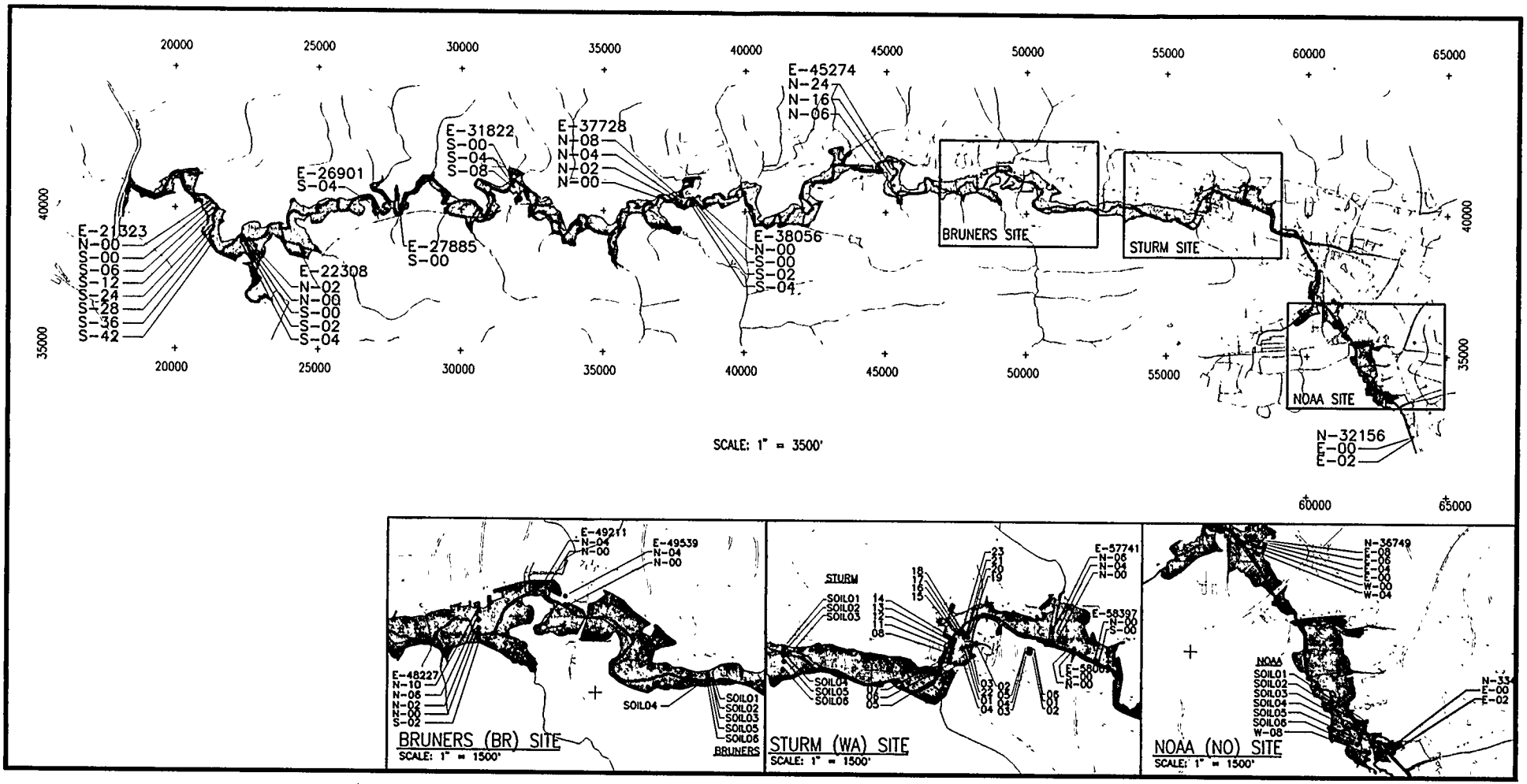

EAST FORK POPLAR CREEK

PLOTTING INFORMATION:		PEN CONFIGURATION
PROJECT NO.: 2-0001	XREFS. /Z-0001B/BASWTR	1 .5 RED
DWG. FILE. /Z-0001/DWGS/333TSS	/Z-0001B/FLOODPLN	2
	/Z-0001B/TRIBS	3
	/Z-0001B/BASRDS	4
DATE: 04-13-93	PLOT FILES:	5 .5 BLUE
PLOTTED BY: R. BEELER	/Z-0001P/333TSS.PLT	6
SHEET 1 OF 1		7 .5 BLACK
		8 .25 BLACK

LEGEND:

02.....SOIL SAMPLE NUMBER

•.....SOIL SAMPLE

.....CREEKS & TRIBUTARIES

.....FLOOD PLAIN

.....ROADS

+.....OAK RIDGE ADMIN. GRID (IN FT.)

TITLE:

Fig. 3.81 Phase Ia and Ib Soil Sampling Locations for CLP Analysis

SAIC

Science Applications International Corporation

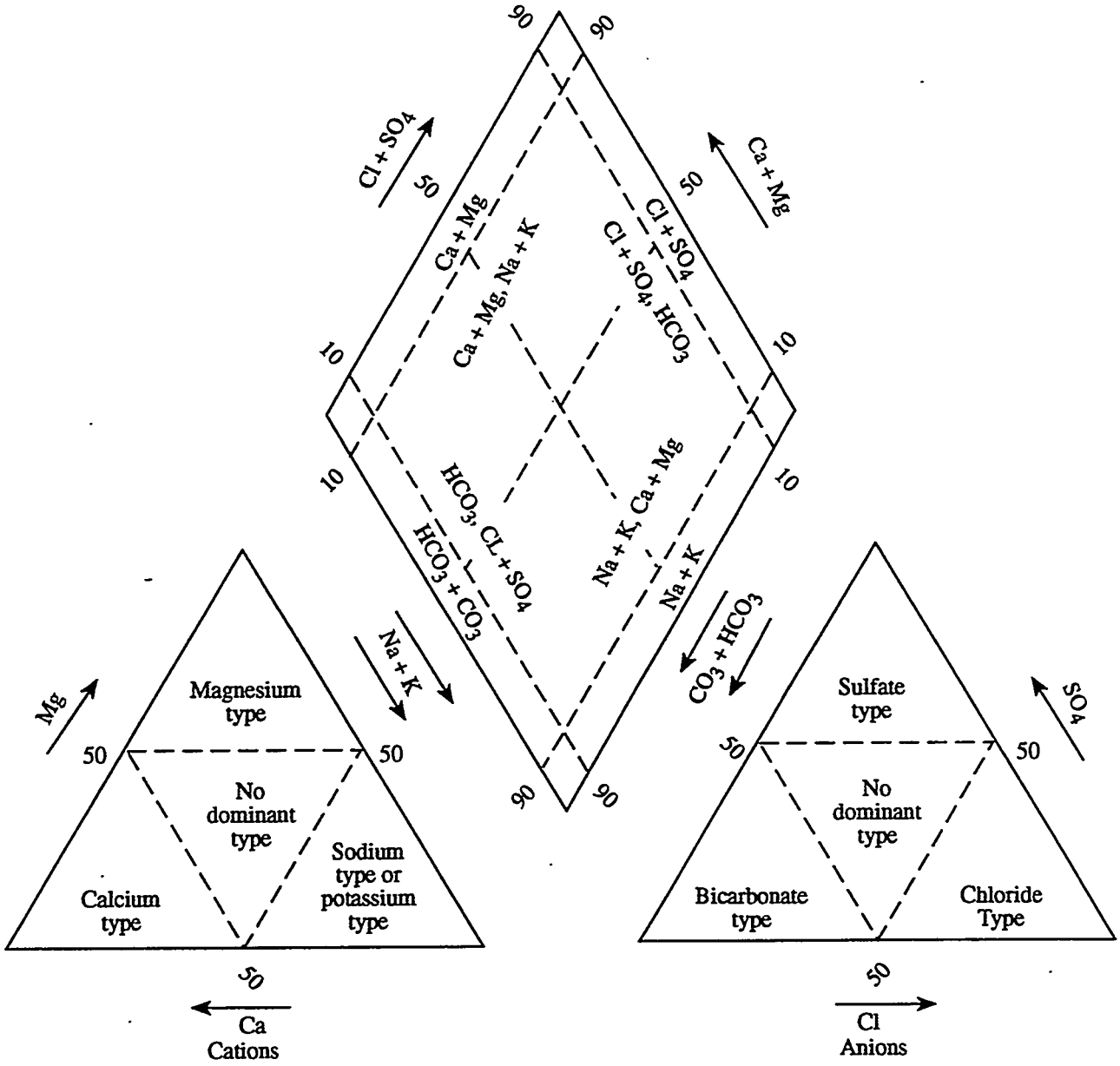

Fig. 3.61. Classification diagram for anion and cation facies in terms of major-ion percentages. Water types are designated according to the domain in which they occur on the diagram segments (after Freeze and Cherry 1979).

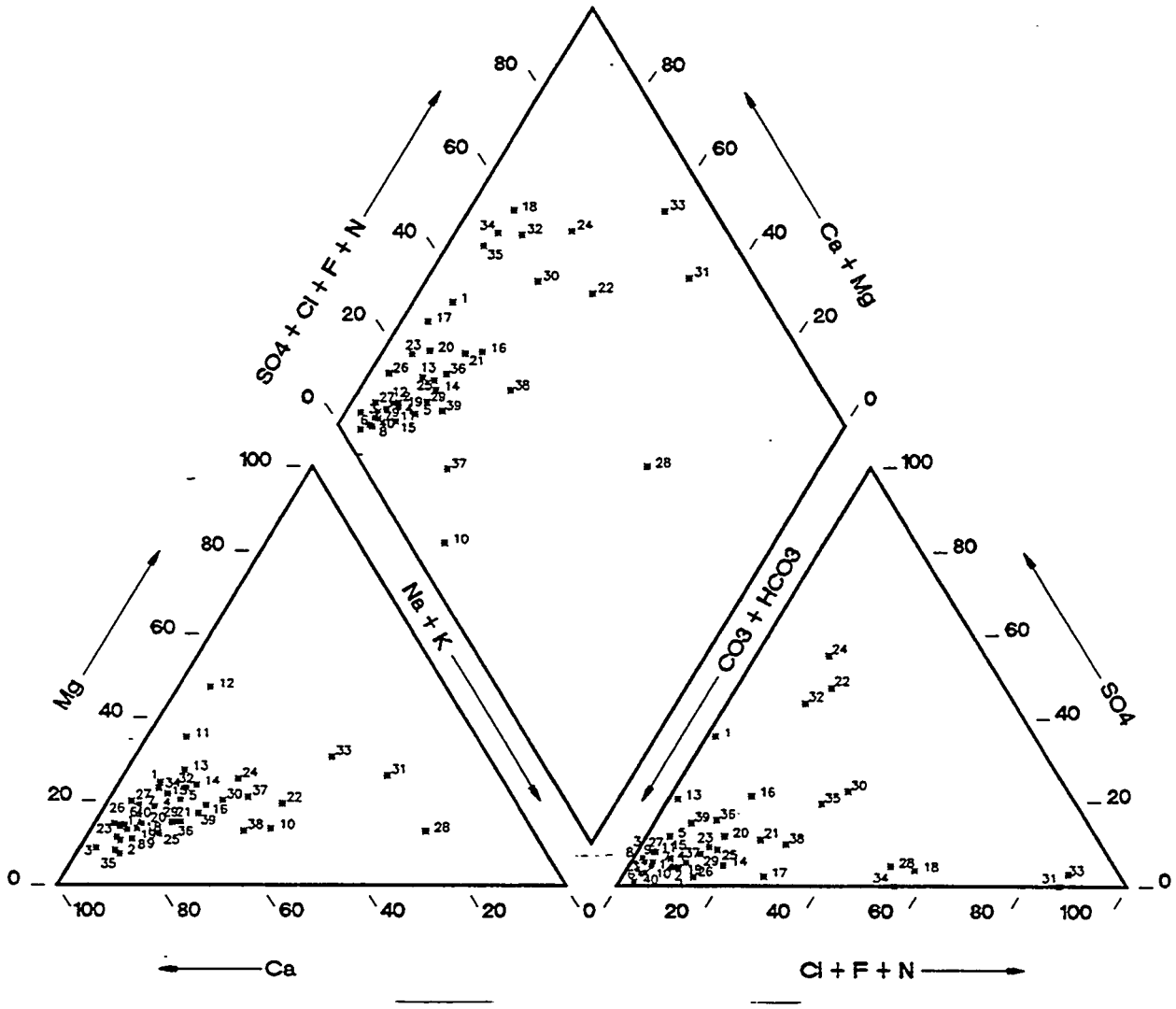

Fig. 3.62. Piper plot-unconsolidated materials in Upper EFPC.

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calculated from the alkalinity measurement and the pH. Recognizing uncertainties in the analytical analyses and in the value of K_{eq}, estimates of equilibrium between groundwater and calcite would fall within the range of $-0.5 < SI < 0.5$. Values of SI greater than 1.0 suggest that calcite should be precipitating from solution, whereas values < -1.0 suggest that the solution should be dissolving any calcite.

Figures 3.63 through 3.65 illustrate the range of saturation state of EFPC groundwater with respect to calcite as a function of groundwater pH. As expected, more acidic pH groundwater is more undersaturated with respect to calcite; conversely, higher pH groundwater is relatively supersaturated. The range of SI_c is from -2.5 to +1.7, with most of the values within the range of -0.5 to 0.5. The results are within the normal range for shallow groundwater and suggest that the assumption required to calculate alkalinity was reasonable.

The only monitoring wells screened in bedrock are AN:E-3, AN:E-6, AN:E-9, and AN:E-11. Each of these wells is identified in Figs 3.59 and 3.62. It is apparent that geochemical data from bedrock wells are not distinctively different from the data for soil wells.

Following screening, the data were used to identify any seasonal and geochemical patterns that may be linked to physical changes in the flow system. Seasonal water level fluctuations are accompanied by changes in pH. These changes, in turn, are related to the amount of bacterial activity in the soil (more active in spring/summer/fall), which tends to increase soil atmosphere carbon dioxide partial pressures. Soil water absorption of carbon dioxide lowers the pH of the soil water during these times. Calcite saturation state is directly related to the groundwater pH, with low pH waters being relatively undersaturated and higher pH waters being saturated to supersaturated.

Finally, the analytical results were used to identify relationships between possible COCs, patterns in the major element geochemistry, and the possibility of contaminant transport.

Many potential COCs (e.g., transition metals, radionuclides) as well as many major elements (e.g., aluminum, iron, potassium) are particle-reactive and tend to be adsorbed to the surface of solid particles or more strongly bound within a mineral structure. In groundwater, these analytes are characterized by detectable concentrations in total analyses but lower concentrations (often undetectable) in dissolved (i.e., filtered) analyses. Comparisons of total and filtered analyses should find, especially for particle-reactive analytes, that the total concentration of an analyte is greater than the dissolved concentration for the same analyte. Comparisons of filtered and total analyses are available for the metal analytes only; samples for anion analyses are not typically filtered. Filtered and total analyses for the soluble alkali and alkaline earth metals (e.g., sodium,

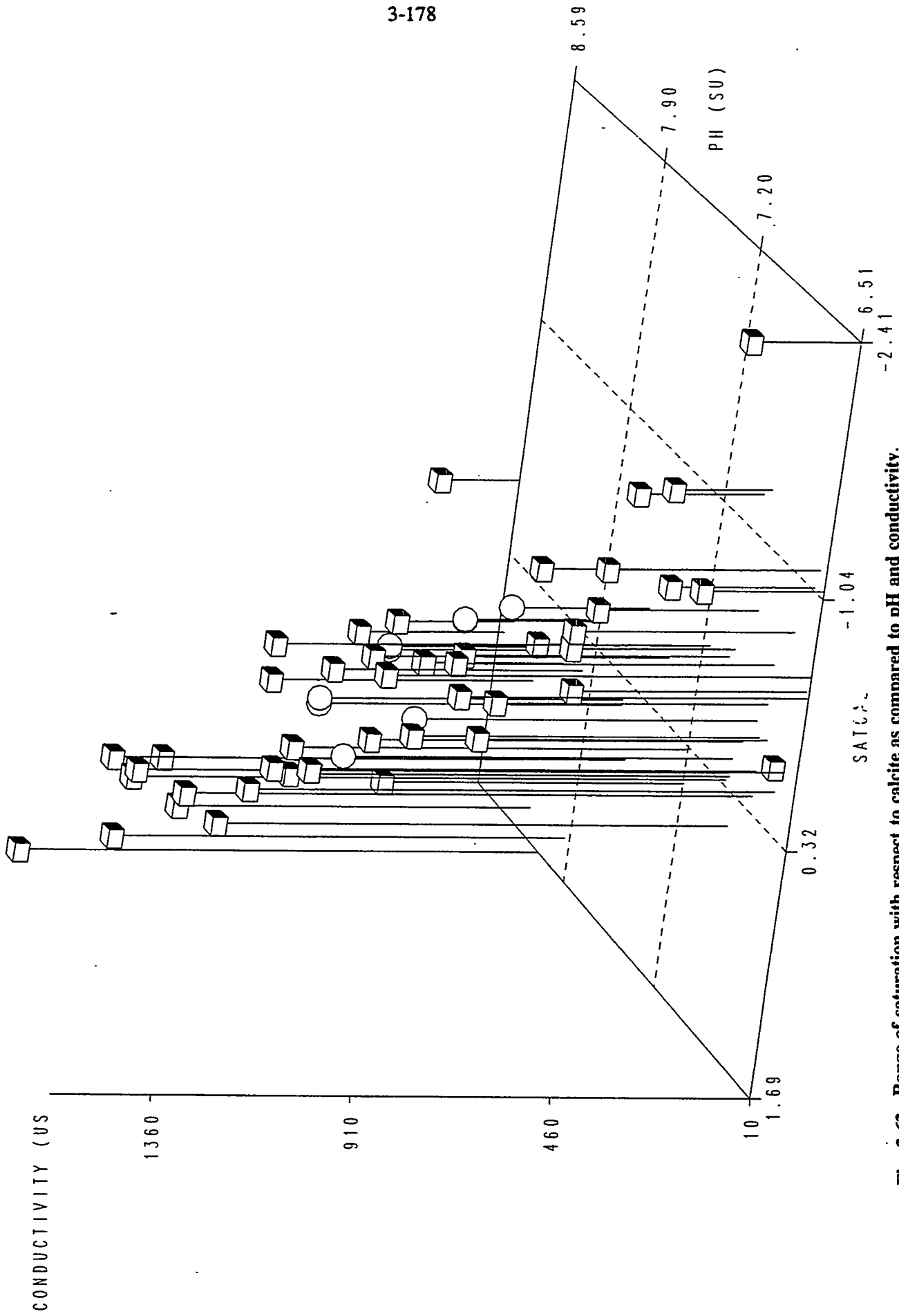

Fig. 3.63. Range of saturation with respect to calcite as compared to pH and conductivity.

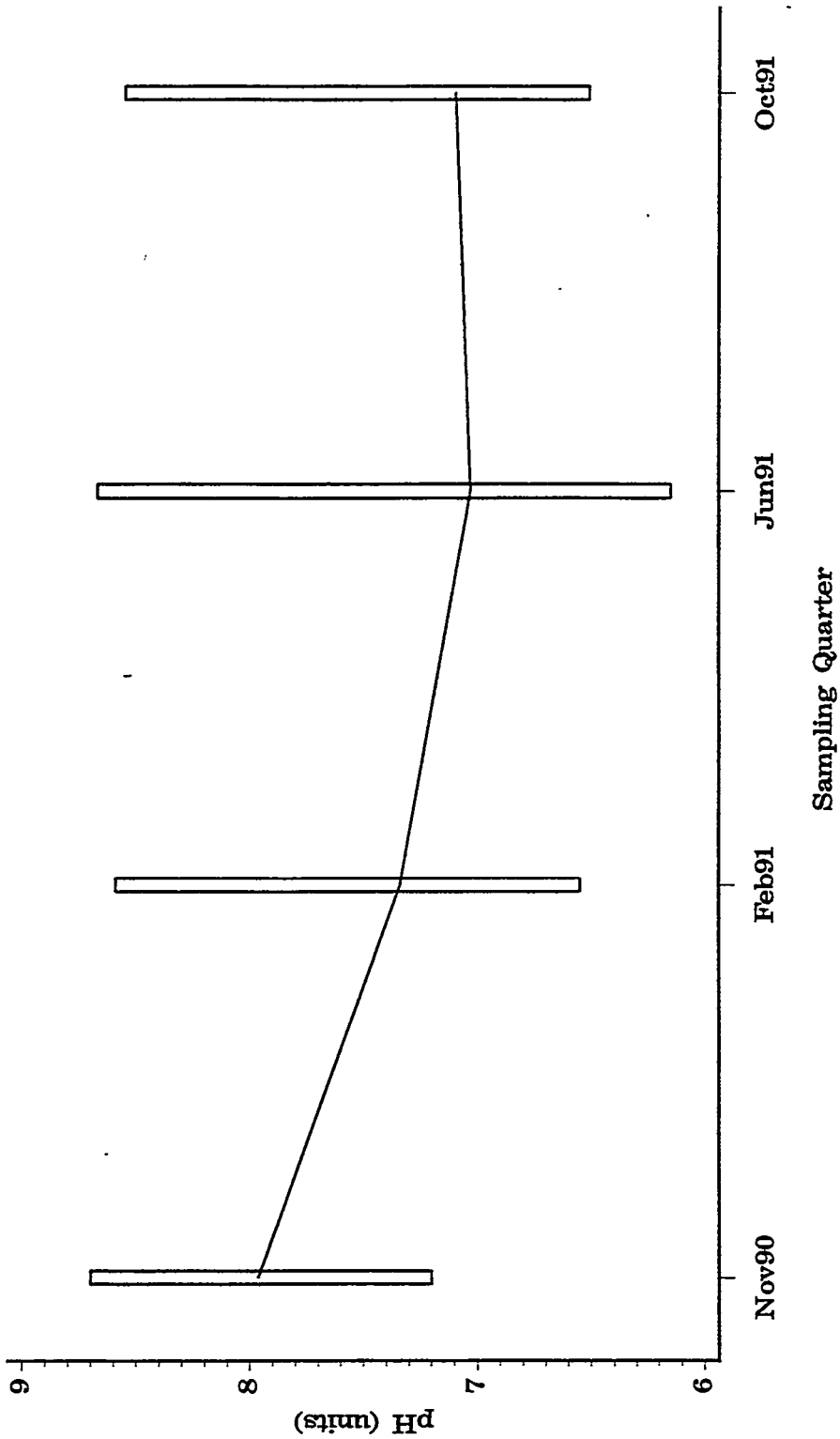

Fig. 3.64. Range of pH values by sampling quarter. The line connects the mean of the values for each quarter.

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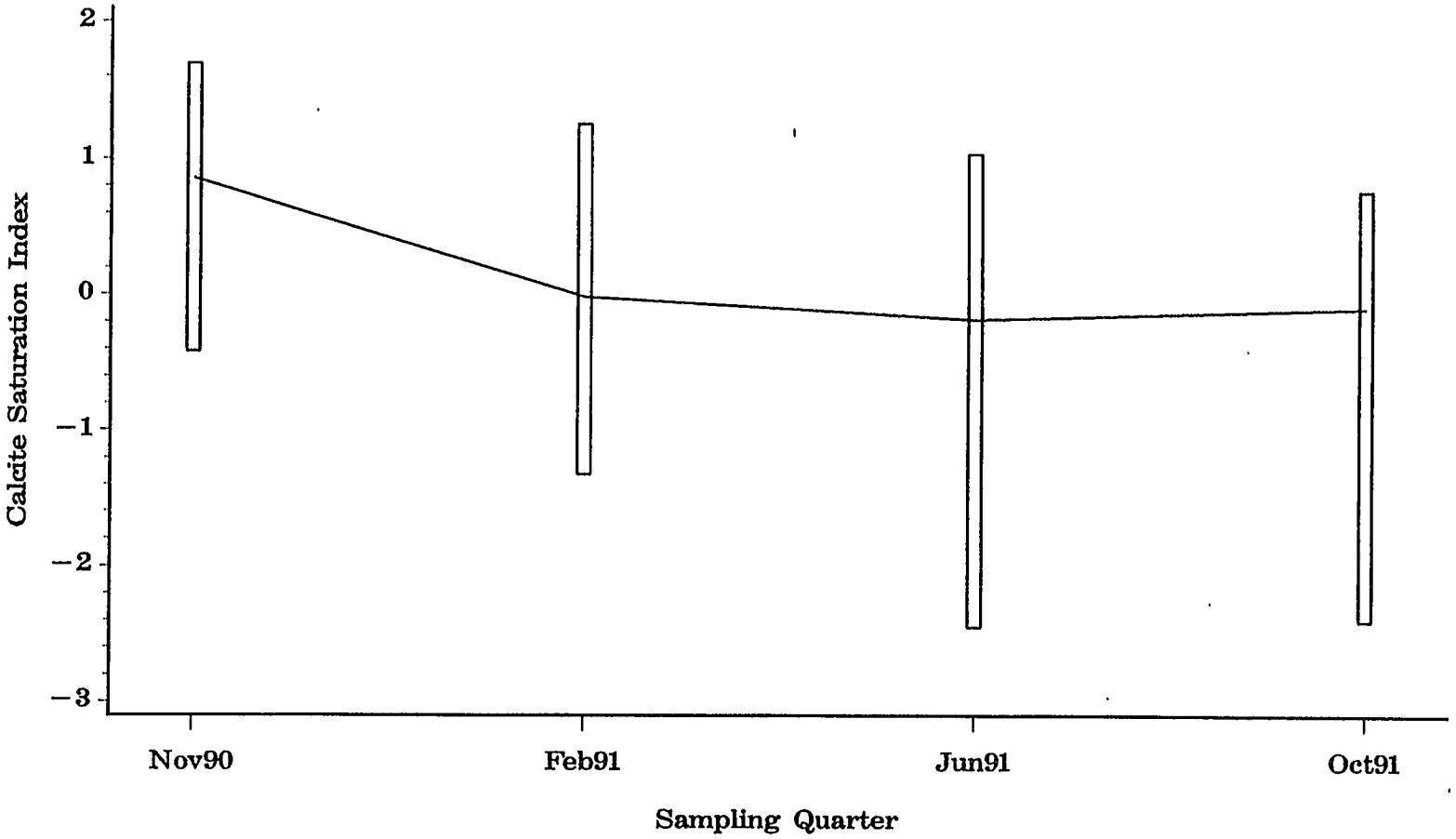


Fig. 3.65. Range of calcite saturation index values by sampling quarter. The line connects the mean of the values for each quarter.

calcium, barium, magnesium, manganese) may be very similar, with differences related more to analytical error than to real differences in the distribution between dissolved and solid phases in the environment.

Evaluation of contaminant transport in groundwater mainly concerns those contaminants that are found in solution, given the ambient environmental conditions (e.g., pH, temperature). In the groundwater samples from the EFPC floodplain, there are very few constituents that are of concern and readily soluble. However, dissolved concentrations are often higher than total concentrations for many analytes, suggesting problems with those data.

Most of the COCs observed in the groundwater analyses are associated with the total analyses. The highest concentrations of mercury, uranium, and the transition metals (e.g., cadmium, lead, zinc, nickel) are found in the total analyses.

The association of contaminants with total analyses suggests that the particle-reactive contaminants are attached to fine-grained particulates in the total sample and are not necessarily mobile in the groundwater. Geochemical modeling of the total analyses can be used to identify those constituents (e.g., iron oxides, aluminum oxides) that are likely to represent particles. If the concentrations of these constituents in the analysis exceed the solubility of a solid phase, the model will precipitate that solid. Any solids thus identified in the total analysis are associated with sorbed, particle-reactive contaminants (e.g., uranium, lead). Furthermore, the model can be used to assign observed mercury concentrations to possible solid phases. The resulting model-calculated equilibrium concentrations of mercury in solution can be compared with observed dissolved concentrations.

Equilibrium Geochemical Modeling. The analytical results from two groundwater monitoring wells (screened in soil) in the EFPC floodplain were used as input to a geochemical model, MINTEQA2 (EPA 1987a). MINTEQA2 is a type of geochemical model, an equilibrium model, wherein the results of total water analyses (i.e., total calcium, total magnesium, total sulfate) are input parameters. The model then checks the input to see if there is charge balance [the sum of all positive charges species in solution (in this case EFPC floodplain groundwater) must equal the sum of all negatively charged species] and then proceeds to calculate the distribution of species (e.g., complex ions in solution, solid mineral phases) that would occur in that solution at equilibrium. One important calculation that occurs during the distribution is a check to see if the solution is supersaturated with respect to any solid mineral phase. The SI is calculated routinely for a broad range of minerals (data for these minerals are stored in the MINTEQA2 data base).

For analysis of EFPC groundwaters, the results of total analyses were used because elevated mercury concentrations were observed and because mercury is not observed in corresponding dissolved analyses. The total analyses were used in full recognition that some of the analyte concentrations used as input (e.g., iron, aluminum, manganese) were elevated because of the presence of fine-grained particulates in the unfiltered sample. The results were used to test the ability of the model to recognize this and precipitate supersaturated iron, aluminum, and manganese phases. The following analytes/parameters were entered:

MINTEQA2 INPUT PARAMETERS

Cations	Anions
calcium	sulfate
magnesium	nitrate
potassium	chloride
sodium	alkalinity
iron	sulfide
manganese	
aluminum	
mercury	

The solution pH (measured in the field) was not allowed to change. The model was free to precipitate any supersaturated mineral phases.

Model results suggest that several mineral phases would precipitate from the input solutions (see Appendix F for model run data) depending on starting assumptions (e.g., manganite MnO(OH), mercury (I) sulfide Hg_2S, mercury (II) carbonate $HgCO_3$, hematite Fe_2O_3, and diaspore AlO(OH).

The lack of any dissolved silica analyses explains the presence of diaspore rather than a common aluminosilicate phase (e.g., kaolinite).

The samples selected for model input represented some of the highest concentrations of mercury in total analyses. In addition, the samples had high concentrations of dissolved sulfide. Despite the elevated mercury concentrations in total analyses, the mercury concentration in the corresponding filtered sample was undetectable. The modeling effort was an attempt to illustrate the fact that the presence of solid phases in a total groundwater analysis requires a corresponding

equilibrium dissolved mercury concentration. Depending on the geochemical conditions in groundwater, the equilibrium dissolved concentration may be either above or below analytical detection limits.

The model calculations, while not comprehensive, serve to illustrate a range of possible dissolved mercury concentrations that could be expected in the dissolved samples. In two cases, the total analyses for dissolved sulfide were assumed to be correct and combined with a reduced form of mercury (and in an additional case with reduced forms of iron and manganese) in the input data set. The model calculations yielded reduced mercury precipitates (e.g., Hg_2S, calomel) and equilibrium solution concentrations that range from 1.6 ppb to 6×10^{-6} ppb.

Another model assumed that, with the exception of the sulfide data, the data from well AN:D-10 were correct and mercury was in an oxidized form. In this case, mercury carbonate was precipitated, and the corresponding dissolved mercury concentration was 0.056 ppb.

The results of these limited model runs (which did not include provisions for sorption reactions) suggest that, depending upon initial model assumptions, dissolved mercury concentrations in LEFPC groundwater may exceed the analytical detection limit (0.1 ppb). However, equilibrium dissolved mercury concentrations did not exceed the MCL (2 ppb) in any model runs.

3.2.4.4 Groundwater evaluation

Quarterly Groundwater Monitoring Results. Figures 3.66 through 3.80b present the quarterly groundwater monitoring results for all the wells by analyte. These figures display only the significant results for 4 quarters of sampling and analyses from the full suite of contaminants (volatiles, semivolatiles, metals, and radionuclides). The wells are grouped in relation to their proximity to each other and the Y-12 Plant. AN:D1-6 is the USGS transect across the NO site, and AN:D 7-11 is the USGS transect across the BR site. AN:E1-6 is the set of Energy Systems monitoring wells situated in the upper reaches of EFPC closest to the Y-12 Plant, and AN:7-12 is the set of wells spaced along the middle reach of EFPC in the vicinity of the BR and WA sites. A different hatching pattern for analyte concentration is presented for each quarter of sampling for all the wells to allow temporal as well as spatial trends to be evident.

Inspection of the graphs reveals two problems in interpretation of the groundwater results. Two VOCs, acetone (Fig. 3.47) and methylene chloride (Fig. 3.57), were present at sporadic

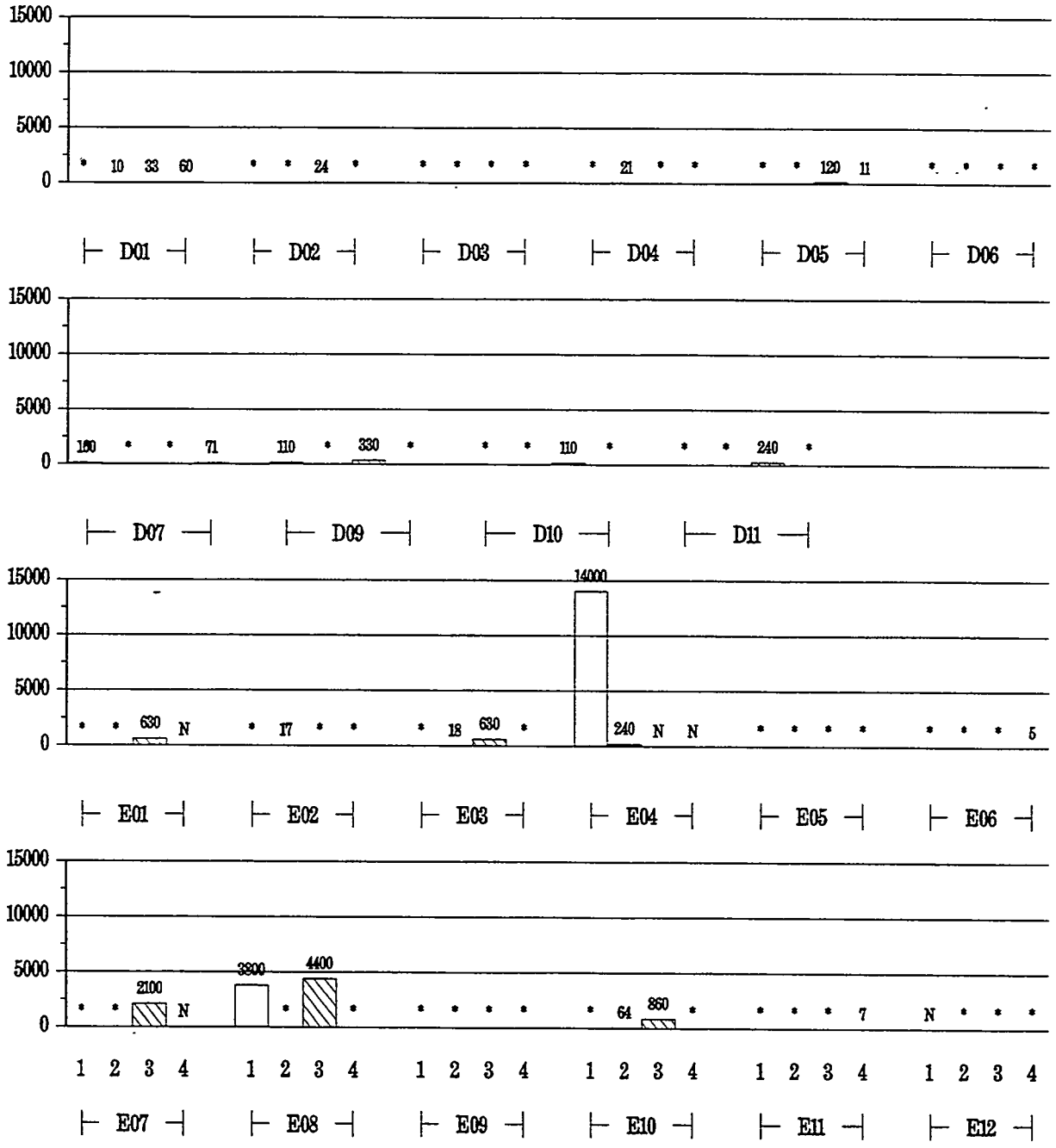


Fig. 3.66. ***Acetone*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

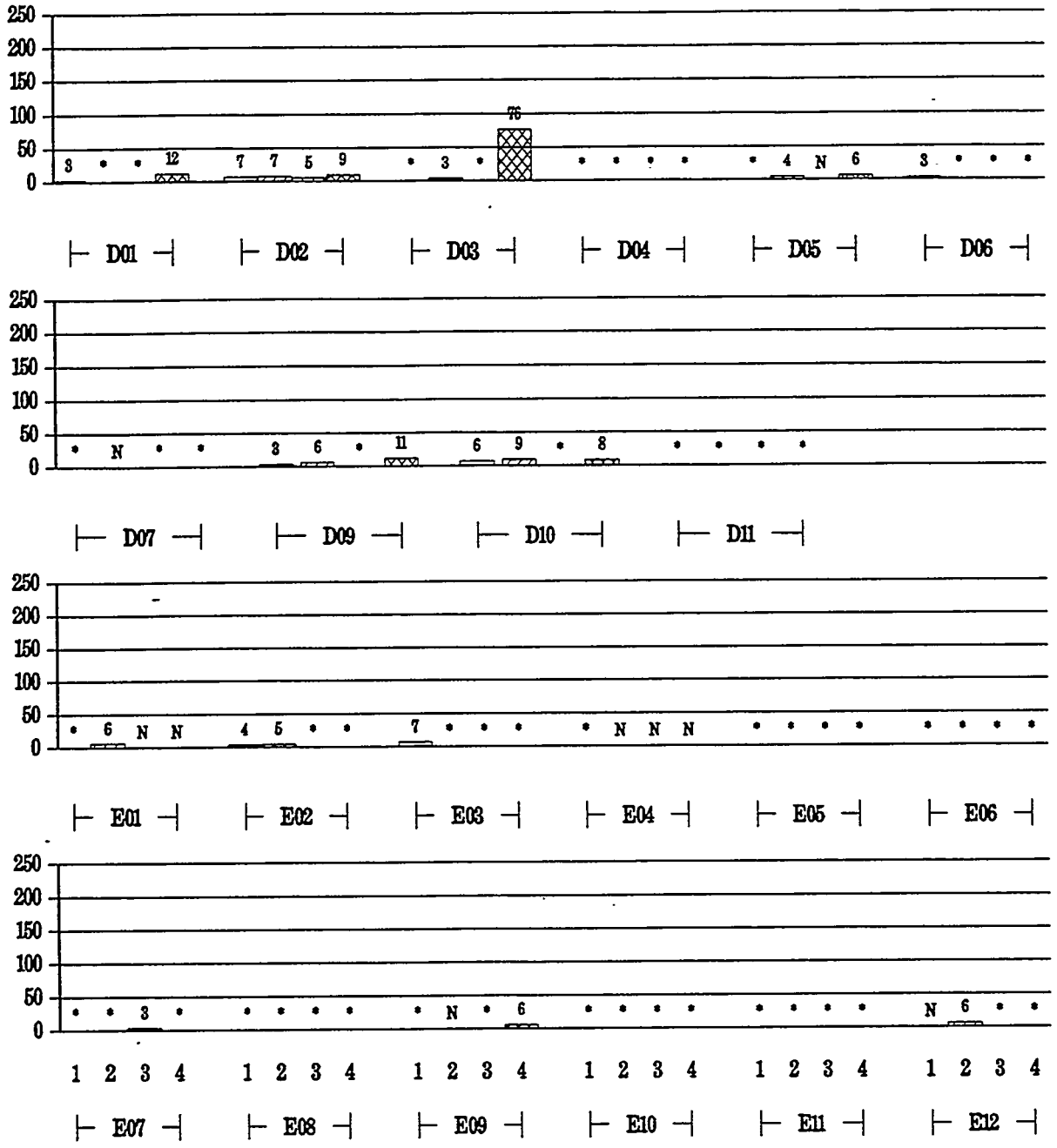


Fig. 3.67a. ***Arsenic*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

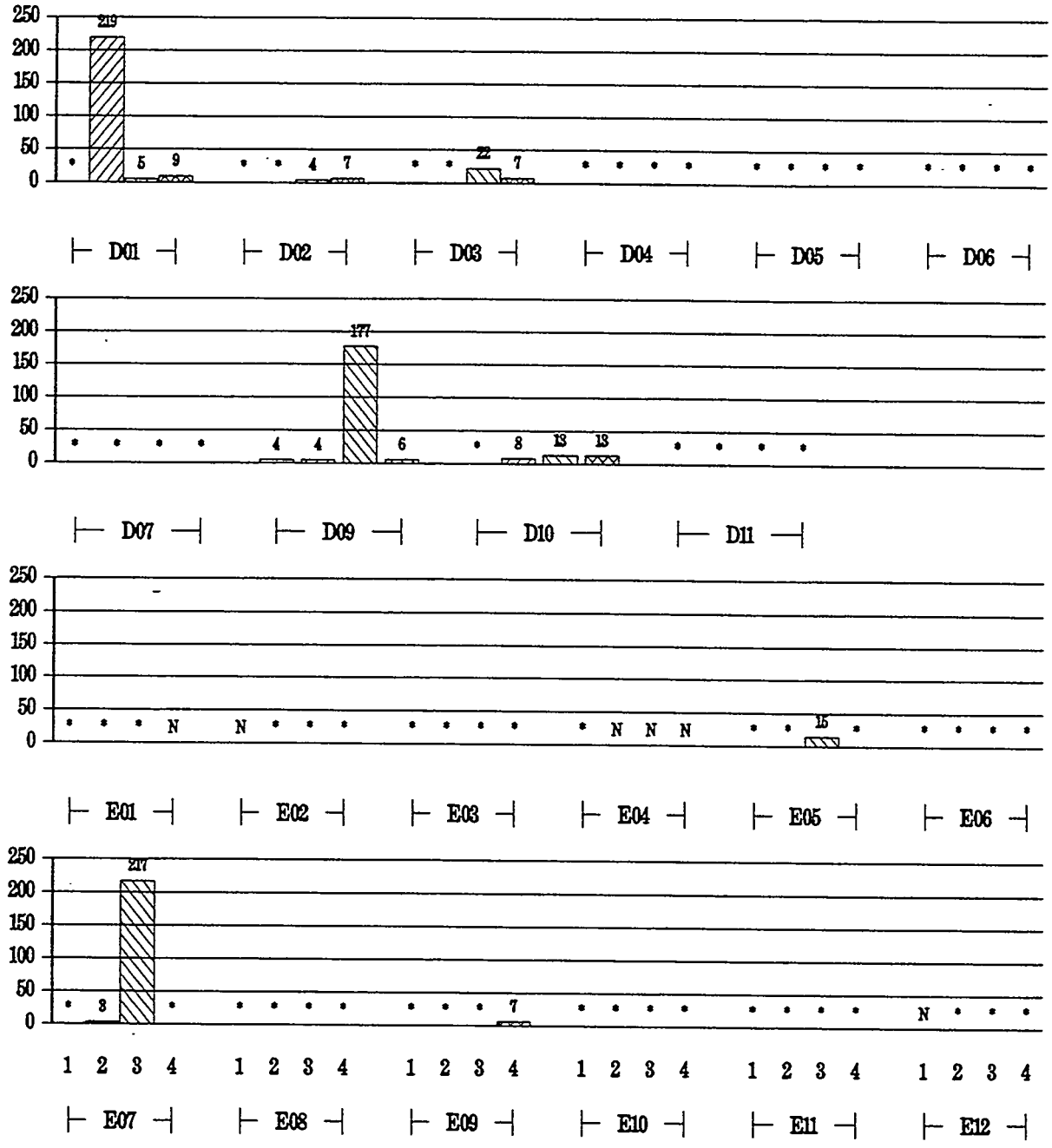


Fig. 3.67b. ***Dissolved Arsenic*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

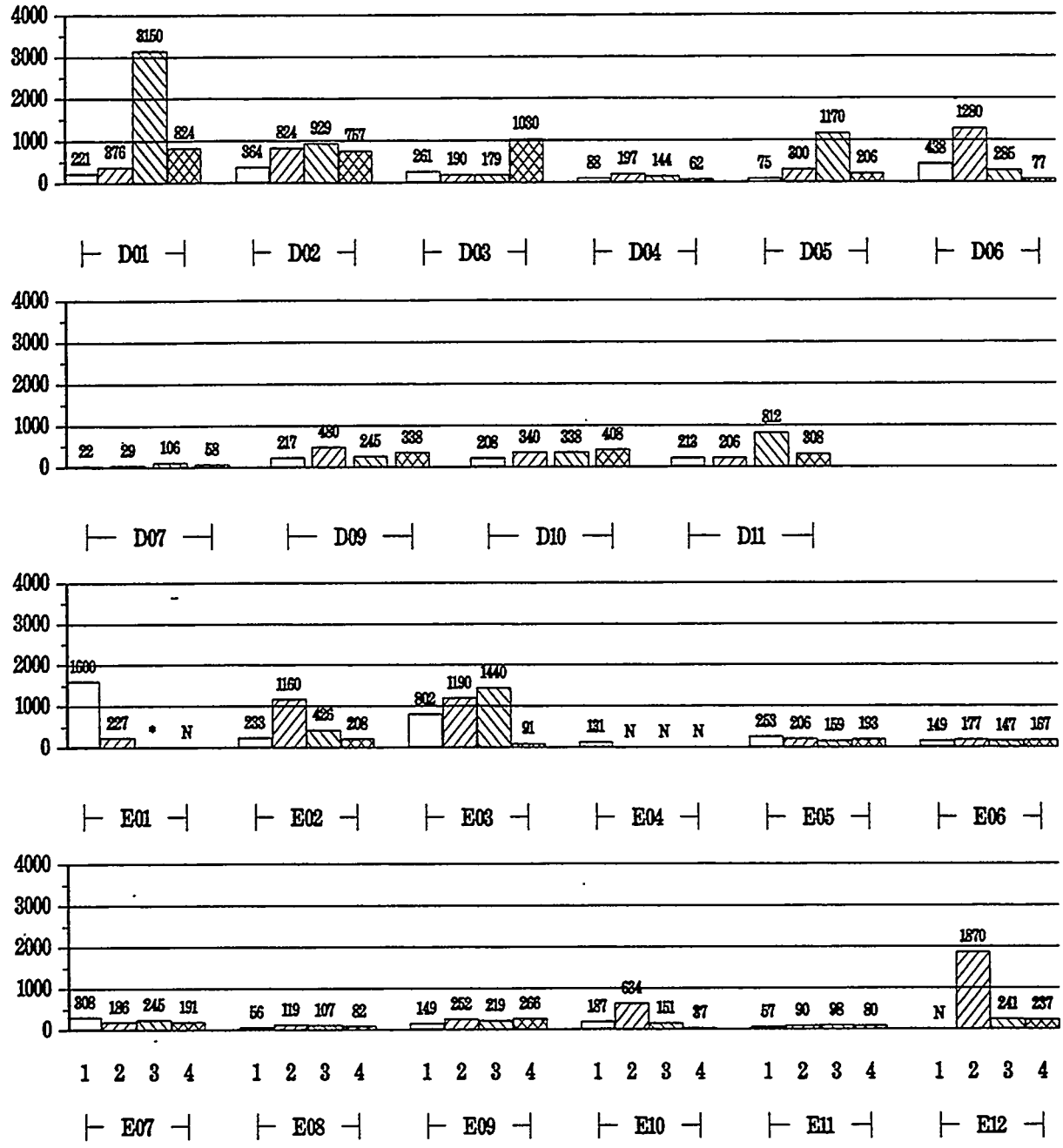


Fig. 3.68a. ***Barium*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

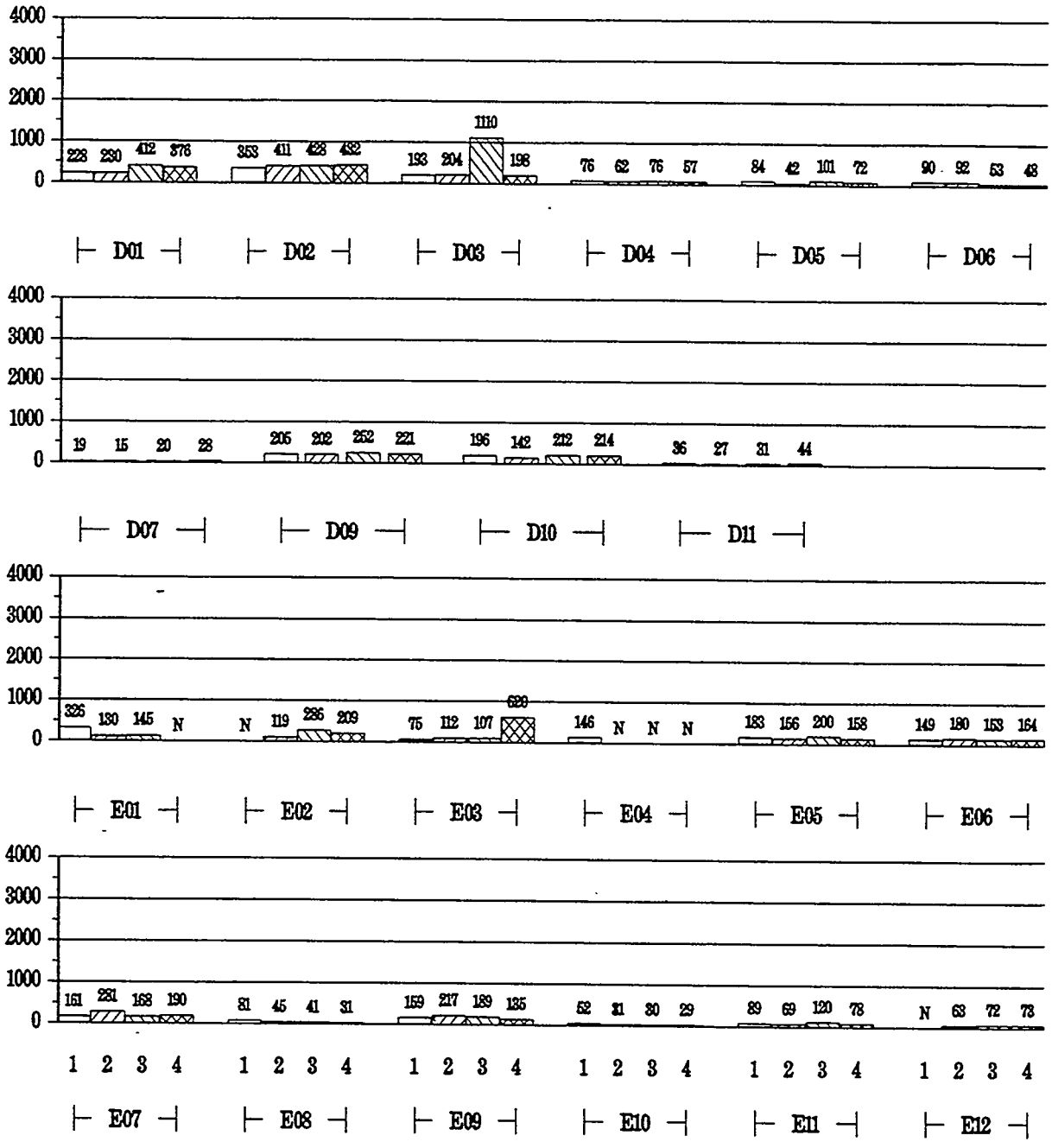


Fig. 3.68b. ***Dissolved Barium*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

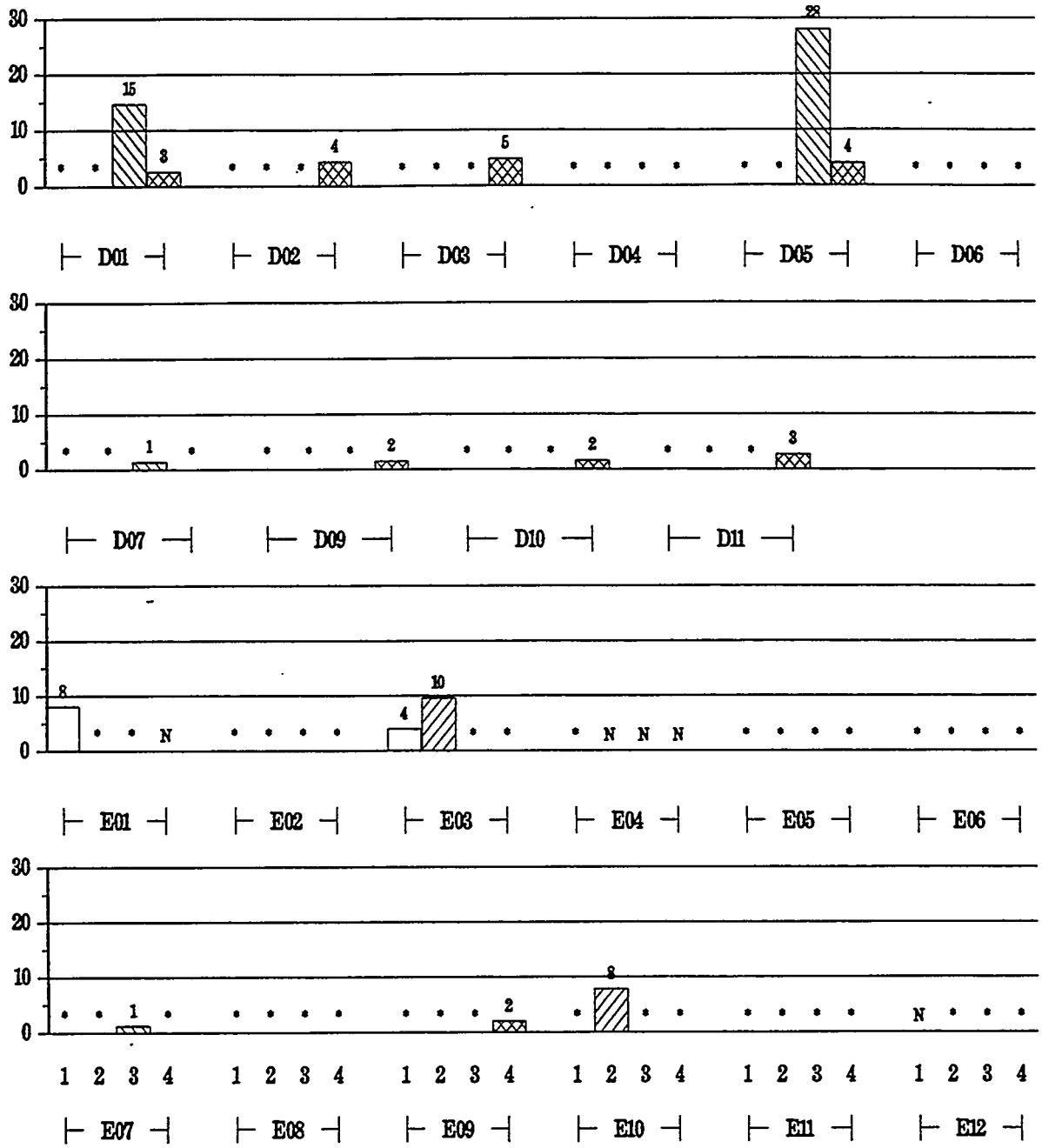


Fig. 3.69a. ***Beryllium*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

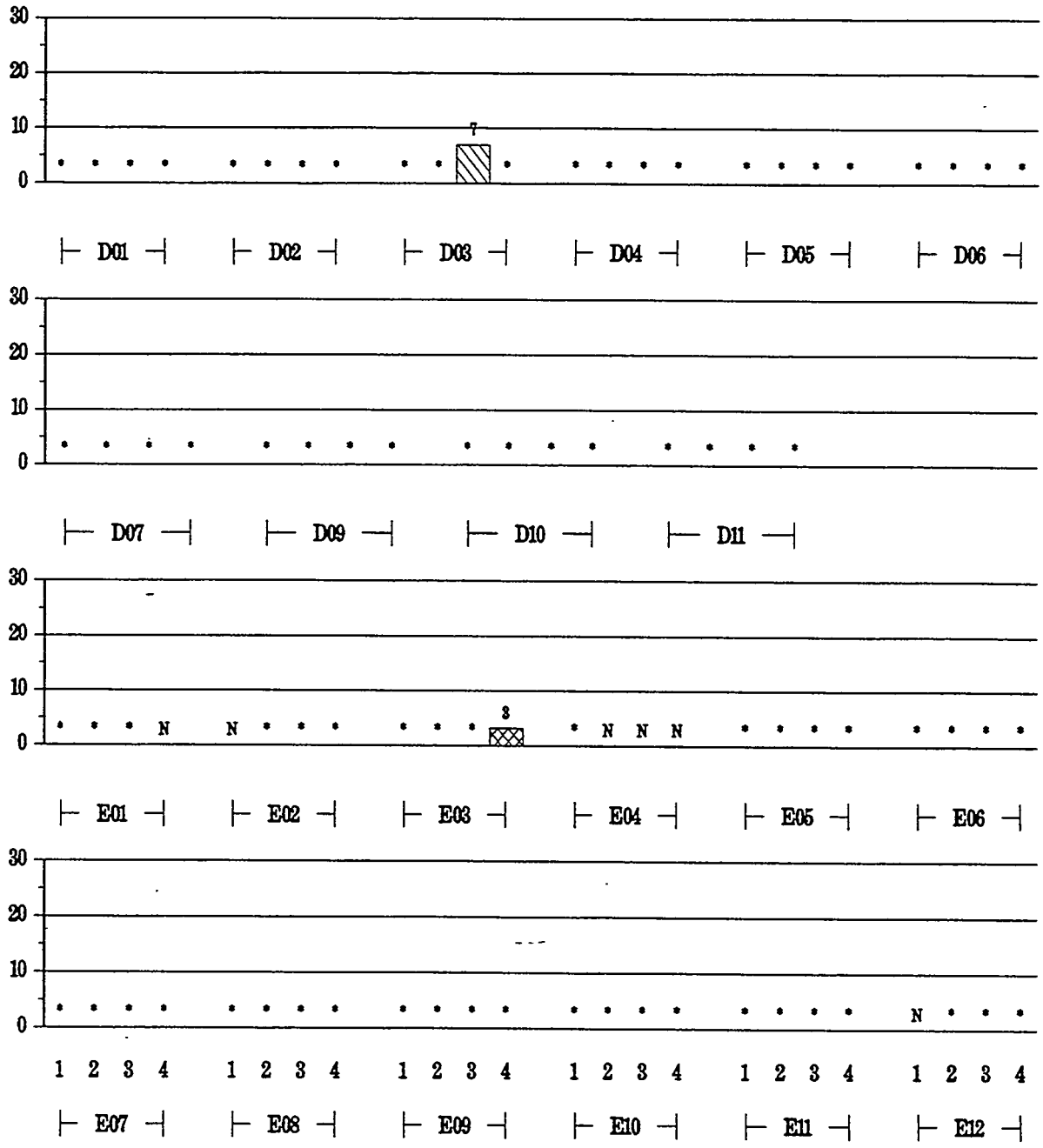


Fig. 3.69b. ***Dissolved Beryllium*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

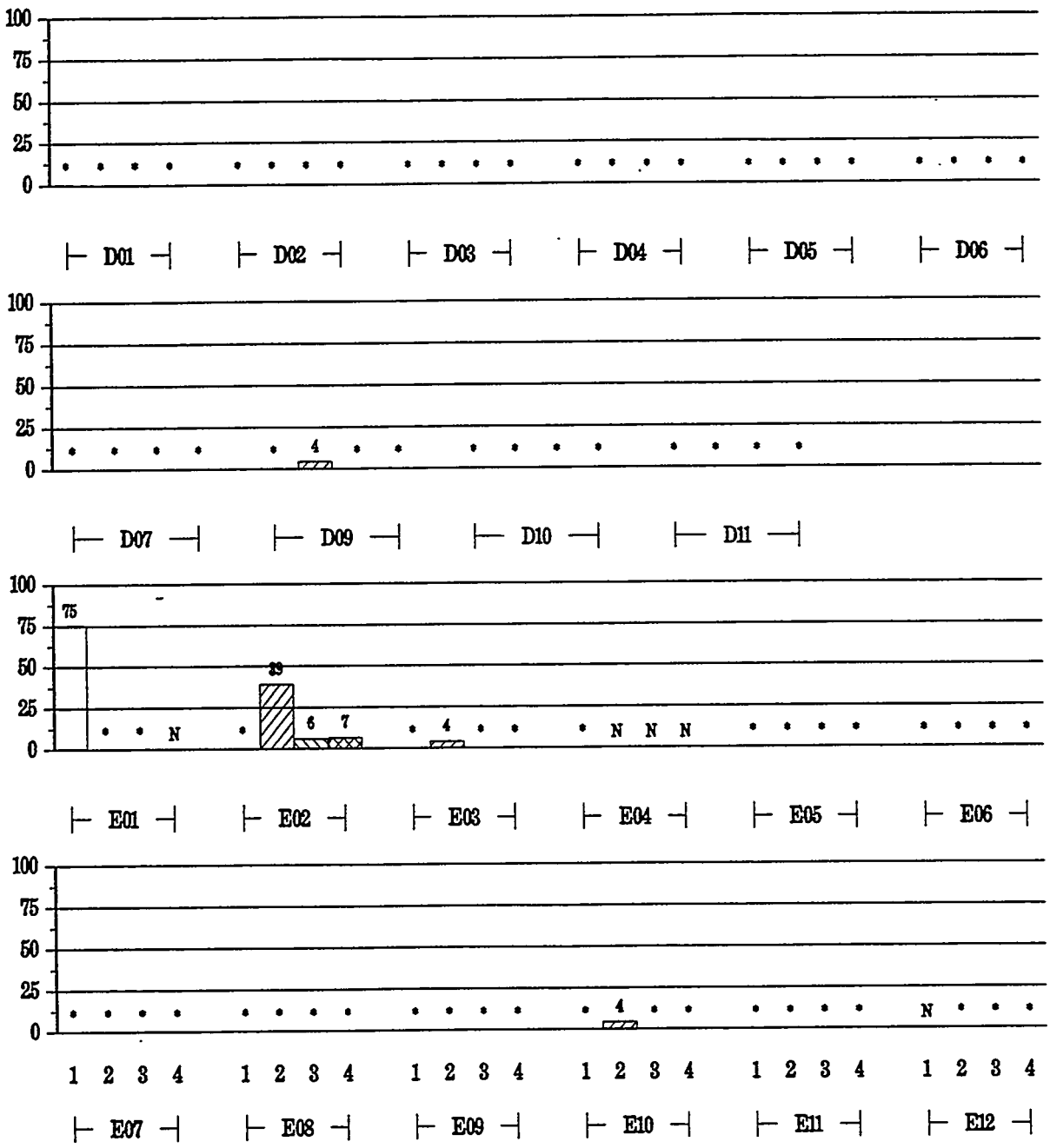


Fig. 3.70a. ***Cadmium*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

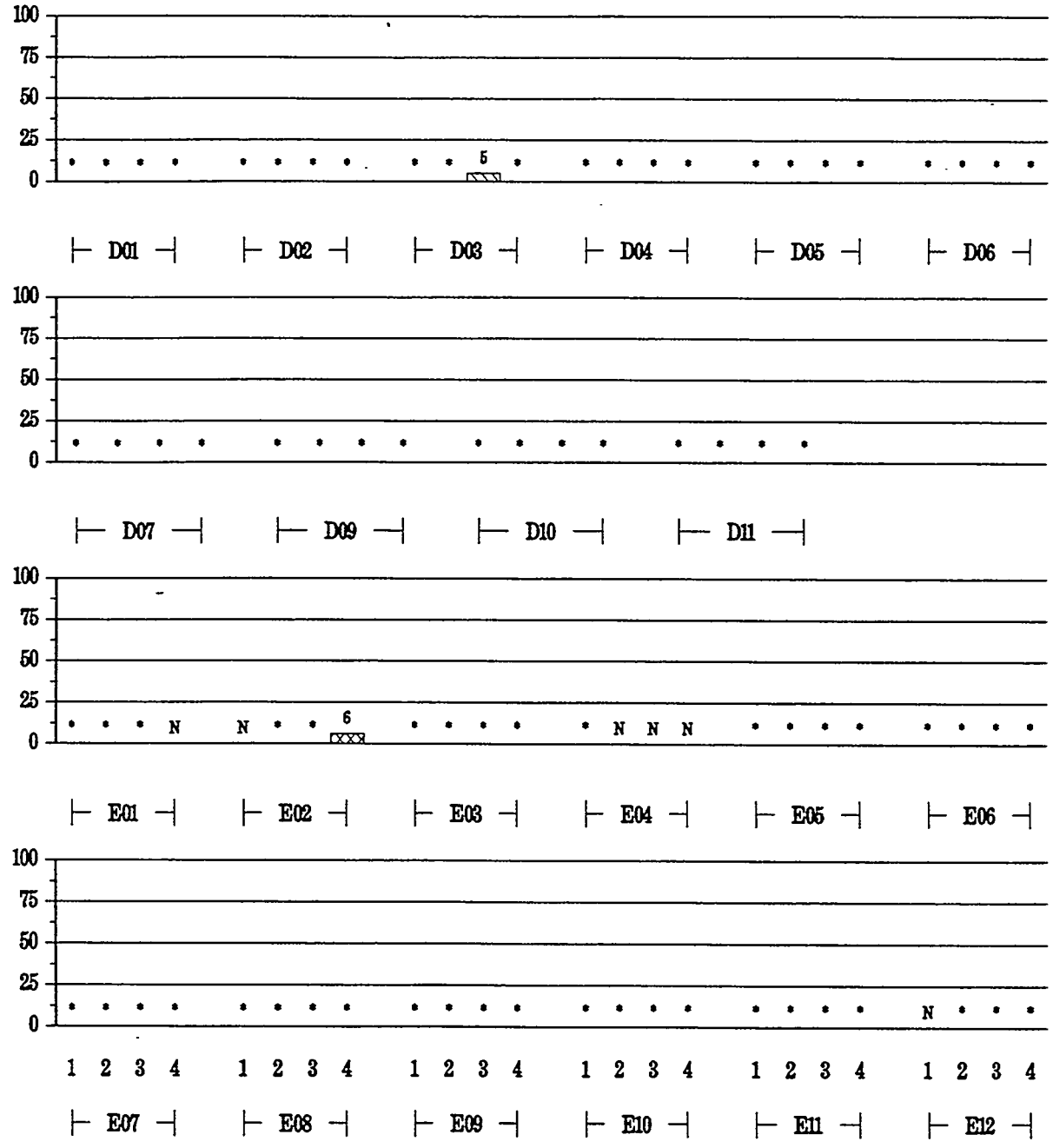


Fig. 3.70b. ***Dissolved Cadmium*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

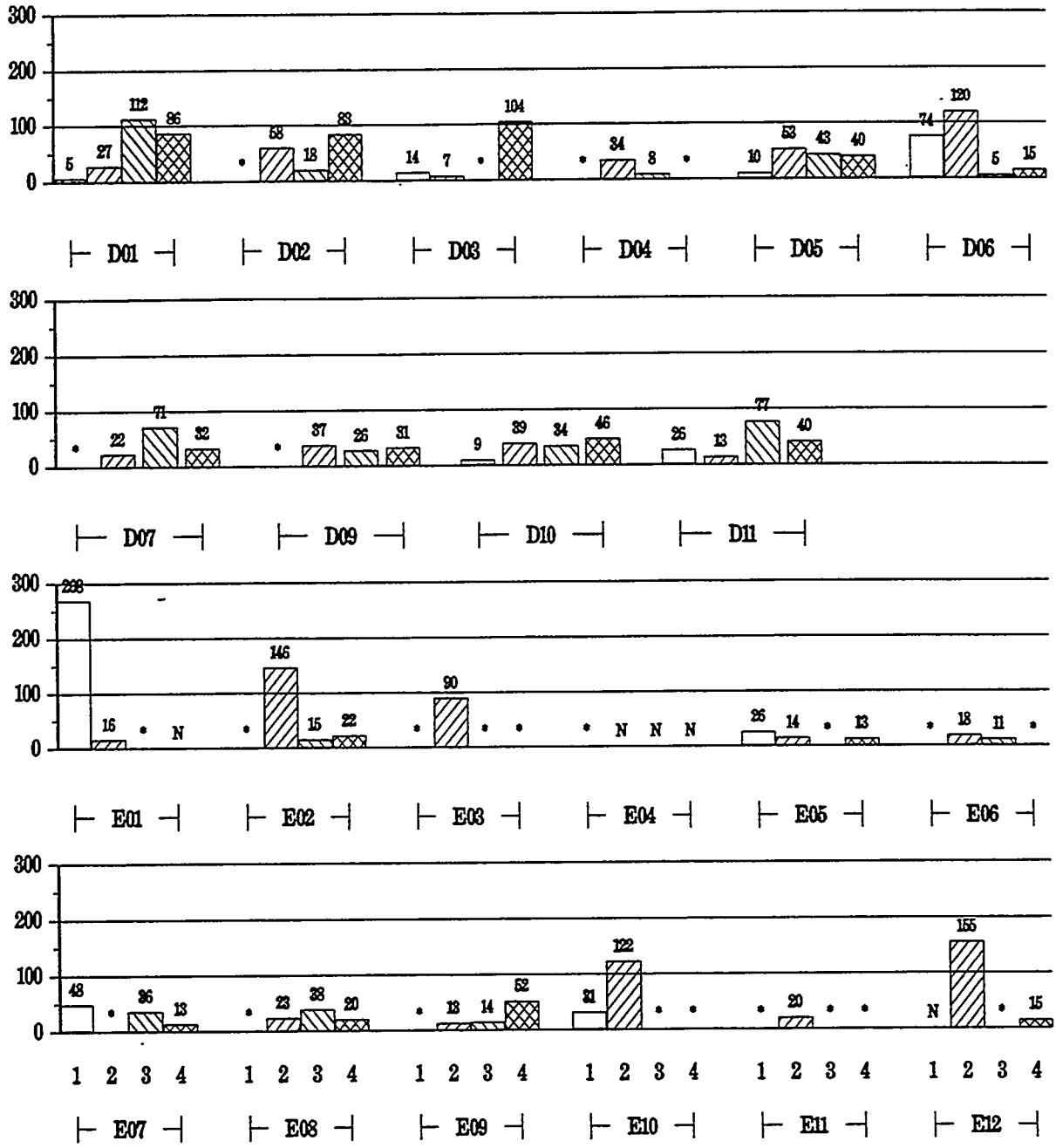


Fig. 3.71a. ***Chromium*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

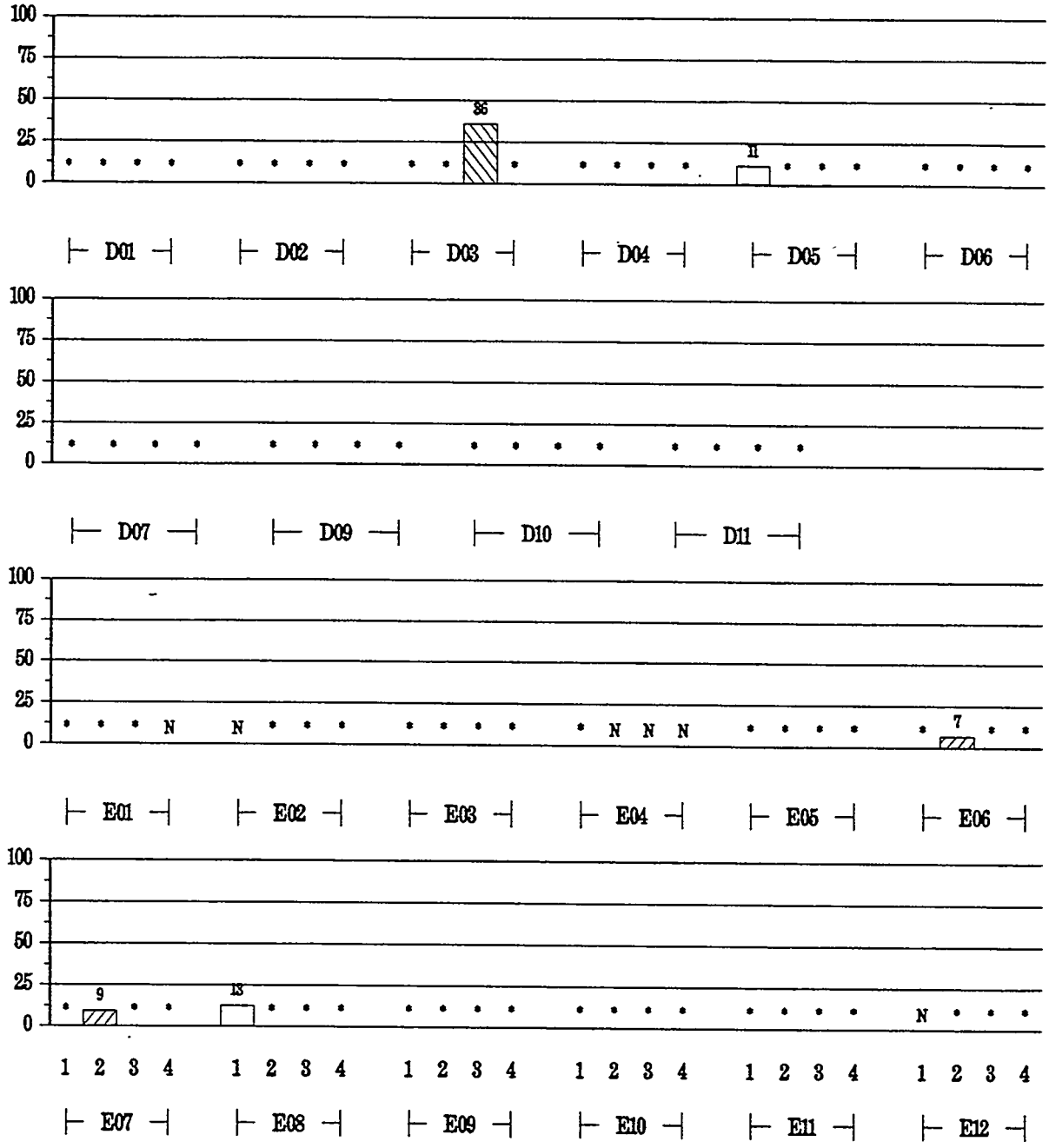


Fig. 3.71b. ***Dissolved Chromium*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

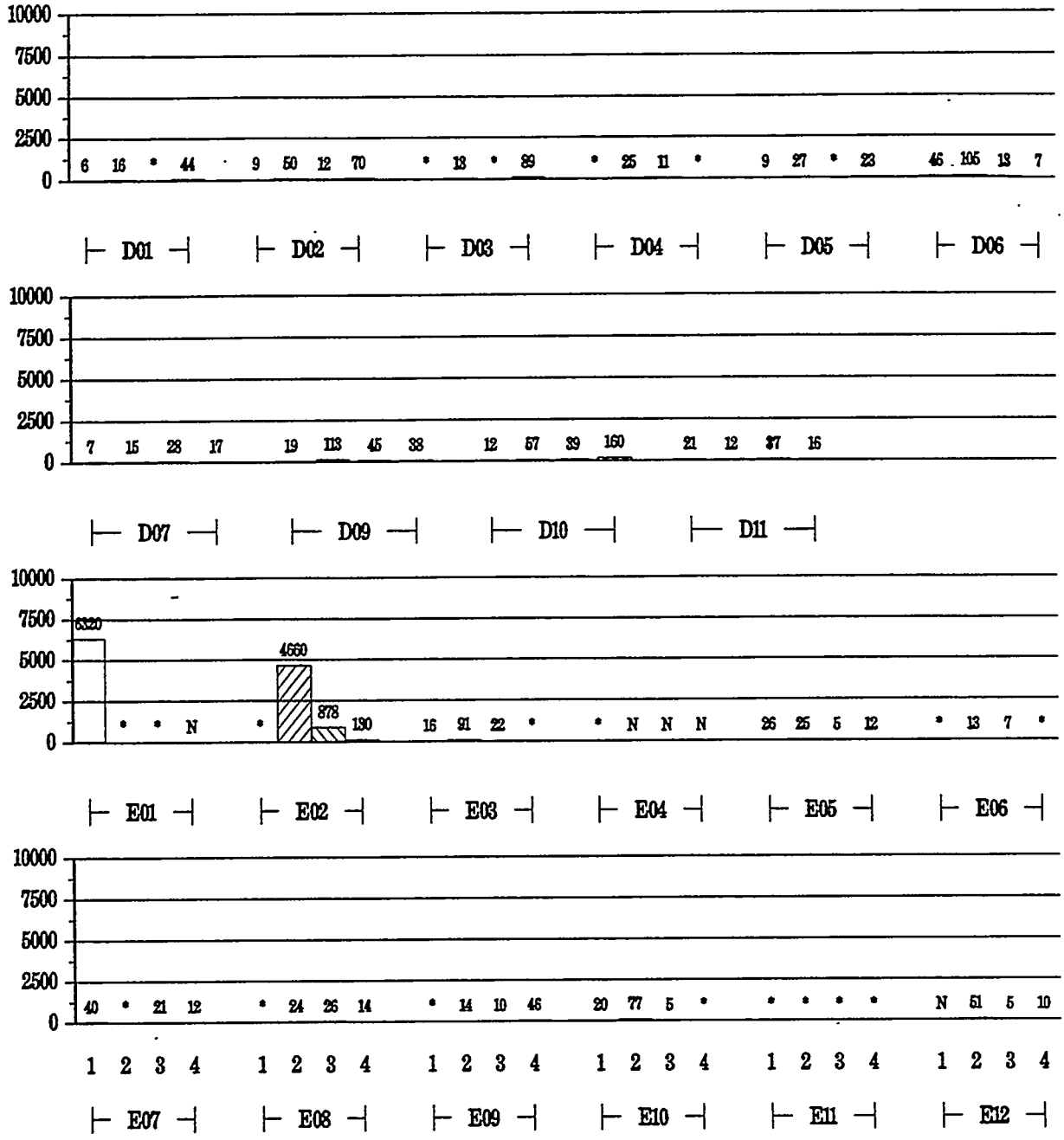


Fig. 3.72a. ***Copper*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

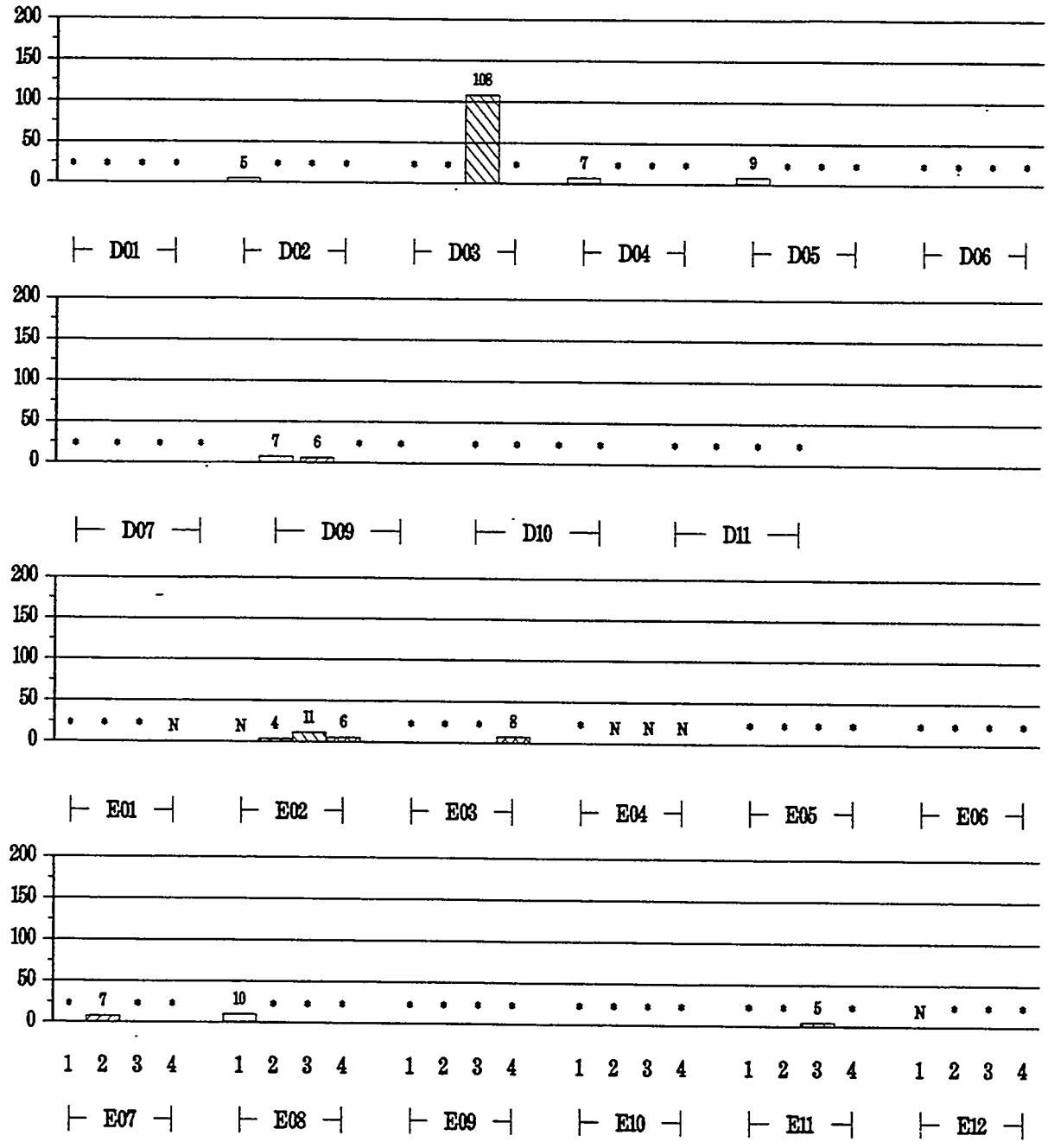


Fig. 3.72b. ***Dissolved Copper*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

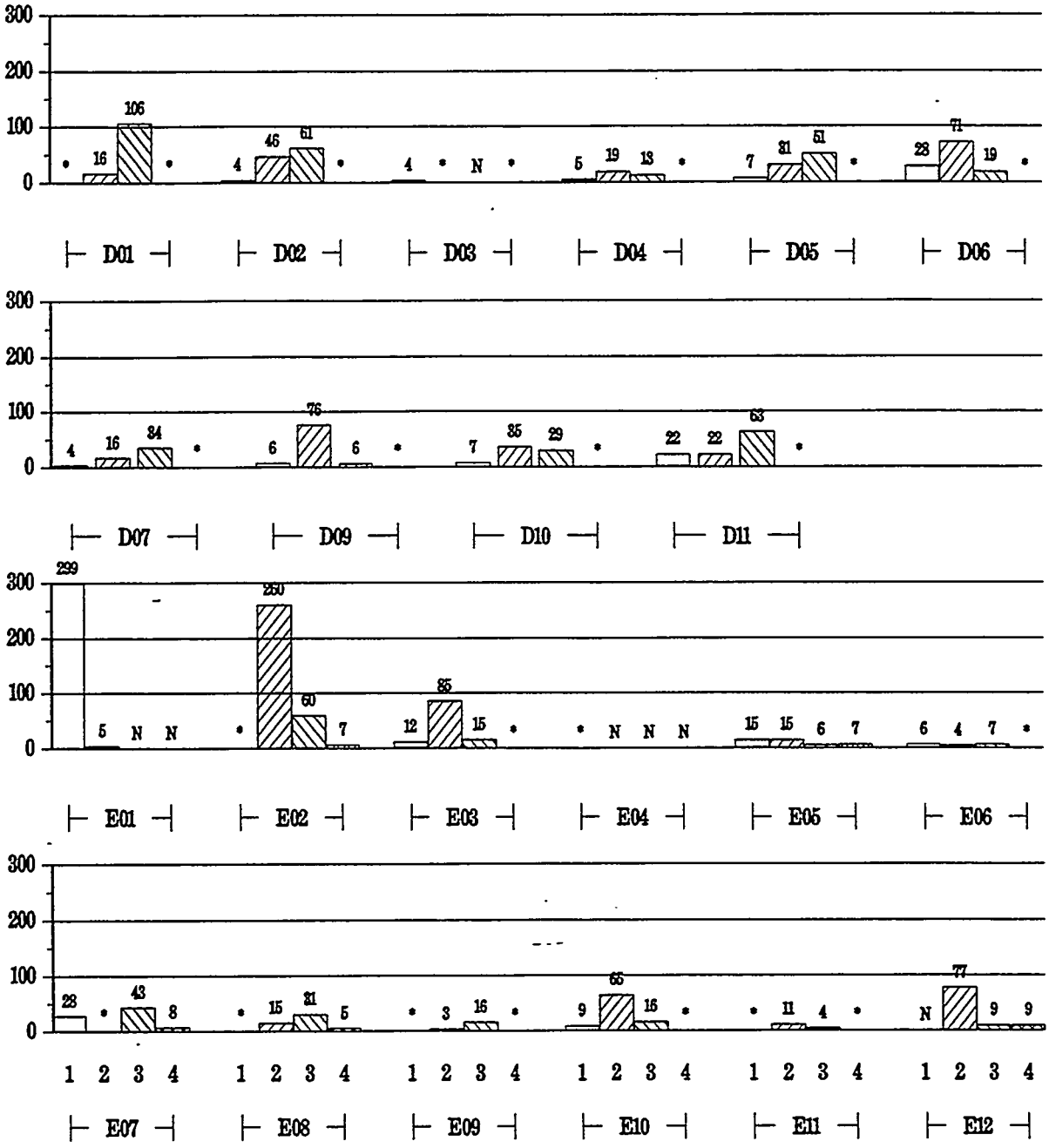


Fig. 3.73a. ***Lead*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

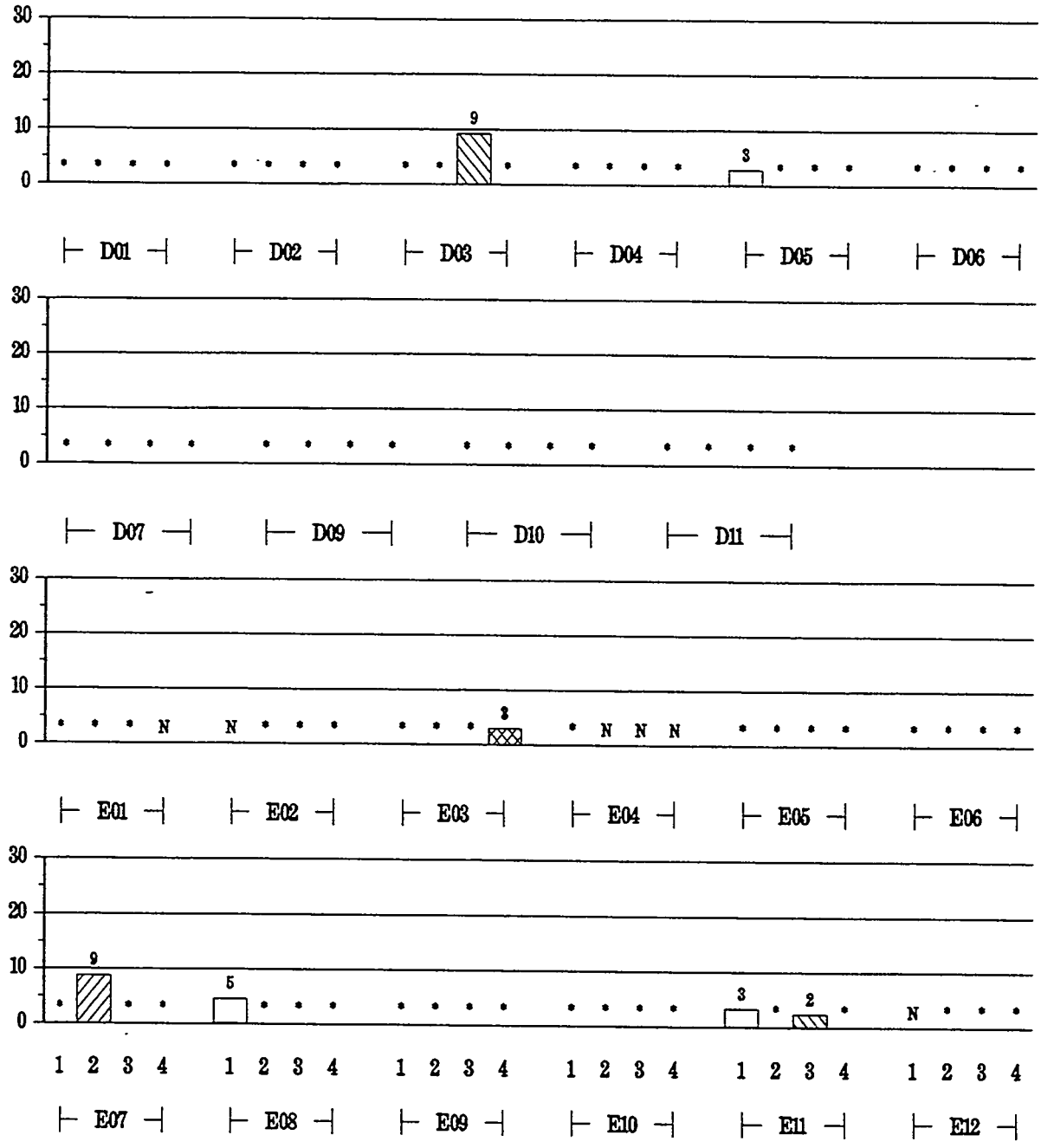


Fig. 3.73b. ***Dissolved Lead*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

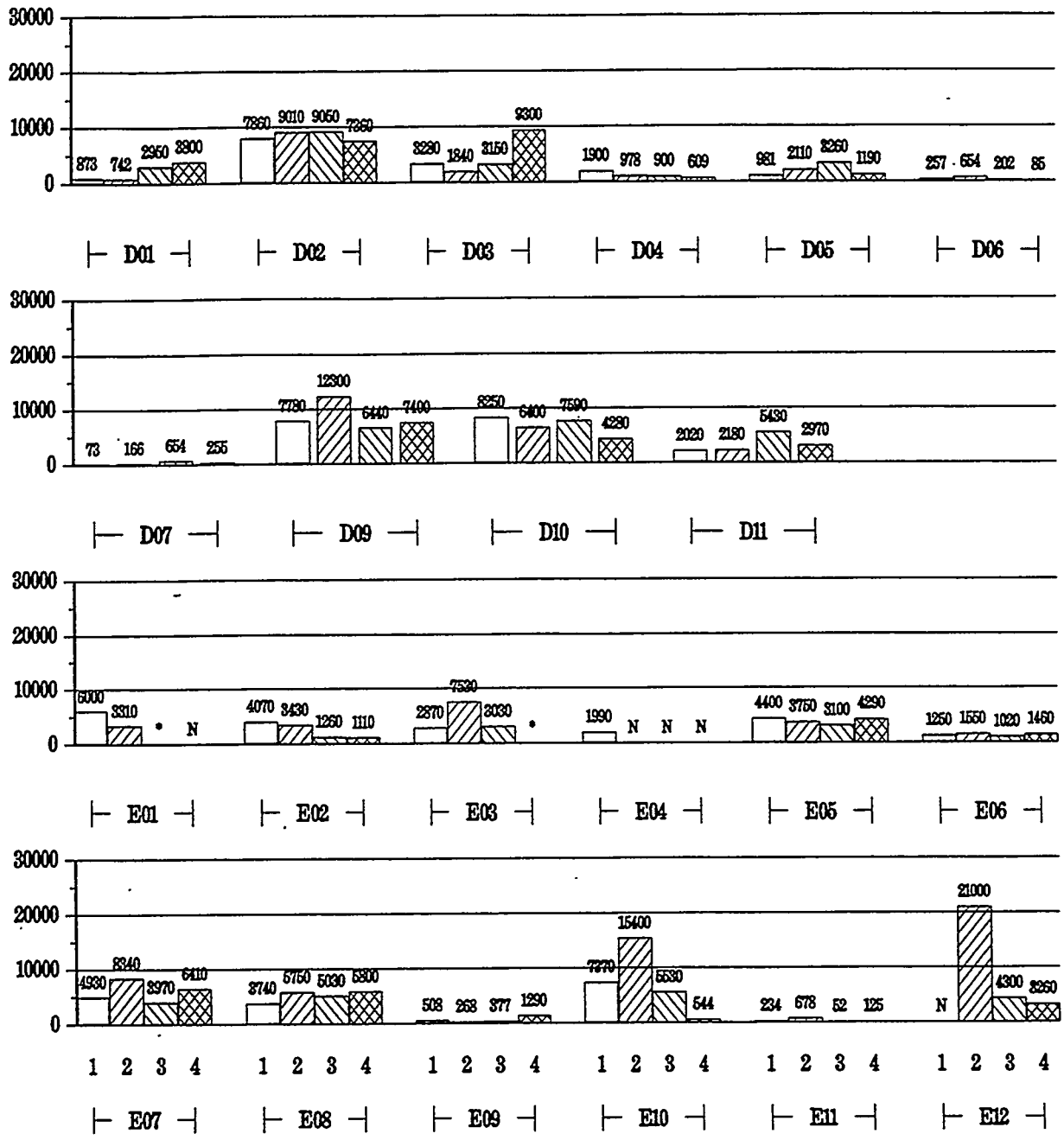


Fig. 3.74a. ***Manganese*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

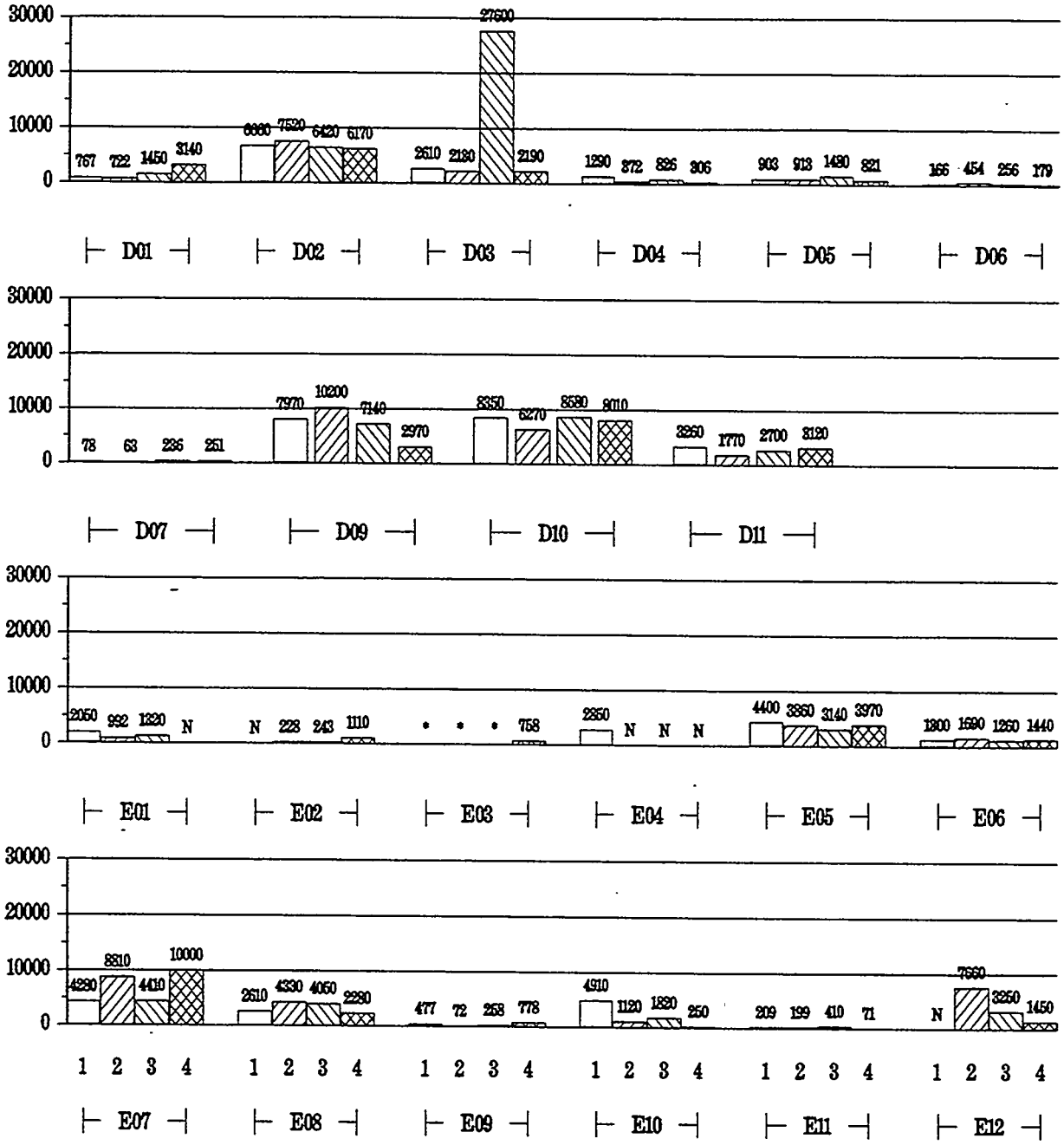


Fig. 3.74b. ***Dissolved Manganese*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

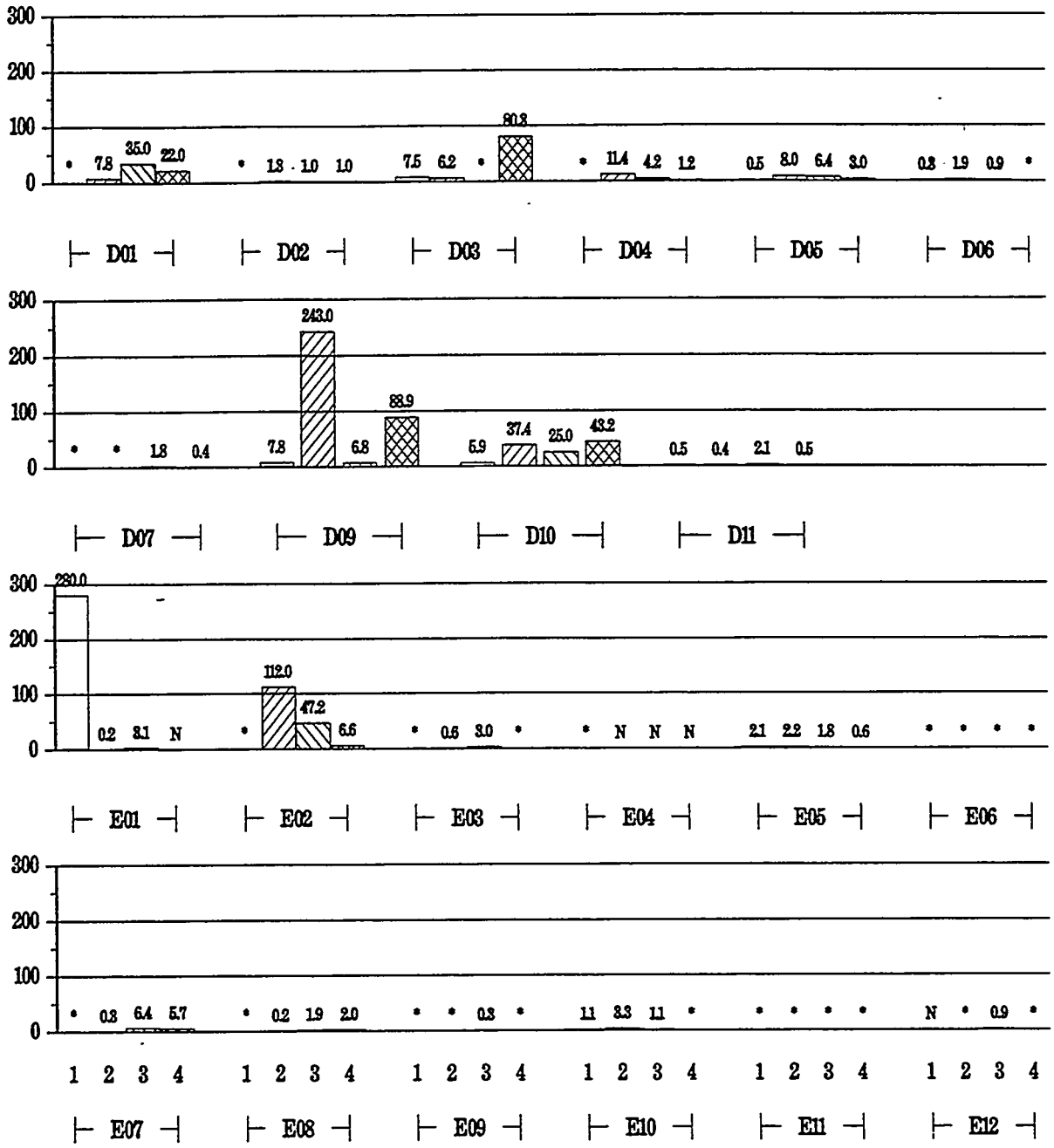


Fig. 3.75a. ***Mercury*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

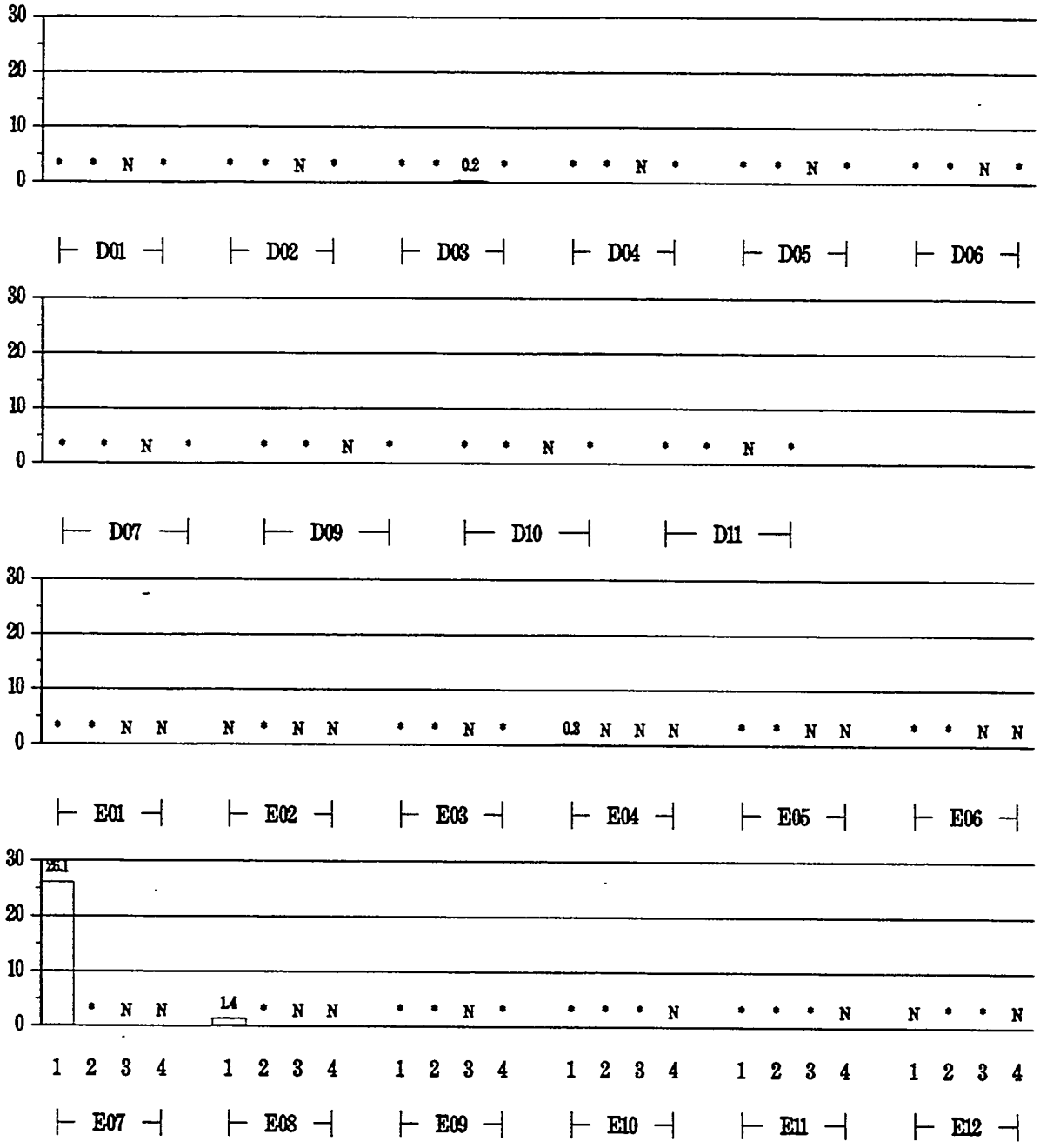


Fig. 3.75b. ***Dissolved Mercury*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

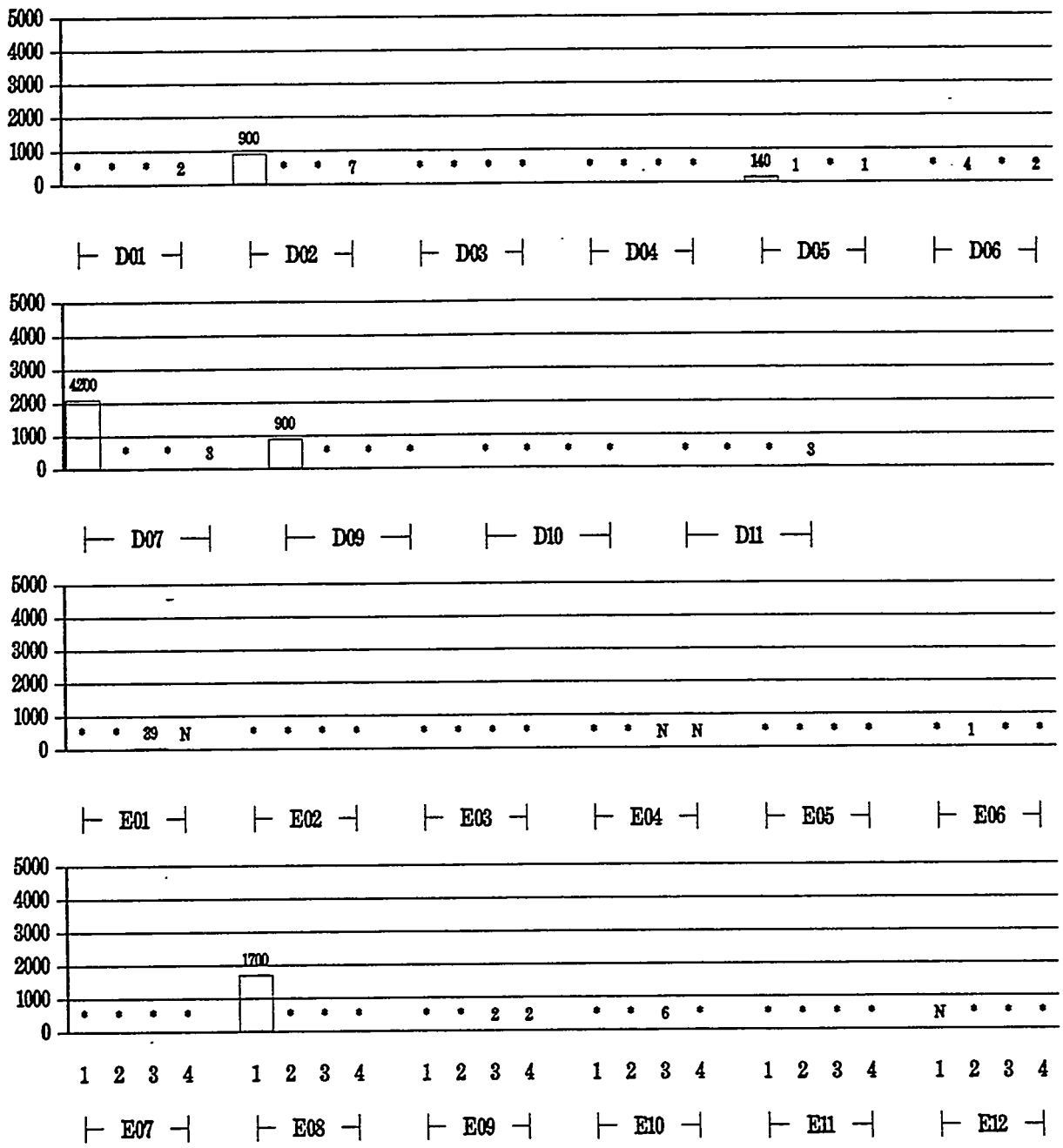


Fig. 3.76. ***Methylene Chloride*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

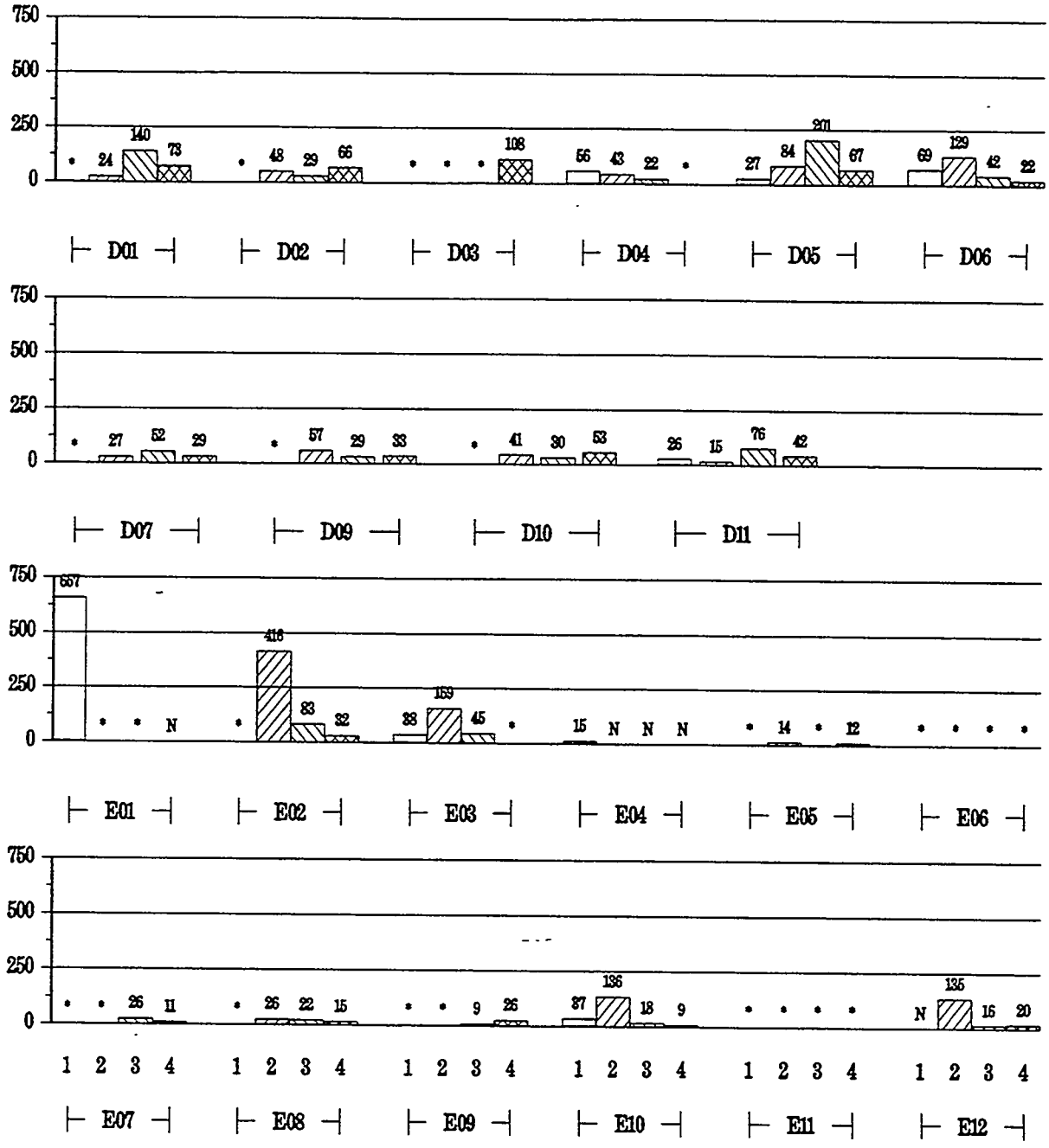


Fig. 3.77a. ***Nickel*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

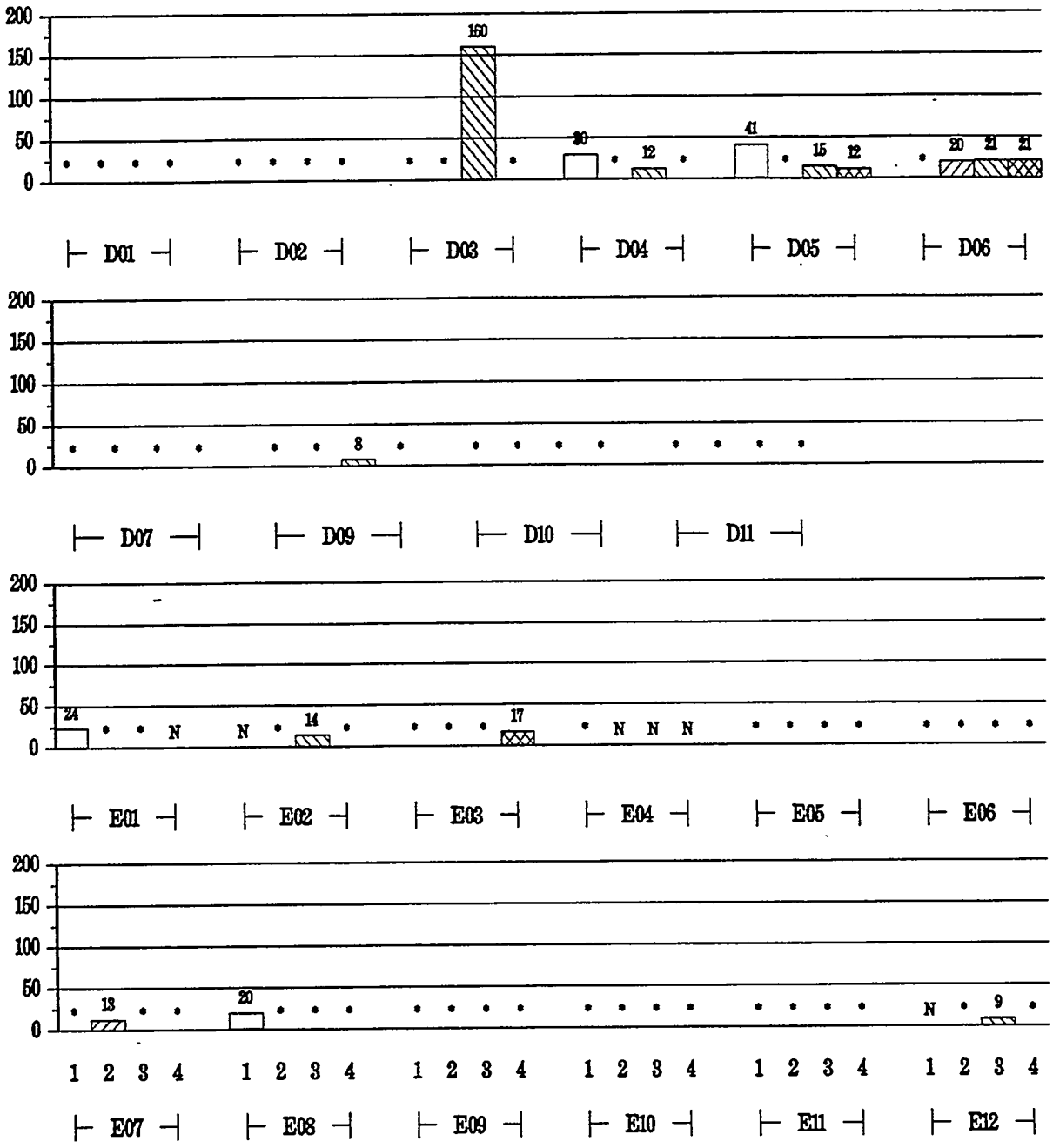


Fig. 3.77b. ***Dissolved Nickel*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with an "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

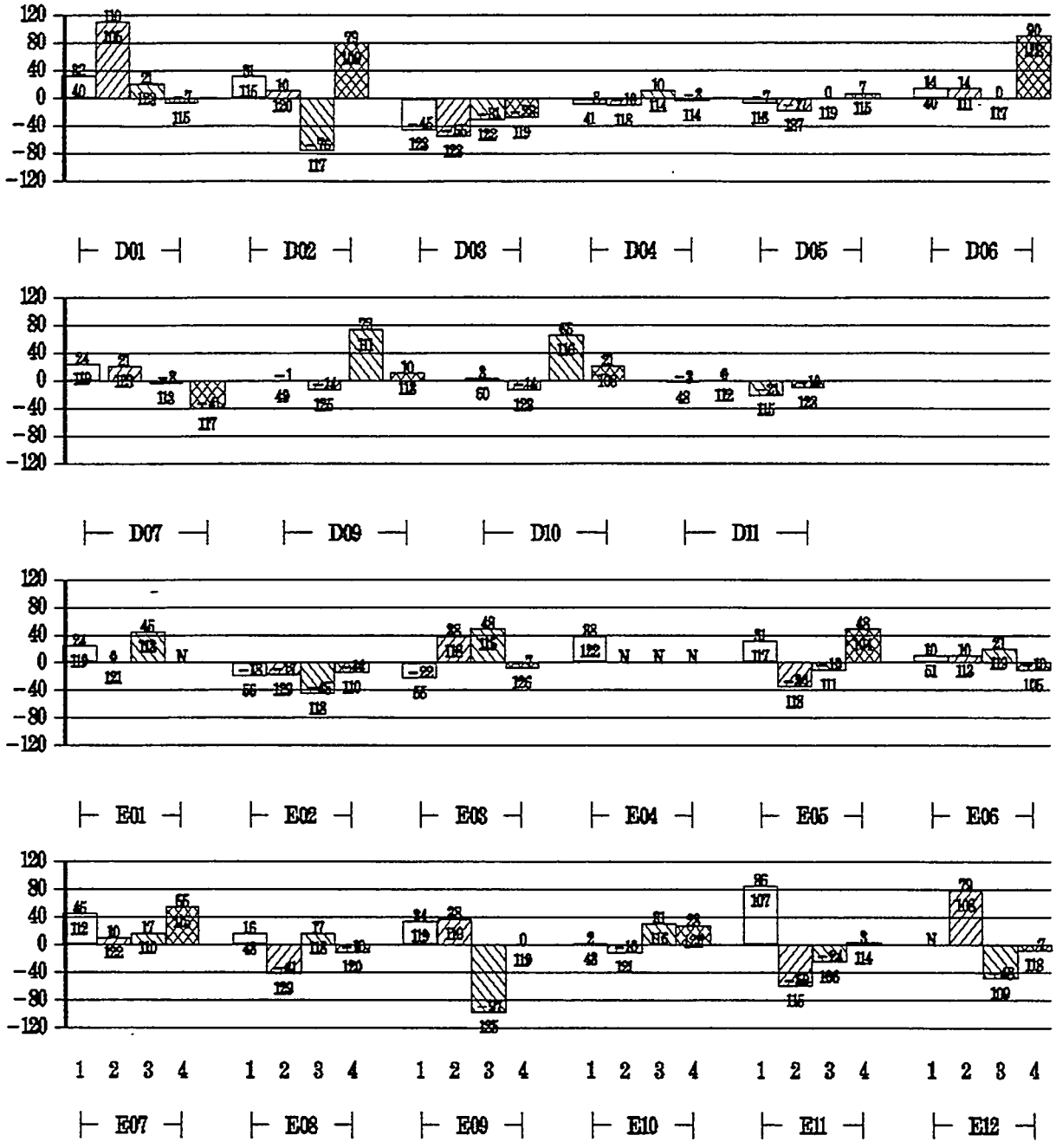


Fig. 3.78a. ***Radionuclide*** ^{241}Am concentrations (pCi/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Values printed above the bar are the results. Values below the bar are the counting uncertainty. Stations with no result are labeled with an "N".

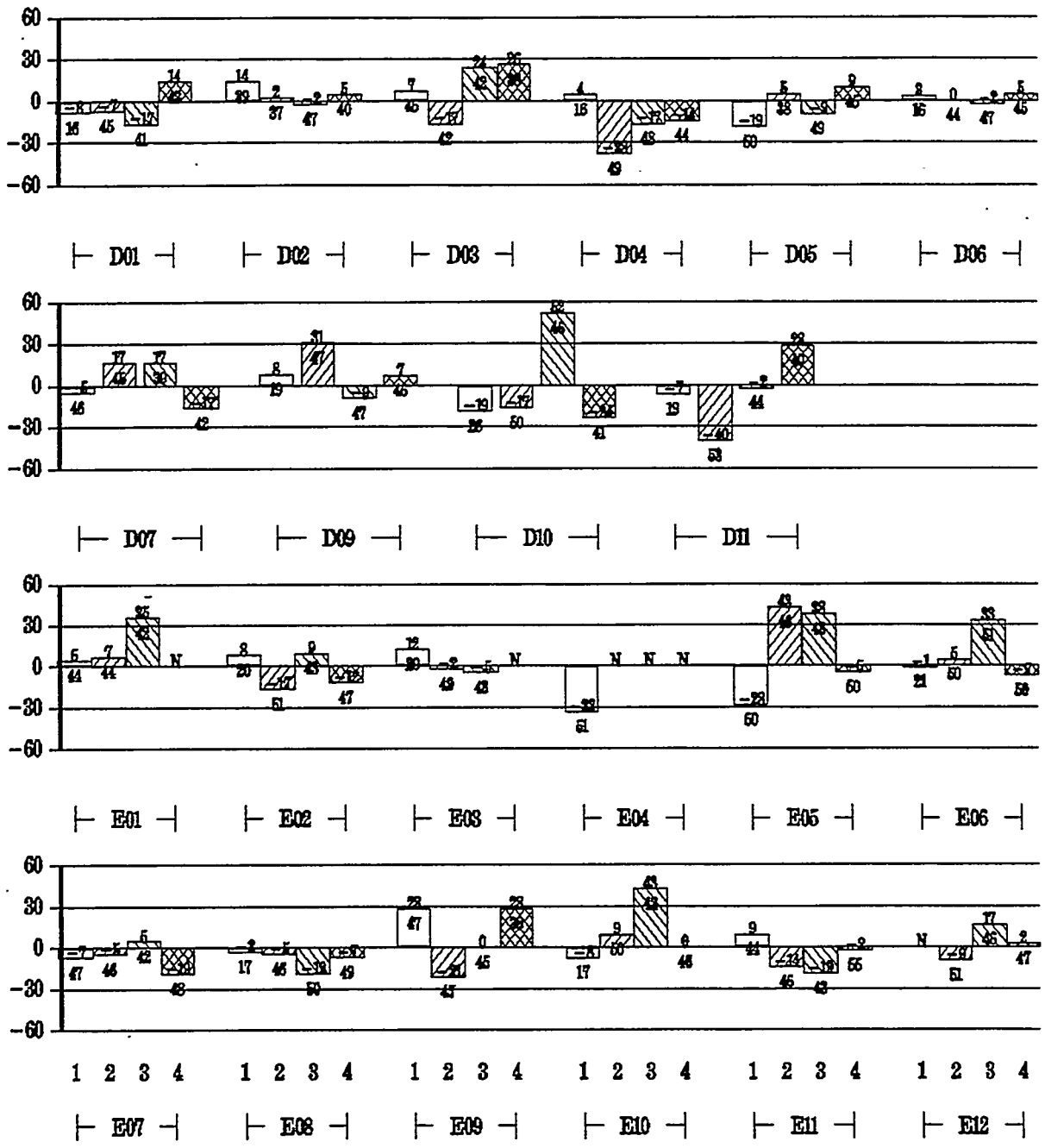


Fig. 3.78b. ***Radionuclide*** **^{137}Cs concentrations (pCi/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Values printed above the bar are the results. Values below the bar are the counting uncertainty. Stations with no result are labeled with an "N".**

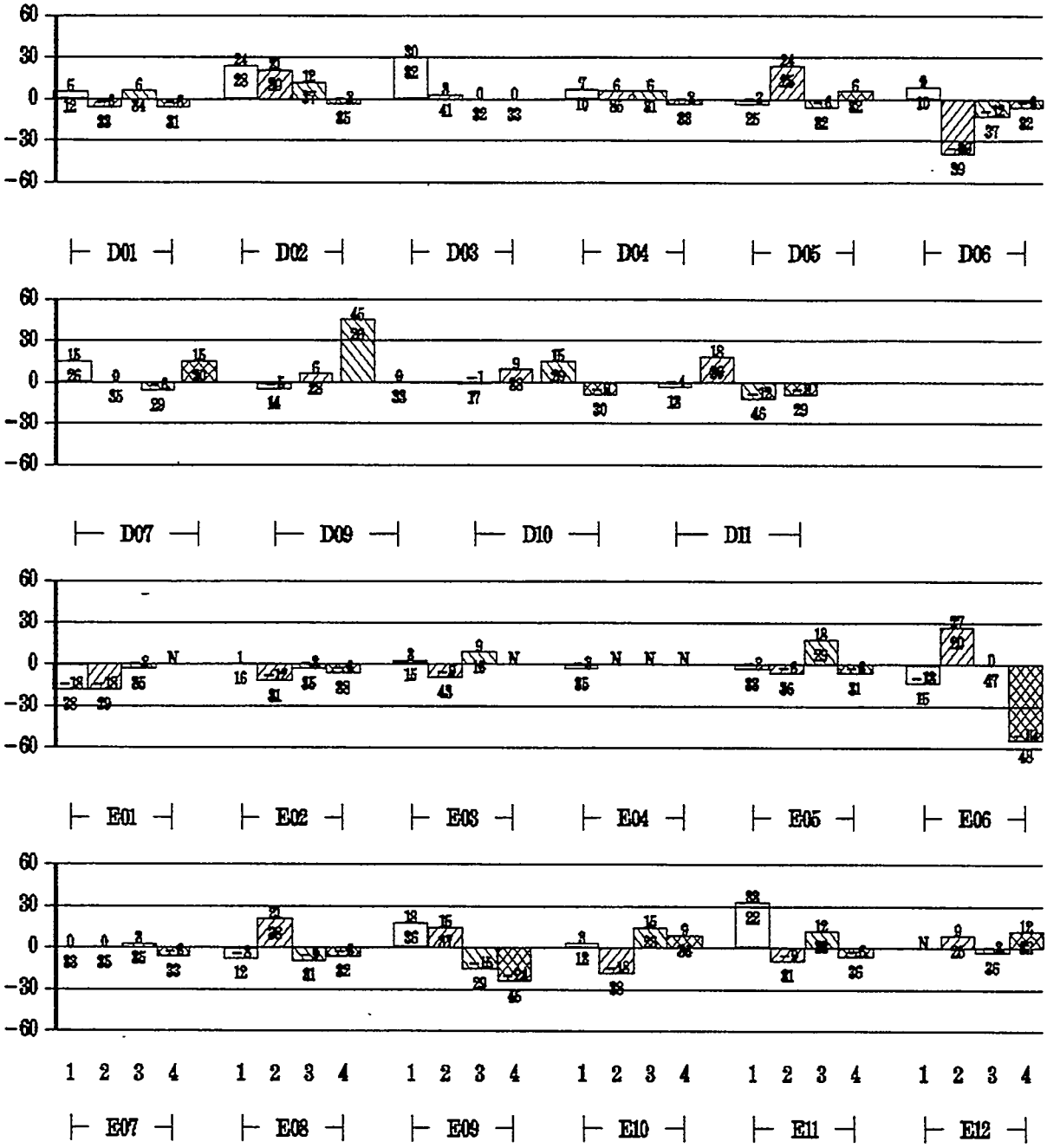


Fig. 3.78c. ***Radionuclide*** **^{60}*Co*** **concentrations (pCi/L) measured quarterly from 18 shallow wells and 4 deep wells (e-03, E-06, E-09, E-11) in the EFPC floodplain. Values printed above the bar are the results. Values below the bar are the counting uncertainty. Stations with no result are labeled with an "N".**

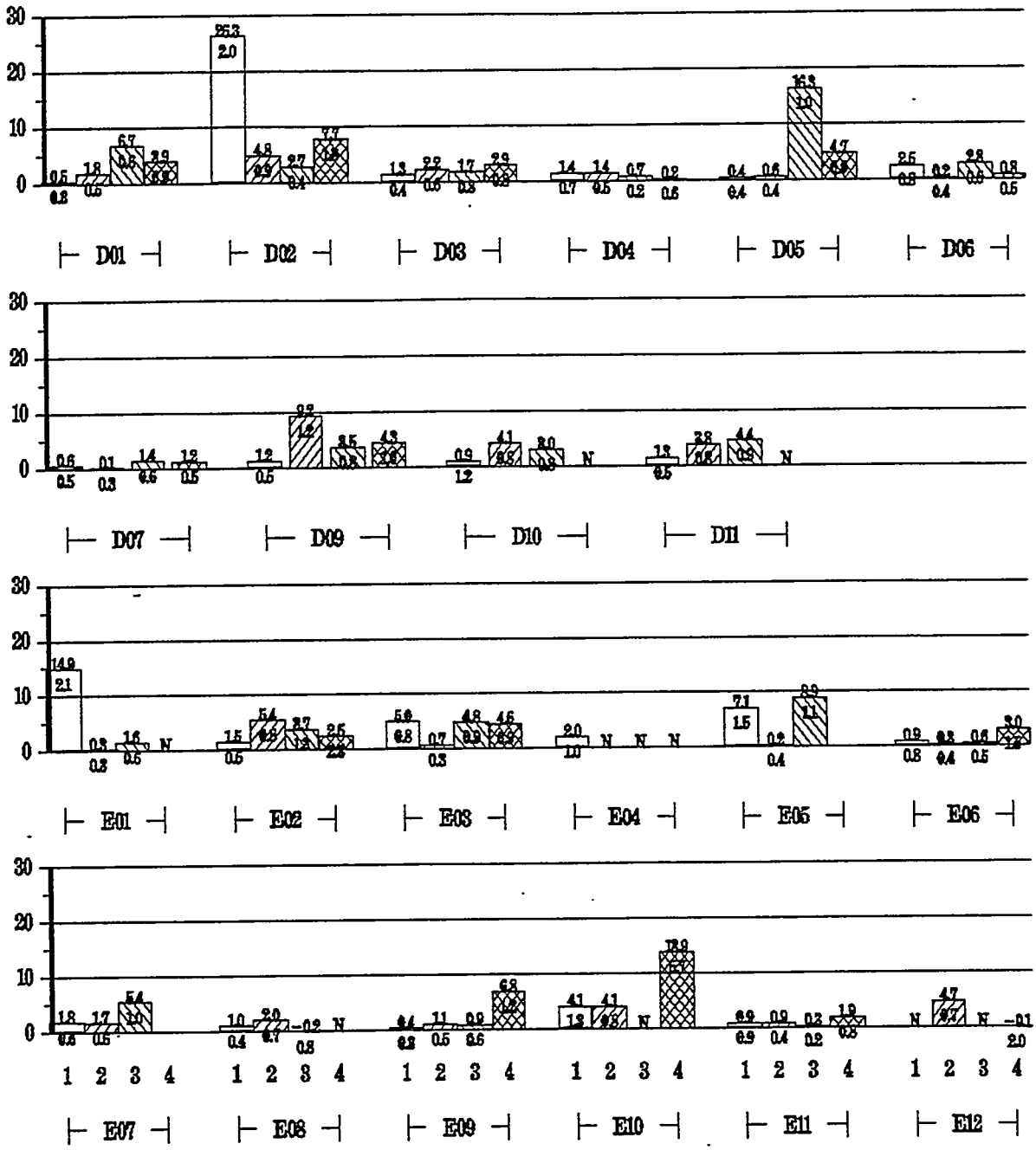


Fig. 3.78d. ***Radionuclide Total Radium*** **concentrations (pCi/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Values printed above the bar are the results. Values below the bar are the counting uncertainty. Stations with no result are labeled with an "N".**

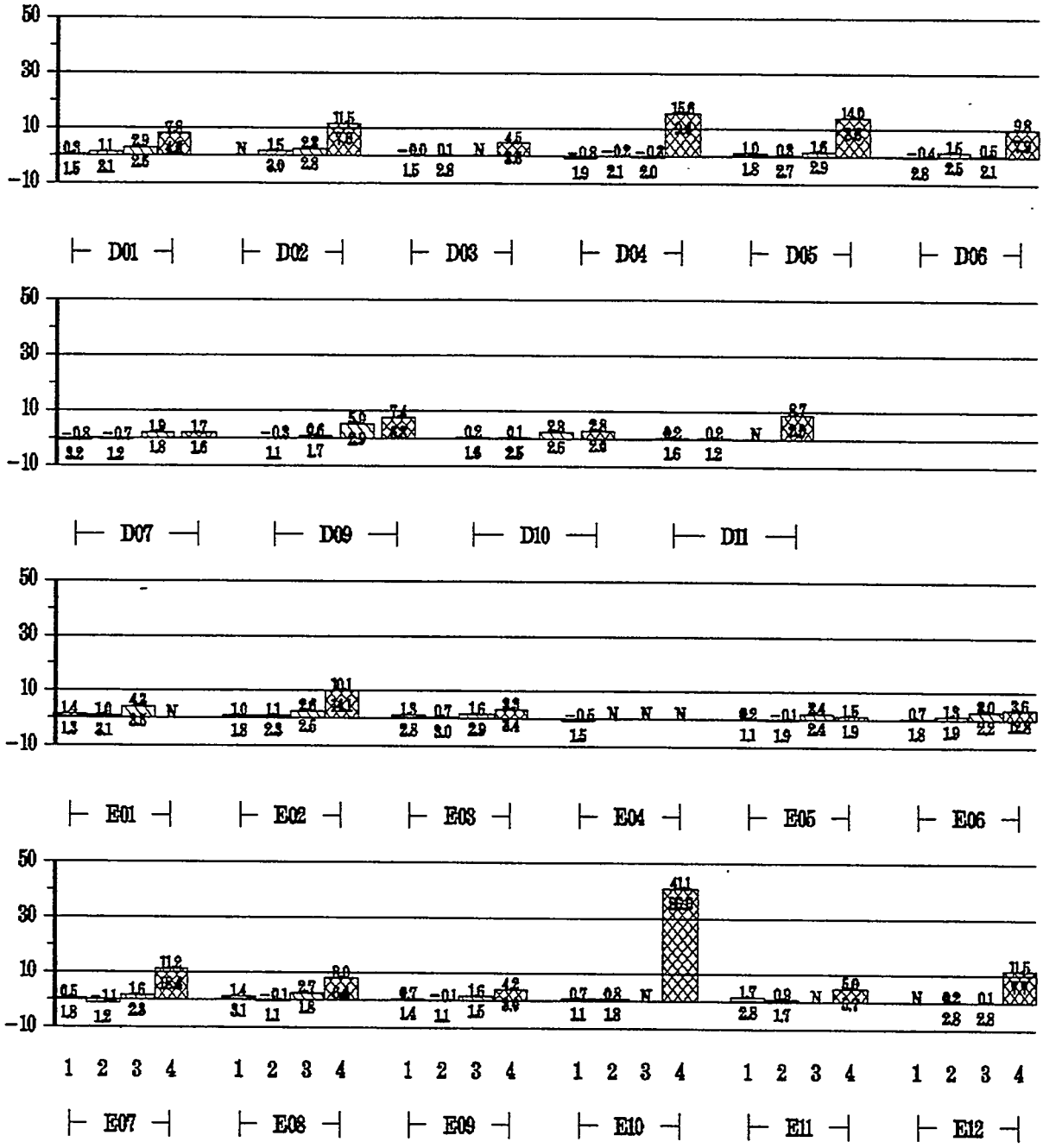


Fig. 3.78e. ***Radionuclide*** ^{89}***Sr*** **concentrations (pCi/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Values printed above the bar are the results. Values below the bar are the counting uncertainty. Stations with no result are labeled with an "N".**

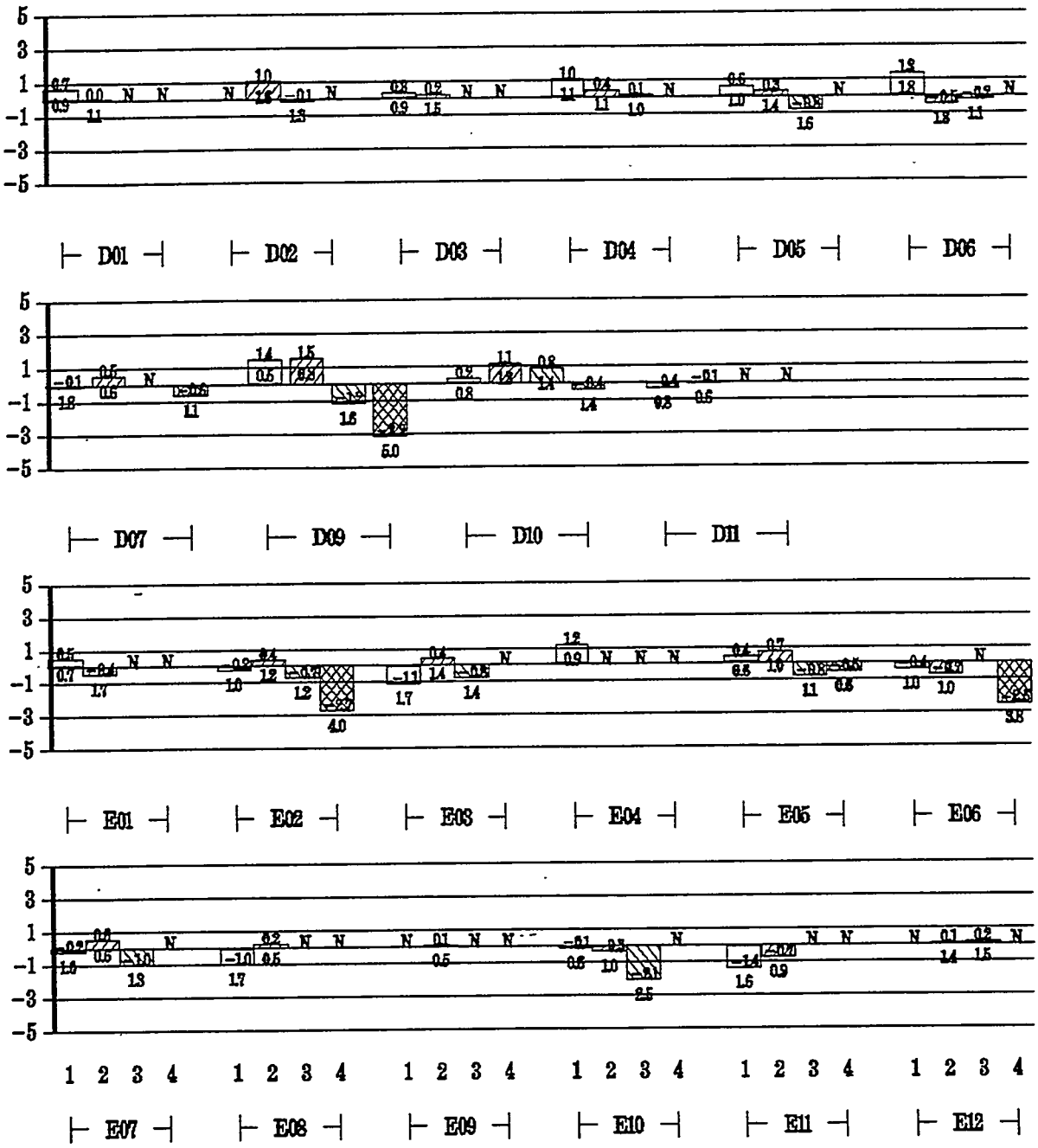


Fig. 3.78f. ***Radionuclide ^{90}Sr*** **concentrations (pCi/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Values printed above the bar are the results. Values below the bar are the counting uncertainty. Stations with no result are labeled with an "N".**

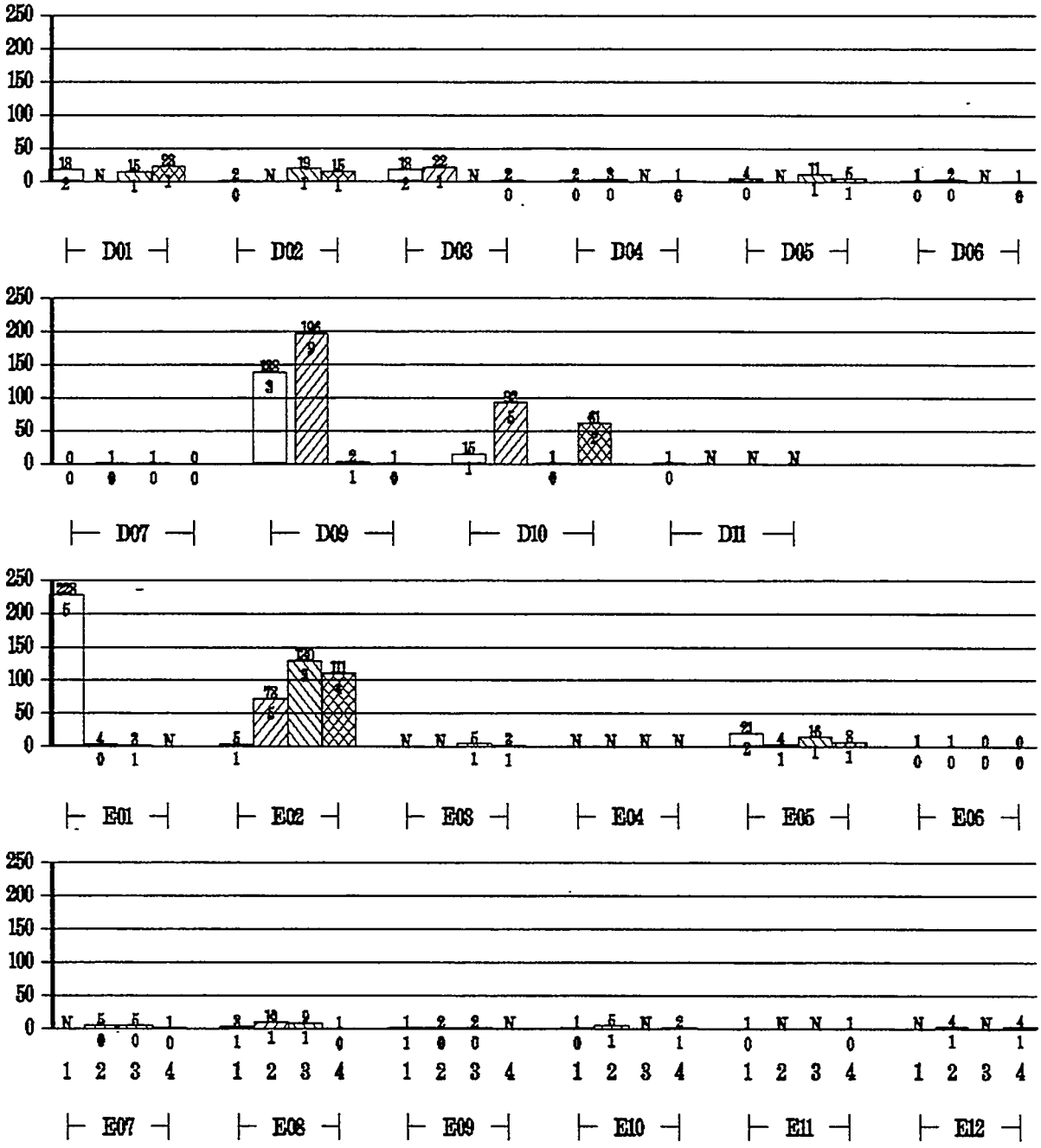


Fig. 3.78g. ***Radionuclide Total Uranium*** **concentrations (pCi/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Values printed above the bar are the results. Values below the bar are the counting uncertainty. Stations with no result are labeled with an "N".**

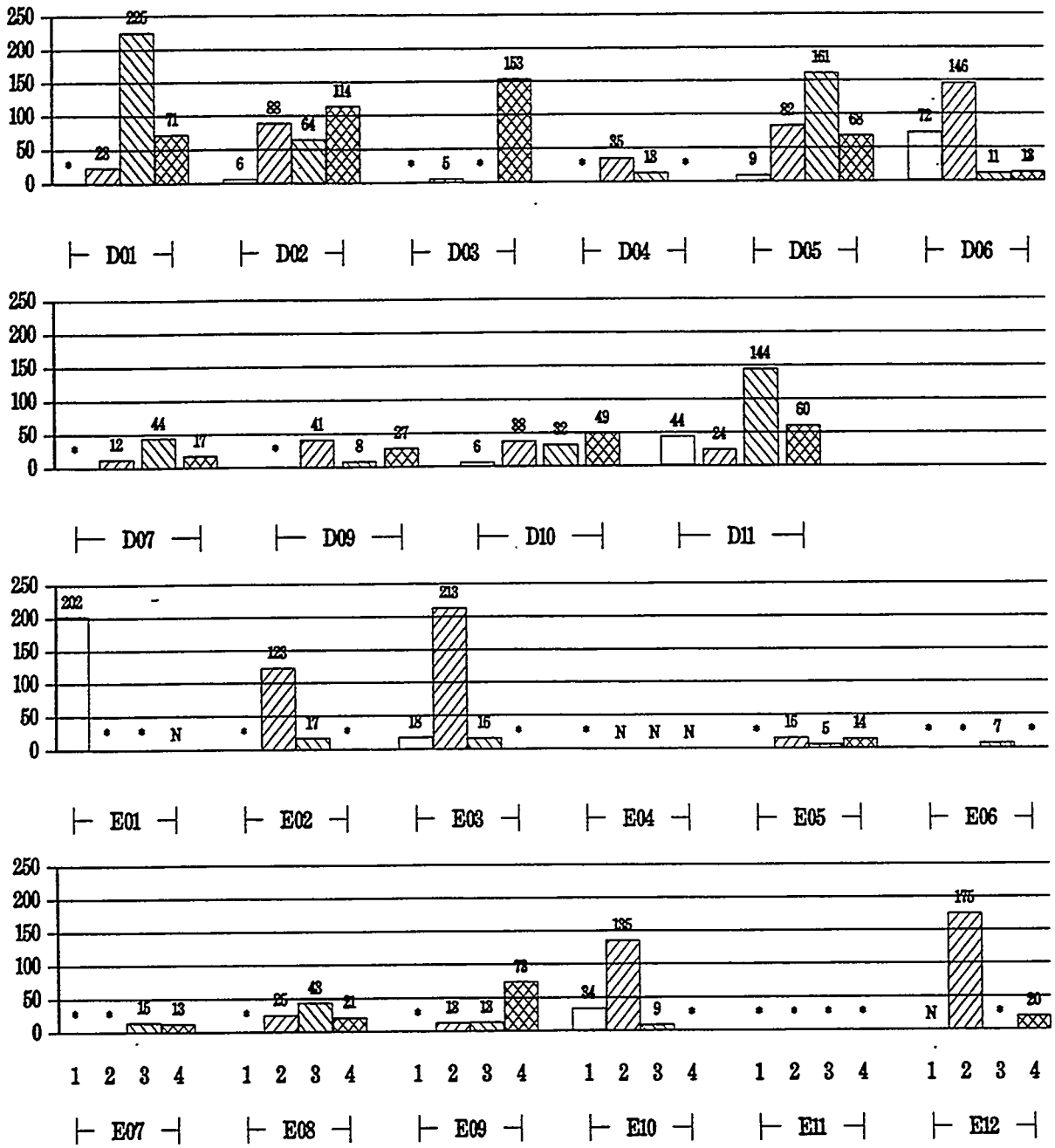


Fig. 3.79a. ***Vanadium*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with a "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

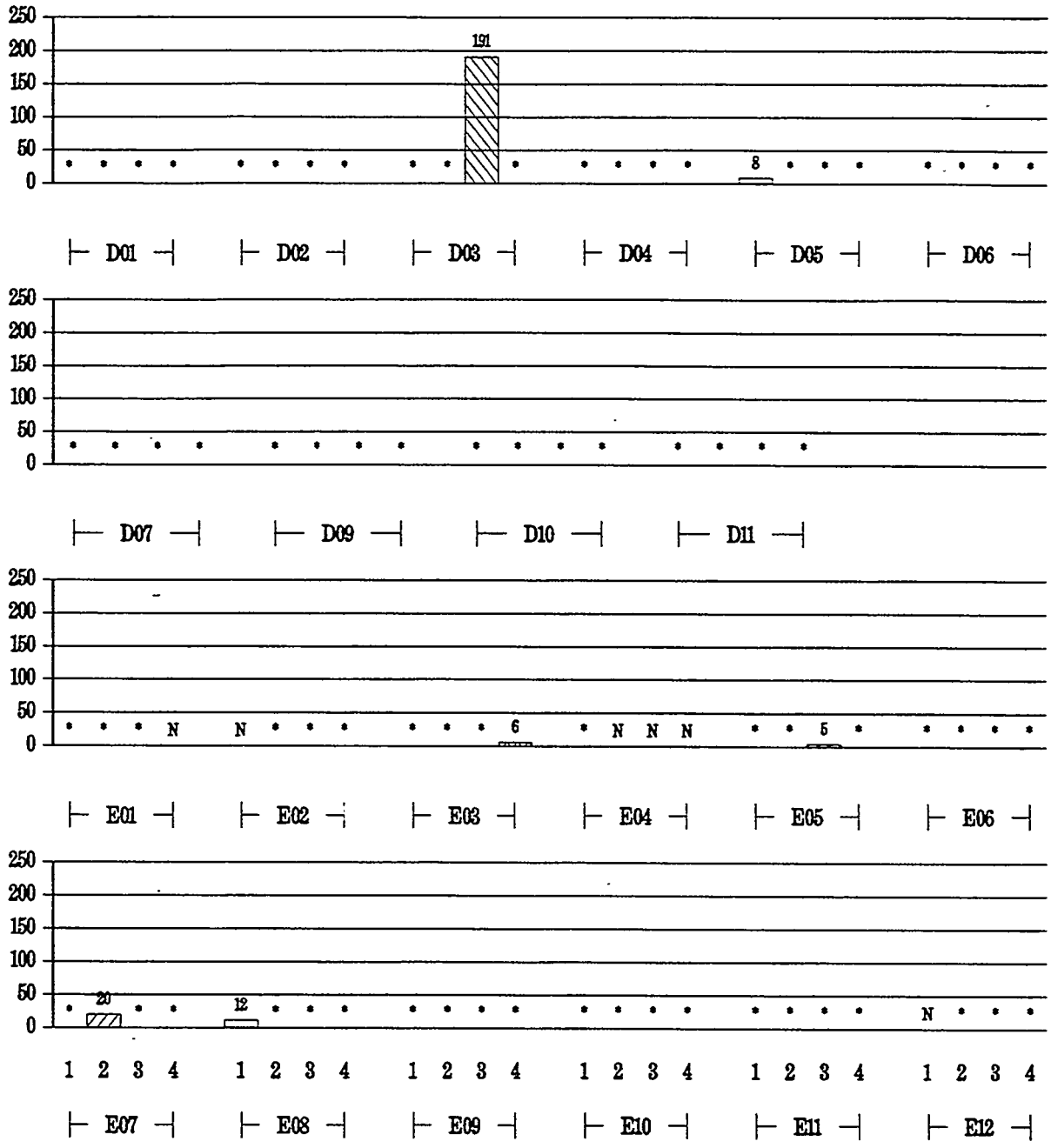


Fig. 3.79b. ***Dissolved Vanadium*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with a "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

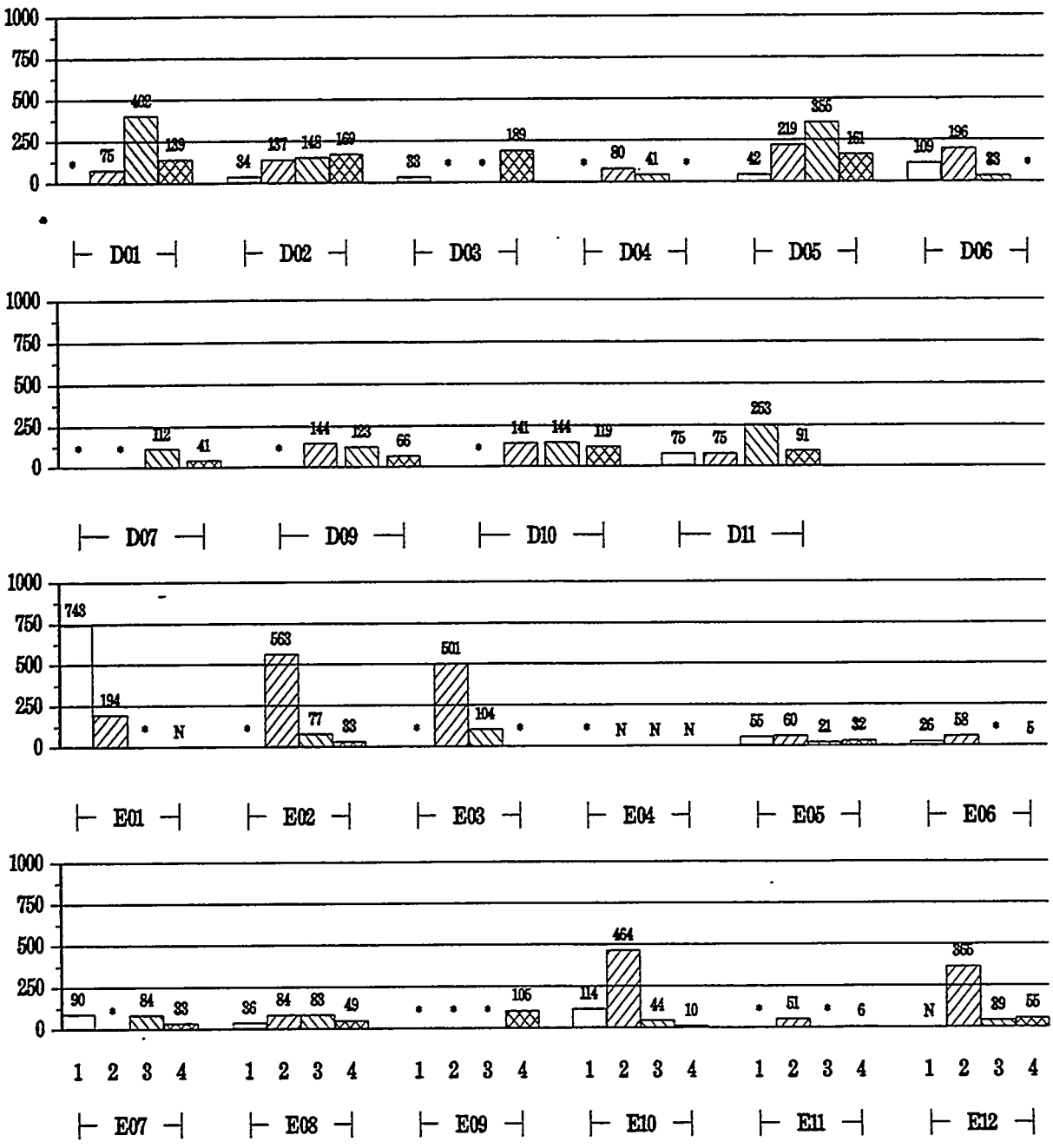


Fig. 3.80a. ***Zinc*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with a "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

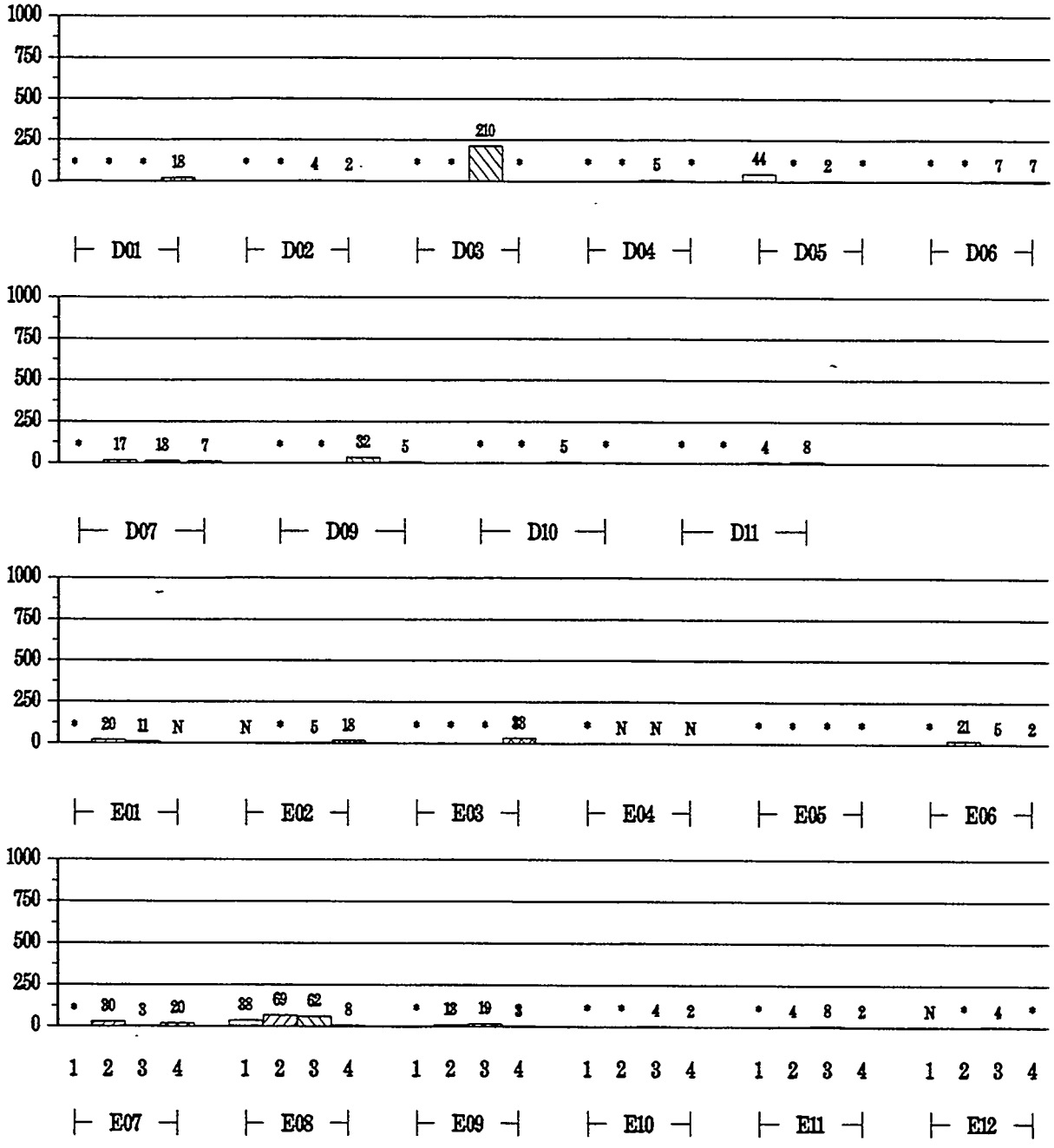


Fig. 3.80b. ***Dissolved Zinc*** **concentrations (μg/L) measured quarterly in groundwater from 18 shallow wells and 4 deep wells (E-03, E-06, E-09, E-11) in the EFPC floodplain. Different patterns in bars represent different quarters' results, and numbers on top of bars are actual concentration levels measured. Results less than the detection limit were set to zero and marked with a "*". Stations with no result are labeled with an "N". See Map 4 for well locations.**

times in various wells. Low levels of acetone and methylene chloride contamination were detected during the first quarter of sampling. These occurrences could be attributed (via blanks) to preservation of sampling vials in the laboratory. This situation was corrected for the three subsequent sampling events. However, samples from three sites had acetone concentrations over 1 mg/L. AN:E-4 had an acetone concentration of 14 mg/L during the first quarter sampling. AN:E-7 had 2.1 mg/L during the third quarter, and AN:E-8 had 3.8 mg/L during the first quarter and 4.4 mg/L during the third.

For a persistent contaminant, the temporal and spatial pattern observed over four quarters of sampling is difficult to understand. The affected sites do have some things in common. All are groundwater monitoring wells developed as part of the EFPC RI. The drilling rig had hydraulic system leaks on the days when these wells were drilled, and some hydraulic fluid may have contaminated the soils nears these sites. Each well is very close to the creek bank, and all three sites are downstream of auto repair shops that likely use solvents. It can only be inferred that acetone was occasionally present at some of the sites, but because the occurrence of acetone and methylene chloride was not confirmed by sampling in the subsequent quarter, neither of these volatiles has been considered a potential COC. Further sampling would be needed to positively define the presence or source of the contamination.

In addition, there are inconsistencies in the results for the groundwater chemistry based on a comparison of concentrations of metals for filtered and unfiltered samples taken from the same well on the same date. For some samples, the concentrations of metals in the filtered sample were greater than the concentration in the unfiltered sample. Closer examination of the results indicates several different reasons for these discrepancies.

One problem was analytical in nature. Three filtered samples had arsenic concentrations of about 200 µg/L, while arsenic was below the detection limit in the unfiltered samples. The results for the three filtered samples were taken from the inductively coupled plasma (ICP) analysis, which apparently had a high detection limit. The samples had also been analyzed by an atomic absorption furnace technique, but the results were not reported as the primary data. The results from the atomic absorption method indicate that the concentration was less than 3 µg/L and comparable to the other analyses. *(These results will be incorporated into the final version of the EFPC RI.)*

In several samples, nearly all metals were higher in filtered than in unfiltered samples. This indicates a procedural problem. The samples could have been labeled incorrectly in the field or

logged incorrectly in the laboratory. However, considering the field QA procedures, a laboratory problem would seem more likely. Another possibility is that water chemistry had not stabilized during the sampling process. Samples were collected sequentially as the well was bailed, but due to slow recharge of wells, bailing for various sets of samples occurred on different days. The filtered and unfiltered aliquots came from different samples and, therefore, may have different chemistry.

Iron and aluminum concentrations are good indicators of the presence of particulates in the filtered samples. In most samples, iron and aluminum were not detected or were orders of magnitude lower in filtered than in unfiltered samples. The following samples had higher iron and aluminum concentrations in the filtered samples:

- For sample NO0203410 (AN:D-3, 3rd quarter), the filtered and unfiltered portions appear to have been switched. Nearly all filtered metals were greater than the unfiltered. Both samples were described by the laboratory as being clear. Sample WB0101316 (AN:E-7, 2nd quarter) had conflicting evidence. The chemistry showed higher concentrations in the filtered sample, but the physical description as recorded by the laboratory indicated that the filtered sample was clear and the unfiltered sample was brown. For four other samples, the filtered and unfiltered portions were both described as clear, but dissolved metals were higher than total metals. These samples were WB0201217 (AN:E-8, 1st quarter); WE0101514 (AN:E-3, 4th quarter); WA0101213 (AN:E-11, 1st quarter); and WA0101415 (AN:E-11, 3rd quarter).

- For WF0101415, dissolved metals were low but higher than total metals because the sample labeled as total metals appears to have been a blank.

The groundwater data will be reviewed prior to the final draft of the RI to resolve as many discrepancies as possible. Nonetheless, results have been incorporated in this draft for the human health risk assessment for both filtered and unfiltered scenarios. The impact of selected samples being reversed should not impact the final assessment of groundwater as a migration pathway.

The following observations are presented in the corresponding graphs depicting results of four sets of analyses from 22 wells:

Arsenic (Figs. 3.67a and b). Taking into account the aforementioned analytical problems, total and dissolved arsenic concentrations were essentially the same and far below the SWDA concentration of 50 μg/L.

Barium (Figs. 3.68a and b) was seen at elevated concentrations nearer the Y-12 Plant in D-1 through D-6 and E-1 through E-3. The SDWA level (2000 μg/L) was exceeded in only a few instances for the total analyses and never for the dissolved analyses.

Beryllium (Figs. 3.69a and b) was observed in the same manner as barium for total analyses and was absent in the dissolved analyses (except for the noted problems). The SDWA level for beryllium is 4 μg/L.

Cadmium (Figs. 3.70a and b) had measurable quantities for three wells, but the only noted dissolved concentrations were at the SDWA level of 5 μg/L.

Chromium (Figs. 3.71a and b) was common in the total analyses, but only one well without identified problems, E-6, had a dissolved detect, and the concentration was far less than the SWDA level of 100 μg/L.

Copper (Figs. 3.72a and b) was observed at low total concentrations in many of the analyses and at elevated concentrations (5000 μg/L) in Energy Systems wells closest to the Y-12 Plant. No wells showed dissolved concentrations greater than the SDWA level of 1300 μg/L.

Lead (Figs. 3.73a and b) had elevated total concentrations, but only E-3 and E-11 (of those wells without noted problems) displayed dissolved concentrations of lead of any real quantity, and those were in the 5 μg/L range, compared to the SDWA level of 15 μg/L.

Manganese (Figs. 3.74a and b) exhibited concentrations in the 500 to 1000 μg/L range in both total and dissolved analyses. It is a common element found in water, but these levels exceed the SDWA level of 50 μg/L.

Mercury (Figs. 3.75a and b) had elevated total concentrations, but only one well (AN:E-7), except for the noted problems, had significant dissolved concentrations. The SDWA level is 2 μg/L.

Nickel (Figs. 3.77a and b) was observed in elevated total quantities near the Y-12 Plant in D1-6 and E1-3. Interestingly, the "D" wells had concentrations generally in the 100 to 200 μg/L range, while the E wells displayed values in the 300 to 600 μg/L range. No reliable analyses of dissolved concentrations exceeded the 100 μg/L limit.

Radionuclides (Figs. 3.78a-g). Only uranium was present in measurable quantities. The other radionuclides had uncertainties equal to or greater than the results.

Vanadium (Figs. 3.79a and b) had total concentrations in the 50 to 200 μg/L range, with elevated levels near the Y-12 Plant, but no significant quantities were detected in dissolved analyses (except for noted problems).

Zinc (Figs. 3.80a and b) was similar to vanadium with respect to occurrence and magnitude, but both total and dissolved concentrations were far below the SDWA level of 5000 μg/L.

Summary. Groundwater was investigated as a potential migration pathway within the conceptual site model of the EFPC system. All groundwater samples were analyzed for the full suite of contaminants, i.e., volatile and semivolatile organics, metals, and radionuclides. No outside sources of contaminants are considered to impact the groundwater medium, and groundwater contributions to other areas and systems are considered negligible. No spatial or temporal gradient or plume of contamination was identified based on groundwater monitoring results. Higher levels of most contaminants (including mercury) were noted in the wells located in the upper reaches of the floodplain, which also have elevated levels of soil contamination. Potential COCs for groundwater include the metals and radionuclides listed for soils but none of the organic compounds. Total analyses (unfiltered) contained much higher contaminant concentrations than the filtered analyses (except for noted problems). In fact, many of the filtered analyses were below the analytical detection limit, which indicates that the majority of contamination is due to suspended sediment in the groundwater samples and not within the groundwater medium itself.

3.2.5 Soil Chemical Data

3.2.5.1 Scope of investigation

Historical Data. Two of the previous investigations provided the most complete information regarding the distribution and extent of contamination in the floodplain soils and form the basis for the conceptual model used for the EFPC RI. As described in Sect. 3.2.2 - Sediments,

TVA's Task 2 involved the analyses of surface layer and core soil samples from 18 transects across the floodplain of EFPC in 1984 and was the most encompassing study involving analyses for metals (including mercury), radionuclides, pesticides/PCBs, and organics (Map 5).

While this study provided the most data concerning potential COCs, contaminant size partitioning, and contaminant fate and transport, it was based on a data density of ~one transect per kilometer. The highest density of sampling was performed by ORAU under the auspices of the ORTF during rapid scan survey of mercury concentrations along the EFPC floodplain and the SLB conducted 1983 through 1987. The rapid scan survey analyzed composite surface soil samples (to a depth of ~5 in.) from 150 transects along EFPC (Map 6). An area of higher density sampling was also performed, in an area of elevated mercury concentrations, to determine the heterogeneity of the distribution of mercury (insert A, Map 6).

EFPC RI. Soil investigation activities were performed during each phase of the EFPC RI. Phase Ia began with soil sampling concurrent with the installation of groundwater monitoring wells throughout the EFPC floodplain. The intent of this sampling effort was to identify any vertical migration of contaminants through the soil. These data were also used in assessing the presence and effectiveness of the glei layer (a clay-rich zone with anaerobic conditions) as an aquitard (see Sect. 2.4). The selection of the NO, BR, and WA study areas and their incorporation into many of the EFPC studies allowed for a detailed investigation of the soil medium. The primary objectives for this activity were to determine the COCs and to develop an initial appraisal of the vertical and horizontal extent of contamination across the floodplain. The geotechnical soil task and the pilot sampling study were also performed in these same locations.

Phase Ib was designed subsequent to Phase Ia. The Phase Ib sampling strategy and analytical methods were chosen based on consideration of the results from the ORAU rapid scan survey and Phase Ia. Soil transects were established across the width of the floodplain and sampled to a maximum depth of 48 in. (depending upon transect). Primary contaminants were analyzed by NAA for six metals and two radionuclides. Phase Ib soil sampling involved the definition of the levels of organic compounds (by CLP methods) and other radionuclides (by conventional gamma and alpha spectrometry) at representative locations throughout the floodplain. The original number of samples planned (~ 200) was reduced to about 50 after evaluation of the Phase Ia results. Sample analysis was performed according to TCLP to characterize the hazardous nature of floodplain soils per RCRA. Soil samples have been submitted for total methylmercury analyses, and optical and electron microscopic studies were accomplished to define the form of the mercury and any soil-matrix associations.

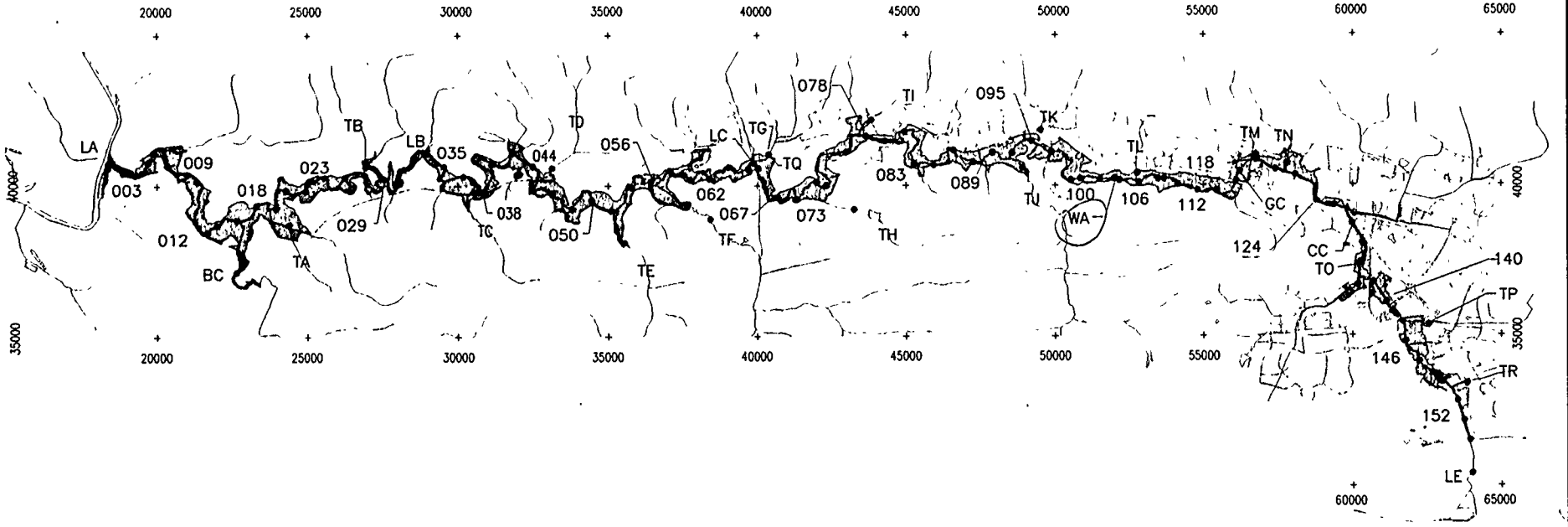
All soil sampling locations established during the RI (as well as groundwater wells) were surveyed by a registered civil surveyor to the nearest 0.01 ft. This information has been used in the graphic information system and in spatial data analysis.

3.2.5.2 Phase Ia investigation

Soil Borings. During the Phase Ia groundwater monitoring well installation, the lithology of soil recovered from 12 boreholes was logged (see Appendix E). Soil morphology was described in accordance with SCS procedures (SCS 1975, 1984) and classified upon soil taxonomy (SCS 1975). Generally, the intervals sampled by the split spoon were: 0 to 45 cm (0 to 1.5 ft), 60 cm to 1.2 m (2 to 4 ft), 1.2 to 2.4 m (4 to 6 ft), etc. until total depth or bedrock was reached. The upper 45-cm (1.5-ft) interval was submitted for analysis of metals, volatile and semivolatile compounds, pesticides and PCBs, and isotopic uranium and for gamma scan. The deeper 60-cm (2-ft) intervals were normally submitted for determination of metals, cyanide, and isotopic uranium and for gamma scan. Because of the inherent difficulties of well drilling, some exceptions to the interval depths and analyses did occur.

Study Area Soil Transects. To investigate the distribution and types of contaminants in the soil medium, sampling transects across the width of the floodplain were established at specific study sites (NO, BR, WA, HC_{2a}, and HC_{2b}) which correspond to the previously installed USGS and Energy Systems groundwater wells to maximize the correlation of soil and water quality data. NO was chosen because of its location in an area of high mercury contamination, at a point where the floodplain is exceptionally wide, and where the creek displays braided flow. In addition, the transect of USGS wells AN:D-1 through D-6 is immediately downstream of the NO site. BR was selected because of its proximity to a second transect of USGS wells AN:D-7 through D-11) and because of the intermediate width of the floodplain. This area also contains a stratigraphic horizon at a depth of ~12 to 18 in., which has the highest level of mercury contamination observed in the floodplain (2500 mg/kg). The third site, WA, is downstream of the BR site and demonstrates a narrow floodplain. Two shallow groundwater wells (AN:E-10 and E-12) and one deep well (AN:E-11) were installed immediately downstream of the WA site by Energy Systems (see Sect. 3.2.4). Hinds Creek (HC_{2a} and HC_{2b}) was selected because it was along strike with the East Fork Valley, contained the same soil types (Hamblen and Newark) as EFPC, and provided reference samples for comparison.

The three soil sampling transects across EFPC were established, and sample cores were taken at six locations along each transect. Transects were established perpendicular to the main channel of the creek and extended across both sides of the creek (see Fig. 3.81 and Map 4). Sampling



EAST FORK POPLAR CREEK

PLOTTING INFORMATION:		PEN CONFIGURATION
PROJECT NO.: Z-0001	XREFS: Z-0001B/TRIBS	1 .5 RED
DWG. FILE./Z-0001/DWGS/333SLM	Z-0001B/BASRDS	2
	Z-0001B/BASWTR	3
	Z-0001B/FLOODPLN	4
DATE: 03-22-93	PLOT FILES: Z-0001P/	5 .5 BLUE
PLOTTED BY: R. BEELER	333SLM PLT	6
SHEET 1 OF 1		7 .5 BLACK
		8 .25 BLACK

LEGEND: SCALE: 1" = 3500'

- TA ..... TRIBUTARY SAMPLE
- 095 ..... TRANSECT COMPOSITE NUMBER
- ● ..... SEDIMENT
- ●●● ... SEDIMENT COMPOSITE LOCATIONS
- ..... CREEKS & TRIBUTARIES
- ..... FLOOD PLAIN
- ..... ROADS
- + ... OAK RIDGE ADMIN. GRID

TITLE.

Fig. 3.33 Sediment
Sample Location Map
Composite & Individual Samples

SAIC
Science Applications
International Corporation

stations were on the levees adjacent to the main channel (stations 03 and 04), in the lowest lying area in the middle of the floodplain (stations 02 and 05), and at the floodplain fringes (stations 01 and 06). The three sampling stations on each side of the creek were sampled with a hand auger to a depth of 1.5 m (5 ft), and samples were submitted for analysis of metals, gamma scan,and isotopic uranium on composites of 30-cm (1-ft) intervals. In addition, the sample from the top 0 to 30 cm (0 to 1 ft) of each sampling location was analyzed for cyanide, semivolatile organic compounds, PCBs, and pesticides.

Approximately 30 samples (six stations with five composite samples/station) were taken for each transect. Tables 3.24 (NO), 3.25 (BR), and 3.26 (WA) show the range of the concentrations for the contaminants at each EFPC site; these data can be compared with data for the reference site, which are presented in Table 3.27 (HC). Contaminants in soils are reported within one of several groups (as listed from top to bottom in the tables): metals, PCBs, radionuclides, and PAHs. The distribution of the primary contaminant, mercury, is displayed in Figs. 3.82 through 3.84.

Among the other EFPC study sites, BR has the highest measured mercury concentrations, which were found to occur in the 30- to 60-cm (1- to 2-ft) horizon. This is a function of a distinctive stratigraphic zone at a 30- to 45-cm (12- to 18-in.) depth in this portion of the creek. Except for this "hot" zone, mercury appears to be concentrated in the upper two horizons at all three sites and decreases by an order of magnitude over the lower three horizons. Both NO and BR contain higher overall mercury concentrations at every horizon than those observed downstream at the WA site.

Pilot Study. As a result of the wide range of concentrations observed during the transect sampling and in historical studies, a pilot study was instituted to determine media heterogeneity and analytical variability for mercury analysis by CLP method 245.1, cold vapor atomic absorption. The results of the pilot study were also used to establish the requirements for Phase Ib sampling. Each of three contiguous stations on the WA transect and two noncontiguous stations at the BR transect (see Map 4 for site location) were offset 6 to 9 m (20 to 30 ft) in surrounding directions (Fig. 3.85) and sampled from 0 to 30 cm (0 to 1 ft) with a hand auger. The extracted soil sample was homogenized in a stainless steel bowl and divided into five duplicate subsamples for analysis. Two of the subsamples were sent to CompuChem Laboratories, two of the subsamples were sent to the Analytical Chemistry Division at ORNL for NAA, and one subsample was submitted to EPA's Environmental Monitoring Systems Laboratory for mercury analysis by the cold vapor atomic absorption method. Figure 3.85 displays the

Table 3.24. Summary of EFPC Phase Ia contaminant concentrations for floodplain soil transects across all depths and stations—NOAA transect

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Aluminum	mg/kg	28/ 28	.	4110	13000	28200	6060	13000	.
Arsenic	mg/kg	27/ 27	.	0.85	4.43	16.7	3.94	4.43	.
Barium	mg/kg	28/ 28	.	36	101	240	47.8	101	.
Beryllium	mg/kg	18/ 28	0.497	0.49	0.984	2.2	0.496	0.633	.
Cadmium	mg/kg	6/ 28	0.759	4	6.43	11.7	2.97	1.38	.
Chromium	mg/kg	28/ 28	.	9.4	26.2	98.7	18.9	26.2	.
Cobalt	mg/kg	28/ 28	.	1.8	9.24	30.7	6.65	9.24	.
Copper	mg/kg	28/ 28	.	4.1	34.1	135	42.9	34.1	.
Cyanide	mg/kg	6/ 17	0.652	0.62	0.783	1.3	0.26	0.277	.
Lead	mg/kg	28/ 28	.	8.2	19.3	62	12.9	19.3	.
Manganese	mg/kg	28/ 28	.	17.1	312	1080	328	312	.
Mercury	mg/kg	21/ 28	0.116	0.12	101	803	230	75.9	.
Nickel	mg/kg	28/ 28	.	3.7	22.6	76.2	21.7	22.6	.
Silver	mg/kg	6/ 28	1.77	2.2	5.57	11.2	3.25	1.19	.
Vanadium	mg/kg	28/ 28	.	13.5	24.7	48.5	10	24.7	.
Zinc	mg/kg	14/ 28	59.3	14.1	33.9	117	26.4	16.9	.
Aroclor-1254	µg/kg	0/ 6	233	.	.	.	.	0	.
Aroclor-1260	µg/kg	4/ 6	200	330	1110	2800	1160	738	.
^{241}Am	pCi/g	27/ 27	.	-0.2533	-0.0388	0.1	0.0774	-0.0388	0.256
^{137}Cs	pCi/g	27/ 27	.	-0.0235	0.429	2.83	0.809	0.429	0.0128
^{60}Co	pCi/g	27/ 27	.	-0.025	0.00341	0.0317	0.015	0.00341	0.00671
^{237}Np	pCi/g	24/ 24	.	-0.0933	-0.00587	0.0694	0.0408	-0.00587	0.0176
^{234}U	pCi/g	15/ 15	.	0.31	6.43	26.8	7.83	6.43	0.0536
^{233}U	pCi/g	15/ 15	.	0.01	0.313	1.25	0.391	0.313	0.0131
^{238}U	pCi/g	15/ 15	.	0.21	5.42	22.6	6.88	5.42	0.0496
2-Methylnaphthalene	µg/kg	2/ 6	487	160	330	500	240	110	.
Acenaphthene	µg/kg	2/ 6	487	99	899	1700	1130	300	.
Acenaphthylene	µg/kg	1/ 6	568	69	69	69	.	11.5	.
Anthracene	µg/kg	3/ 6	500	63	751	2000	1080	376	.
Benzo(a)anthracene	µg/kg	4/ 6	415	280	1260	3400	1440	837	.
Benzo(a)pyrene	µg/kg	4/ 6	415	350	1090	2700	1080	727	.
Benzo(b)fluoranthene	µg/kg	4/ 6	415	620	1730	3900	1470	1150	.
Benzo(g,h,i)perylene	µg/kg	4/ 6	415	240	707	1800	732	472	.

Table 3.24 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Benzo(k)fluoranthene	µg/kg	4/ 6	415	620	1010	1300	285	670	.
Benzoic Acid	µg/kg	0/ 6	1870	.	.	.	.	0	.
Butylbenzylphthalate	µg/kg	1/ 6	500	82	82	82	.	13.7	.
Chrysene	µg/kg	4/ 6	415	360	1180	3100	1290	787	.
Di-n-butylphthalate	µg/kg	0/ 6	548	.	.	.	.	0	.
Dibenzo(a,h)anthracene	µg/kg	2/ 6	487	66	353	640	406	118	.
Dibenzofuran	µg/kg	2/ 6	487	60	380	700	453	127	.
Fluoranthene	µg/kg	4/ 6	415	630	2910	8200	3550	1940	.
Fluorene	µg/kg	2/ 6	487	87	644	1200	787	214	.
Indeno(1,2,3-c,d)pyrene	µg/kg	4/ 6	415	210	695	1800	742	463	.
Naphthalene	µg/kg	2/ 6	487	110	955	1800	1190	318	.
Phenanthrene	µg/kg	4/ 6	415	230	2350	7800	3640	1570	.
Pyrene	µg/kg	4/ 6	415	550	2310	6500	2810	1540	.
bis(2-Ethylhexyl)phthalate	µg/kg	2/ 6	487	67	114	160	65.8	37.8	.

Results less than the detection limit were set to zero to compute grand mean.
Source: EFPC Phase Ia validated results on December 18, 1992.

Table 3.25. Summary of EFPC Phase Ia contaminant concentrations for floodplain soil transects across all depths and stations—Bruners transect

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Aluminum	mg/kg	27/ 27	.	10600	18400	31500	5620	18400	.
Arsenic	mg/kg	27/ 27	.	1.4	5.98	15.1	3.62	5.98	.
Barium	mg/kg	27/ 27	.	36.4	166	556	121	166	.
Beryllium	mg/kg	3/ 27	0.977	2	2.13	2.2	0.116	0.237	.
Cadmium	mg/kg	20/ 27	0.761	0.91	9.43	41.3	10.4	6.99	.
Chromium	mg/kg	27/ 27	.	12.4	43.6	112	31.4	43.6	.
Cobalt	mg/kg	27/ 27	.	6.1	14.9	28.3	4.96	14.9	.
Copper	mg/kg	27/ 27	.	6.4	157	1140	227	157	.
Cyanide	mg/kg	3/ 6	0.647	0.79	6.66	17.1	9.06	3.33	.
Lead	mg/kg	27/ 27	.	8.6	60.8	155	43.1	60.8	.
Manganese	mg/kg	27/ 27	.	161	1120	2750	570	1120	.
Mercury	mg/kg	25/ 27	0.12	0.22	291	2110	545	270	.
Nickel	mg/kg	27/ 27	.	5.5	48.2	174	46.7	48.2	.
Silver	mg/kg	10/ 27	1.78	2.4	13.1	29.7	8.19	4.84	.
Vanadium	mg/kg	27/ 27	.	19	31.2	44.9	6.47	31.2	.
Zinc	mg/kg	27/ 27	.	19.7	99.2	262	72.4	99.2	.
Aroclor-1254	µg/kg	3/ 6	207	1900	2370	3000	569	1180	.
Aroclor-1260	µg/kg	4/ 6	210	1100	2030	3800	1210	1350	.
^{241}Am	pCi/g	27/ 27	.	-0.3205	0.0057	0.479	0.182	0.0057	0.0983
^{137}Cs	pCi/g	27/ 27	.	-0.0267	1.11	6.45	1.7	1.11	0.0203
^{60}Co	pCi/g	27/ 27	.	-0.0282	0.00618	0.0769	0.0256	0.00618	0.00778
^{237}Np	pCi/g	27/ 27	.	-0.0759	0.0178	0.169	0.0594	0.0178	0.05
^{234}U	pCi/g	8/ 8	.	2.05	12.2	20.9	6.37	12.2	0.0985
^{235}U	pCi/g	8/ 8	.	0.1	0.626	1.65	0.487	0.626	0.0243
^{238}U	pCi/g	8/ 8	.	1.62	8.82	18.4	5.37	8.82	0.0858
2-Methylnaphthalene	µg/kg	4/ 6	690	43	72	120	34.8	48	.
Acenaphthene	µg/kg	0/ 6	528	.	.	.	.	0	.
Acenaphthylene	µg/kg	1/ 6	546	53	53	53	.	8.83	.
Anthracene	µg/kg	4/ 6	695	53	81.7	120	33.6	54.5	.
Benzo(a)anthracene	µg/kg	6/ 6	.	300	470	780	177	470	.
Benzo(a)pyrene	µg/kg	6/ 6	.	340	463	710	130	463	.

Table 3.25 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Benzo(b)fluoranthene	µg/kg	6/ 6	.	550	998	1700	429	998	.
Benzo(g,h,i)perylene	µg/kg	1/ 6	546	320	320	320	.	53.3	.
Benzo(k)fluoranthene	µg/kg	6/ 6	.	170	862	1700	593	862	.
Benzoic acid	µg/kg	0/ 6	1830	.	.	.	.	0	.
Butylbenzylphthalate	µg/kg	0/ 6	528	.	.	.	.	0	.
Chrysene	µg/kg	6/ 6	.	360	527	860	198	527	.
Di-n-butylphthalate	µg/kg	2/ 6	557	51	70.5	90	27.6	23.5	.
Dibenzo(a,h)anthracene	µg/kg	0/ 6	528	.	.	.	.	0	.
Dibenzofuran	µg/kg	0/ 6	528	.	.	.	.	0	.
Fluoranthene	µg/kg	6/ 6	.	620	973	1700	414	973	.
Fluorene	µg/kg	0/ 6	528	.	.	.	.	0	.
Indeno(1,2,3-c,d)pyrene	µg/kg	2/ 6	580	49	170	290	170	56.5	.
Naphthalene	µg/kg	2/ 6	557	53	68.5	84	21.9	22.8	.
Phenanthrene	µg/kg	6/ 6	.	220	420	690	185	420	.
Pyrene	µg/kg	6/ 6	.	490	805	1400	361	805	.
bis(2-Ethylhexyl)phthalate	µg/kg	4/ 6	680	79	147	250	79.8	98	.

Results less than the detection limit were set to zero to compute grand mean.
Source: EFPC Phase Ia validated results on December 18, 1992.

Table 3.26. Summary of EFPC Phase IA contaminant concentrations for floodplain soil transects across all depths and stations—Sturm Transect

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (> DL = 0)	Radiation counting uncertainty of mean
Aluminum	mg/kg	28/ 28	.	11600	14900	22000	2640	14900	.
Arsenic	mg/kg	28/ 28	.	1.7	4.68	9.7	2.03	4.68	.
Barium	mg/kg	28/ 28	.	56.9	98.7	182	28.4	98.7	.
Beryllium	mg/kg	0/ 28	0.749	.	.	.	.	0	.
Cadmium	mg/kg	13/ 28	0.757	1	5.44	15	4.69	2.53	.
Chromium	mg/kg	28/ 28	.	14.2	28.2	62	12.9	28.2	.
Cobalt	mg/kg	24/ 28	7.7	12.9	16.6	30.6	3.69	14.2	.
Copper	mg/kg	28/ 28	.	8.1	103	655	158	103	.
Cyanide	mg/kg	1/ 6	0.628	62.6	62.6	62.6	.	10.4	.
Lead	mg/kg	28/ 28	.	14.9	39.9	81.1	21	39.9	.
Manganese	mg/kg	28/ 28	.	339	1170	2790	538	1170	.
Mercury	mg/kg	28/ 28	.	0.23	40.3	529	101	40.3	.
Nickel	mg/kg	25/ 28	8.8	7.5	26.7	76.6	19.8	23.8	.
Silver	mg/kg	6/ 28	1.75	2.6	5.3	9.1	2.58	1.14	.
Vanadium	mg/kg	28/ 28	.	19.3	28.1	35.9	4.27	28.1	.
Zinc	mg/kg	28/ 28	.	26	66	162	42.4	66	.
Aroclor-1254	µg/kg	0/ 5	204	.	.	.	.	0	.
Aroclor-1260	µg/kg	2/ 5	203	310	340	370	42.4	136	.
^{241}Am	pCi/g	28/ 28	.	-0.2933	-0.0085	0.452	0.158	-0.0085	0.0582
^{137}Cs	pCi/g	28/ 28	.	-0.0263	0.416	4.36	0.882	0.416	0.01
^{60}Co	pCi/g	28/ 28	.	-0.0361	0.00141	0.0256	0.0133	0.00141	0.00549
^{237}Np	pCi/g	27/ 27	.	-0.0886	0.0168	0.0959	0.0502	0.0168	0.0163
^{234}U	pCi/g	18/ 18	.	0.51	4.26	14.6	3.55	4.26	0.0367
^{235}U	pCi/g	18/ 18	.	0.03	0.178	0.44	0.119	0.178	0.00754
^{238}U	pCi/g	18/ 18	.	0.36	2.91	8.24	2.25	2.91	0.0308
2-Methylnaphthalene	µg/kg	2/ 5	417	45	50	55	7.07	20	.
Acenaphthene	µg/kg	0/ 5	420	.	.	.	.	0	.
Acenaphthylene	µg/kg	1/ 5	420	90	90	90	.	18	.
Anthracene	µg/kg	2/ 5	417	110	155	200	63.6	62	.
Benzo(a)anthracene	µg/kg	4/ 5	430	120	458	820	364	366	.
Benzo(a)pyrene	µg/kg	4/ 5	430	140	497	940	395	398	.
Benzo(b)fluoranthene	µg/kg	4/ 5	430	290	980	1800	784	784	.

Table 3.26 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (> DL=0)	Radiation counting uncertainty of mean
Benzo(g,h,i)perylene	µg/kg	4/ 5	430	100	410	730	331	328	.
Benzo(k)fluoranthene	µg/kg	4/ 5	430	290	980	1800	784	784	.
Benzoic acid	µg/kg	2/ 5	2100	45	72.5	100	38.9	29	.
Butylbenzylphthalate	µg/kg	0/ 5	420	.	.	.	.	0	.
Chrysene	µg/kg	4/ 5	430	160	592	1100	493	474	.
Di-n-butylphthalate	µg/kg	1/ 5	240	71	71	71	.	14.2	.
Dibenzo(a,h)anthracene	µg/kg	2/ 5	417	180	180	180	0	72	.
Dibenzofuran	µg/kg	0/ 5	420	.	.	.	.	0	.
Fluoranthene	µg/kg	5/ 5	.	49	864	2100	923	864	.
Fluorene	µg/kg	1/ 5	420	53	53	53	.	10.6	.
Indeno(1,2,3-c,d)pyrene	µg/kg	4/ 5	430	83	358	640	292	287	.
Naphthalene	µg/kg	0/ 5	420	.	.	.	.	0	.
Phenanthrene	µg/kg	4/ 5	430	110	420	800	353	336	.
Pyrene	µg/kg	4/ 5	430	230	825	1500	669	660	.
bis(2-Ethylhexyl)phthalate	µg/kg	2/ 5	417	120	135	150	21.2	54	.

Results less than the detection limit were set to zero to compute grand mean.
Source: EFPC Phase Ia validated results on December 18, 1992.

Table 3.27. Summary of EFPC Phase IA contaminant concentrations for floodplain soil transects across all depths and stations—Hinds Creek Transect

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Aluminum	mg/kg	41/ 41	.	7950	14400	26800	4900	14400	y.
Arsenic	mg/kg	41/ 41	.	1.1	2.76	6.4	1.36	2.76	.
Barium	mg/kg	41/ 41	.	69.2	152	325	63.3	152	.
Beryllium	mg/kg	41/ 41	.	0.4	0.829	1.4	0.252	0.829	.
Cadmium	mg/kg	0/ 41	0.737	.	.	.	.	0	.
Chromium	mg/kg	41/ 41	.	12.9	24.5	45.5	8.22	24.5	.
Cobalt	mg/kg	41/ 41	.	3.4	11	25.5	4.99	11	.
Copper	mg/kg	41/ 41	.	4.2	10.2	26	4.36	10.2	.
Cyanide	mg/kg	0/ 12	0.619	.	.	.	.	0	.
Lead	mg/kg	41/ 41	.	5.5	12.8	78.3	10.9	12.8	.
Manganese	mg/kg	41/ 41	.	109	574	1980	517	574	.
Mercury	mg/kg	2/ 41	0.118	0.13	0.255	0.38	0.177	0.0124	.
Nickel	mg/kg	41/ 41	.	7.2	19.1	42.7	8.81	19.1	.
Silver	mg/kg	0/ 41	1.73	.	.	.	.	0	.
Vanadium	mg/kg	41/ 41	.	13.1	22.5	36.5	5.82	22.5	.
Zinc	mg/kg	35/ 41	26.1	18.5	41.5	79.8	14.4	35.4	.
Aroclor-1254	µg/kg	0/ 12	197	.	.	.	.	0	.
Aroclor-1260	µg/kg	0/ 12	197	.	.	.	.	0	.
^{241}Am	pCi/g	41/ 41	.	-0.4231	-0.0107	0.305	0.121	-0.0107	0.0518
^{137}Cs	pCi/g	40/ 40	.	-0.037	0.135	1.29	0.262	0.135	0.0113
^{60}Co	pCi/g	41/ 41	.	-0.0395	0.000127	0.0366	0.0171	0.000127	0.00543
^{237}Np	pCi/g	40/ 40	.	-0.0843	-0.00764	0.135	0.0412	-0.00764	0.0142
^{234}U	pCi/g	34/ 34	.	0.19	0.292	0.4	0.0453	0.292	0.0052
^{235}U	pCi/g	34/ 34	.	0	0.0135	0.04	0.00849	0.0135	0.00209
^{238}U	pCi/g	34/ 34	.	0.15	0.218	0.3	0.033	0.218	0.00456
2-Methylnaphthalene	µg/kg	0/ 12	408	.	.	.	.	0	.
Acenaphthene	µg/kg	0/ 12	408	.	.	.	.	0	.
Acenaphthylene	µg/kg	0/ 12	408	.	.	.	.	0	.
Anthracene	µg/kg	0/ 12	408	.	.	.	.	0	.
Benzo(a)anthracene	µg/kg	0/ 12	408	.	.	.	.	0	.
Benzo(a)pyrene	µg/kg	0/ 12	408	.	.	.	.	0	.
Benzo(b)fluoranthene	µg/kg	0/ 12	408	.	.	.	.	0	.

Table 3.27 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Benzo(g,h,i)perylene	µg/kg	0/ 12	408	.	.	.	.	0	.
Benzo(k)fluoranthene	µg/kg	0/ 12	408	.	.	.	.	0	.
Benzoic Acid	µg/kg	2/ 12	1540	58	929	1800	1230	155	.
Butylbenzylphthalate	µg/kg	0/ 12	408	.	.	.	.	0	.
Chrysene	µg/kg	0/ 12	408	.	.	.	.	0	.
Di-n-butylphthalate	µg/kg	0/ 12	408	.	.	.	.	0	.
Dibenzo(a,h)anthracene	µg/kg	0/ 12	408	.	.	.	.	0	.
Dibenzofuran	µg/kg	0/ 12	408	.	.	.	.	0	.
Fluoranthene	µg/kg	0/ 12	408	.	.	.	.	0	.
Fluorene	µg/kg	0/ 12	408	.	.	.	.	0	.
Indeno(1,2,3-c,d)pyrene	µg/kg	0/ 12	408	.	.	.	.	0	.
Naphthalene	µg/kg	0/ 12	408	.	.	.	.	0	.
Phenanthrene	µg/kg	0/ 12	408	.	.	.	.	0	.
Pyrene	µg/kg	0/ 12	408	.	.	.	.	0	.
bis(2-Ethylhexyl)phthalate	µg/kg	2/ 12	410	330	430	530	141	71.7	.

Results less than the detection limit were set to zero to compute grand mean.
Source: EFPC Phase Ia validated results on December 18, 1992.

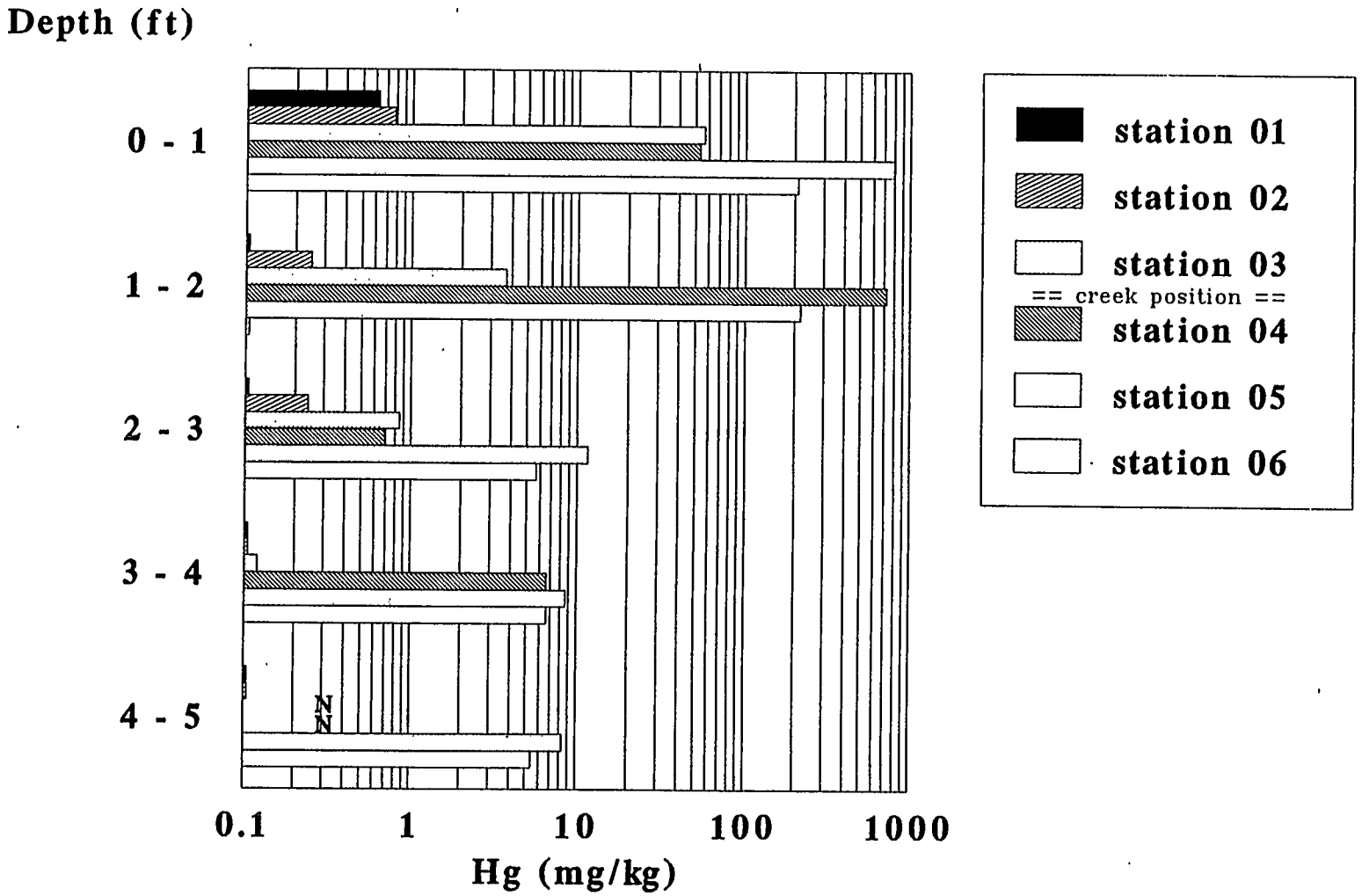


Fig. 3.82. NO Site: Mercury concentrations for 5 layers at each station in transect across the floodplain. Stations 1-3 and 4-6 are on opposite sides of the creek. Stations where no sample was obtained at a particular depth are labeled with an "N".

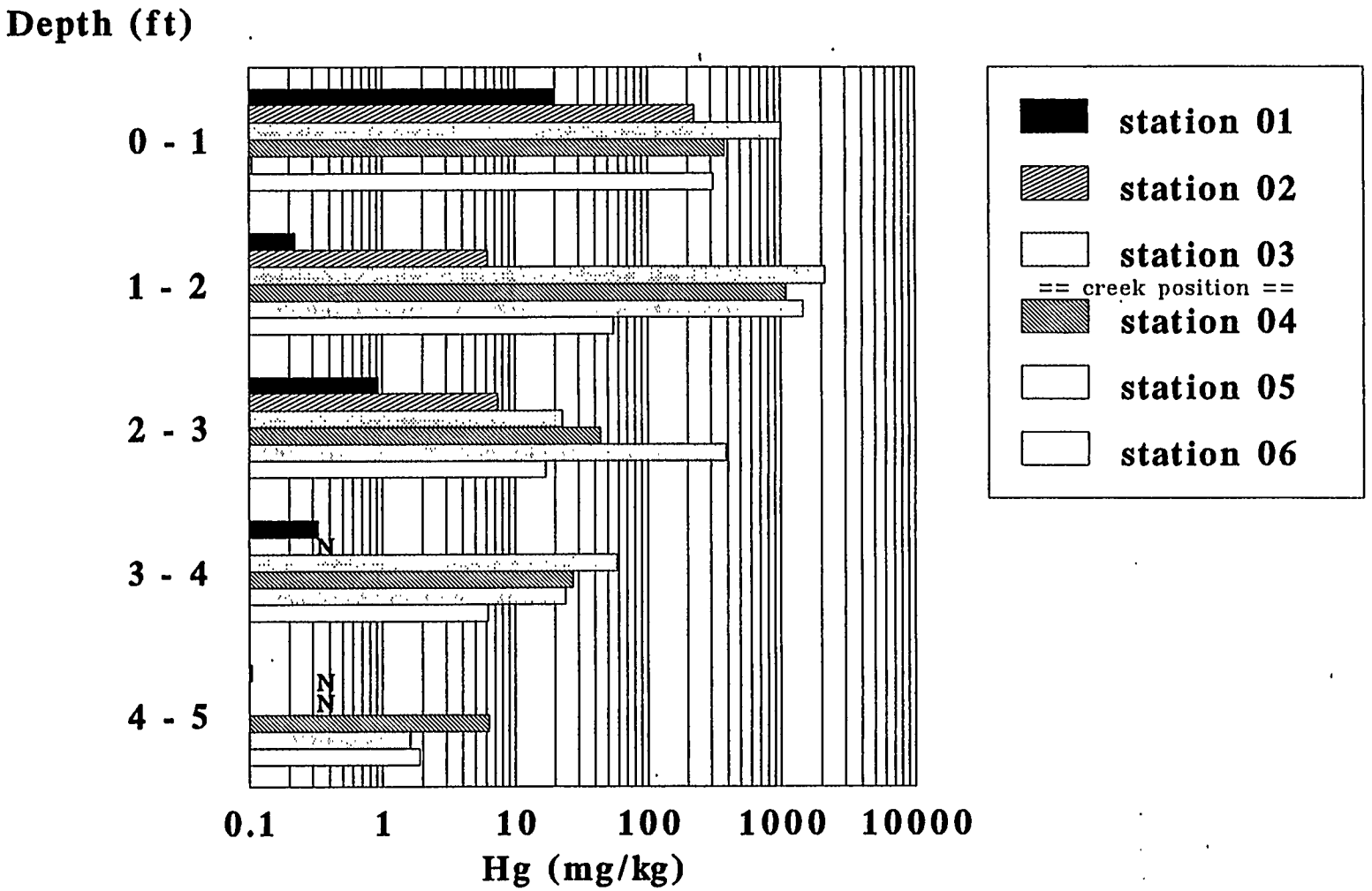


Fig. 3.83. BR Site: Mercury concentrations from 5 layers at each station in transect across the floodplain. Stations 1-3 were on one side of the creek and 4-6 were on the other side. Stations where no sample was obtained at a particular depth are labeled with an "N".

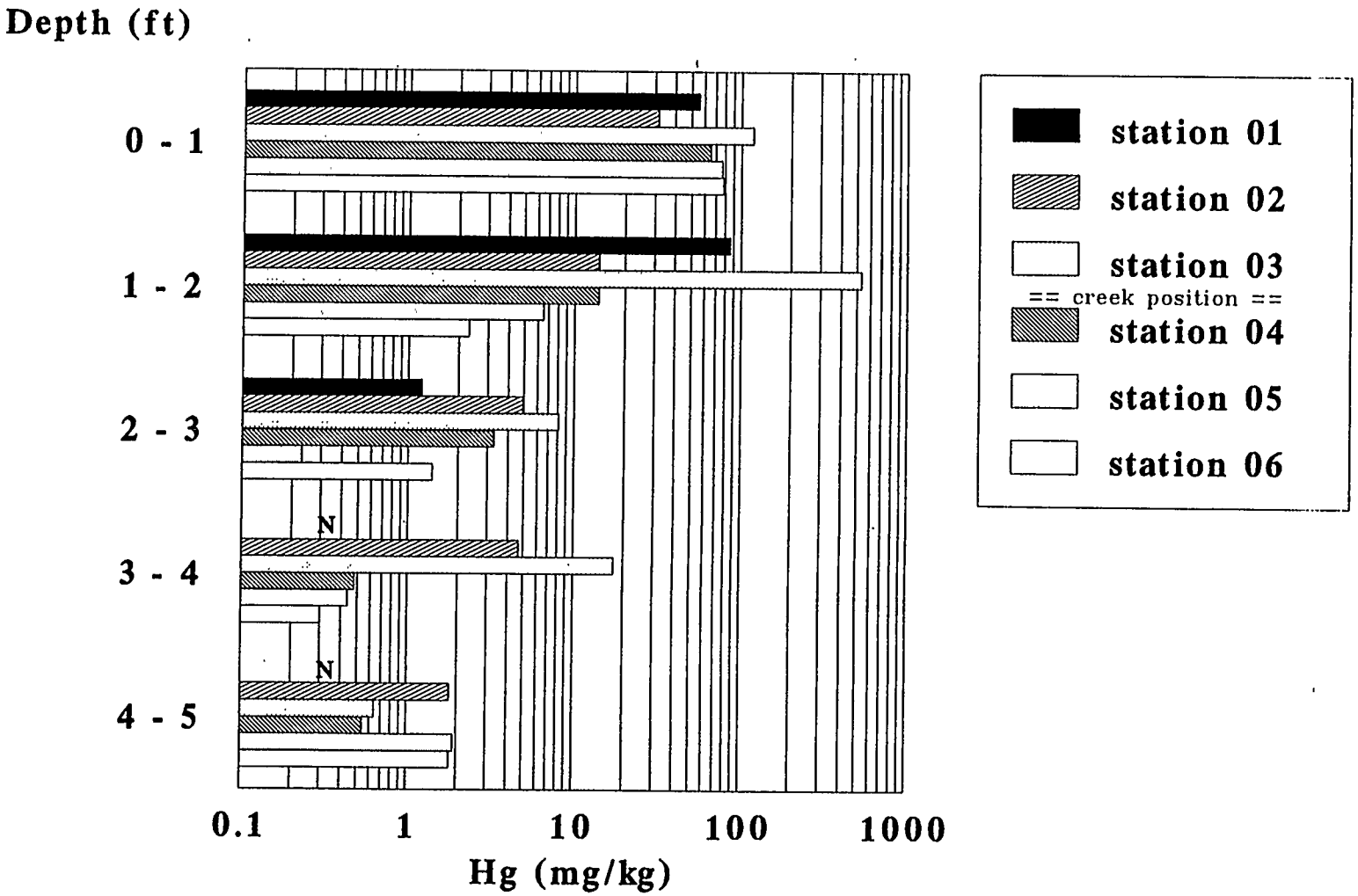
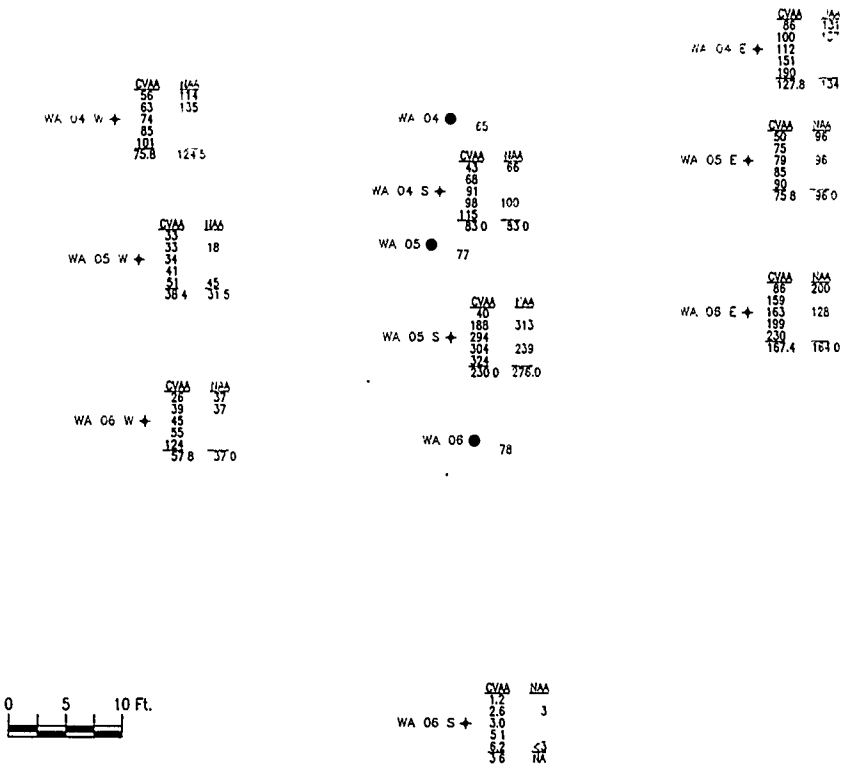
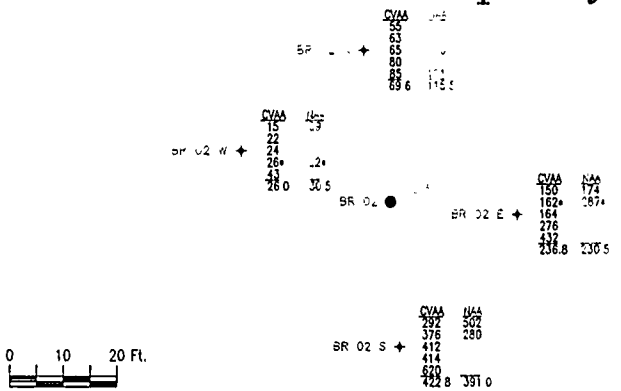


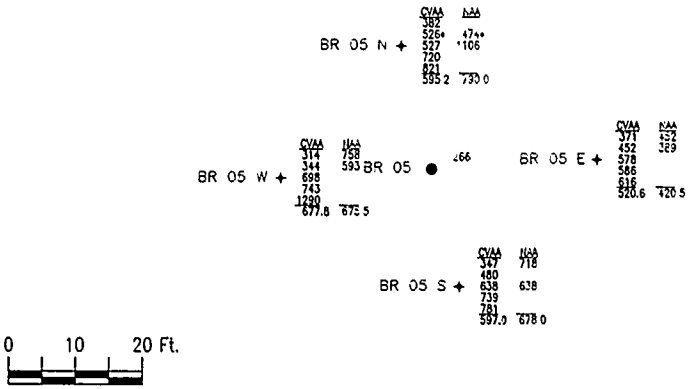
Fig. 3.84. WA Site: Mercury concentrations from 5 layers at each station in transect across the floodplain. Stations 1-3 were on one side of the creek and 4-6 were on the other side. Stations where no sample was obtained at a particular depth are labeled with an "N".

Sturm Property



Bruner Property





EAST FORK POPLAR CREEK

PLOTTING INFORMATION:			PEN CONFIGURATION
PROJECT NO.: 1-0001	PLOT FILES:	XREFS:	CLOSPACE
DWG FILE: 1-00014/ sleepace.dwg	1-0001p/ close-3.plt		1 .50 BLK 2 .25 BLK 3 .50 GRN 4 .5 BLK 5 .5 BLU 6 .25 BLU 7 .50 BLK 8 .25 BLK
DATE: 1-6-93			
PLOTTED BY: J. L. Chisman			
SHEET 1 OF 1			

LEGEND:

Station Id.	Analytical Method CVAA	NAA	
WA 04 +	55 63 65*	110*	Mercury (ppm)
	80 85 Avg. 69.6	121 115.5	* Multiple replicates used for equivalency test

Fig. 3.85

TITLE: **Close-Spaced Sampling with Replicate Analyses**

Science Applications International Corporation

results for cold vapor atomic absorption analyses for mercury as well as the NAA (to be discussed later in this section and in Sect. 5.1) and also illustrates the spatial relationship of the pilot-study samples to the transect samples. While no systemic difference was observed between laboratories (results are listed by concentration, not grouped by laboratory), the range of mercury concentrations is appreciable. Note that although the Sturm transect stations WA04, WA05, and WA06 provided mercury concentrations of 65, 77, and 78 ppm, respectively, concentrations for the offsetting locations ranged from the low 30s to over 300 ppm mercury. Similarly, the Bruner's Center transect produced a value of 225 ppm for station BR02 but ranged from 20 to 600 ppm in offset samples. Station BR05 had a value of 266 ppm mercury but a range of 300 to 1200 ppm. Inter-sample variability between the five duplicates, while sometimes significant, was not as great as the spatial variability observed during this pilot study. An obvious conclusion from the study was that a large number of samples would be required to adequately determine the extent and distribution of contamination within the EFPC floodplain and that careful consideration must be given on how to aggregate the data to provide meaningful contaminant concentration data.

3.2.5.3 Phase Ib investigation

Soil Transects. After considering the heterogeneity of contamination within the soil medium as displayed by the results of the Phase Ia soil investigation, a sampling plan was developed that defined the extent and distribution of the primary contaminants throughout the 271 ha (670 acres) of EFPC floodplain. A statistical basis for the soil sampling during Phase Ib was designed with the assistance of Ken Brown and Evan Englund of the EPA Environmental Monitoring and Support Laboratory in Las Vegas. Historical data were provided on a 16.2-ha (40-acre) parcel (study area), which was densely sampled during the ORAU study and contained 321 samples with mercury analyses. The statistical modeling process performed by EPA is displayed in Fig. 3.86. A semivariogram (covariance model) was computed using the historical data to provide a distance-variance relationship. With this relationship, a conditional simulation was performed in which a simulated map was constructed with tens of thousands of data points for mercury values. This represented the "reality" against which multiple sampling scenarios were measured. Sampling scenarios ranged from 100 to 4096 samples randomly distributed throughout the "reality" study area. The sampling results were block kriged and compared to block kriging for the simulated map. The efficiency of an individual sampling scenario is judged by the number of blocks identified above a set action level as compared to the number of blocks identified in the block kriging of the "reality" map. A "linear loss" curve constructed from this comparison depicts the total costs as a function of sampling size. From this curve, the smallest linear loss

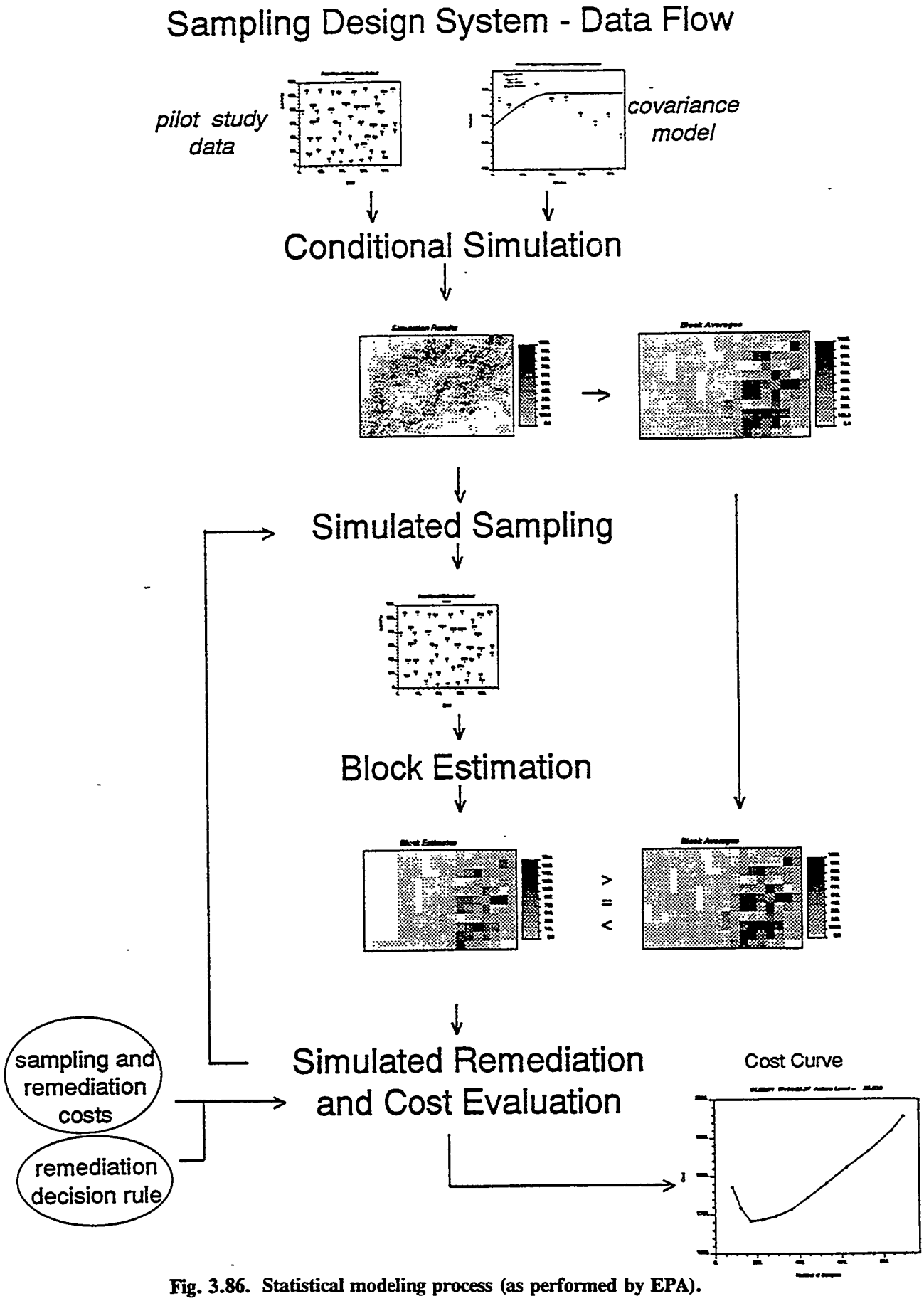


Fig. 3.86. Statistical modeling process (as performed by EPA).

(total cost) can be chosen that correlates with a certain sample size and degree of representativeness, from which a sample spacing and sample size can be inferred. The linear loss is composed of three values that use dollars as the quantitative parameter. Although absolute quantification in terms of dollars is suspect, it can be used in a relative sense to obtain the optimal sample size. The three values are (1) sampling cost, which is simply the cost per sample and is linear with the number of samples taken; (2) remediation cost, which is an estimated cost to clean up each block identified with mercury concentrations above a selected action level; and (3) linear cost, which is the societal/environmental cost associated with not identifying and remediating a block at or above the action level. This linear cost is equal to the remediation cost at the action level and proportionately increases as a function of mercury concentrations above the action level. Figure 3.87 shows linear loss curves for the four action levels 10, 50, 100, and 200 ppm of mercury. Within the range of the four action levels, the optimal size appears independent. The samples, which total 484 for the study area, approximately equate to a 20-m (65-ft) grid.

The disadvantage of this modeling is that it optimizes for a single round of sampling based on a given set of data. An underlying assumption is that the distribution and contaminant levels are consistent throughout the site and can be defined with a single sampling scenario derived from the model output. It was not feasible to sample the entire 100-year floodplain on a 20-m (65-ft) grid; therefore, a compromise was agreed upon to incorporate a two-staged sampling plan. The first stage was a systematic sampling design where soil sampling transects were situated across the floodplain. The sample distance between points across the floodplain was 20 m (65 ft) (the axis of greatest variance), and the transects were stationed every 100 m (328 ft) along the length of the creek.

Soil samples were collected with a hand-operated trier-type device (backsaver). Field crew members employed 45.7-cm (18-in.) long sample tubes that cut a 1.7-cm (11/16-in.) core and recovered approximately a 40.6-cm (16-in.) soil section per sample. From August 1991 to February 1992, 159 transects were sampled over the length of the creek. Soil samples were obtained at the edge of the creek and every 20 m (65 ft) away from the creek until the elevation of the 100-year flood event was reached. The 100-year flood stage was defined as the limits of the investigation per the conceptual model. In practice, the civil surveying crews that established the sampling locations were conservative and usually went beyond the 100-year elevation. Surface soil cores from 0 to 40.6 cm (0 to 16 in.) were extracted at each station on the transects and composited in a stainless steel bowl prior to the sample being placed in a 250-mL glass jar. At the even-numbered transects (i.e., every other transect), second- and third-layer samples were

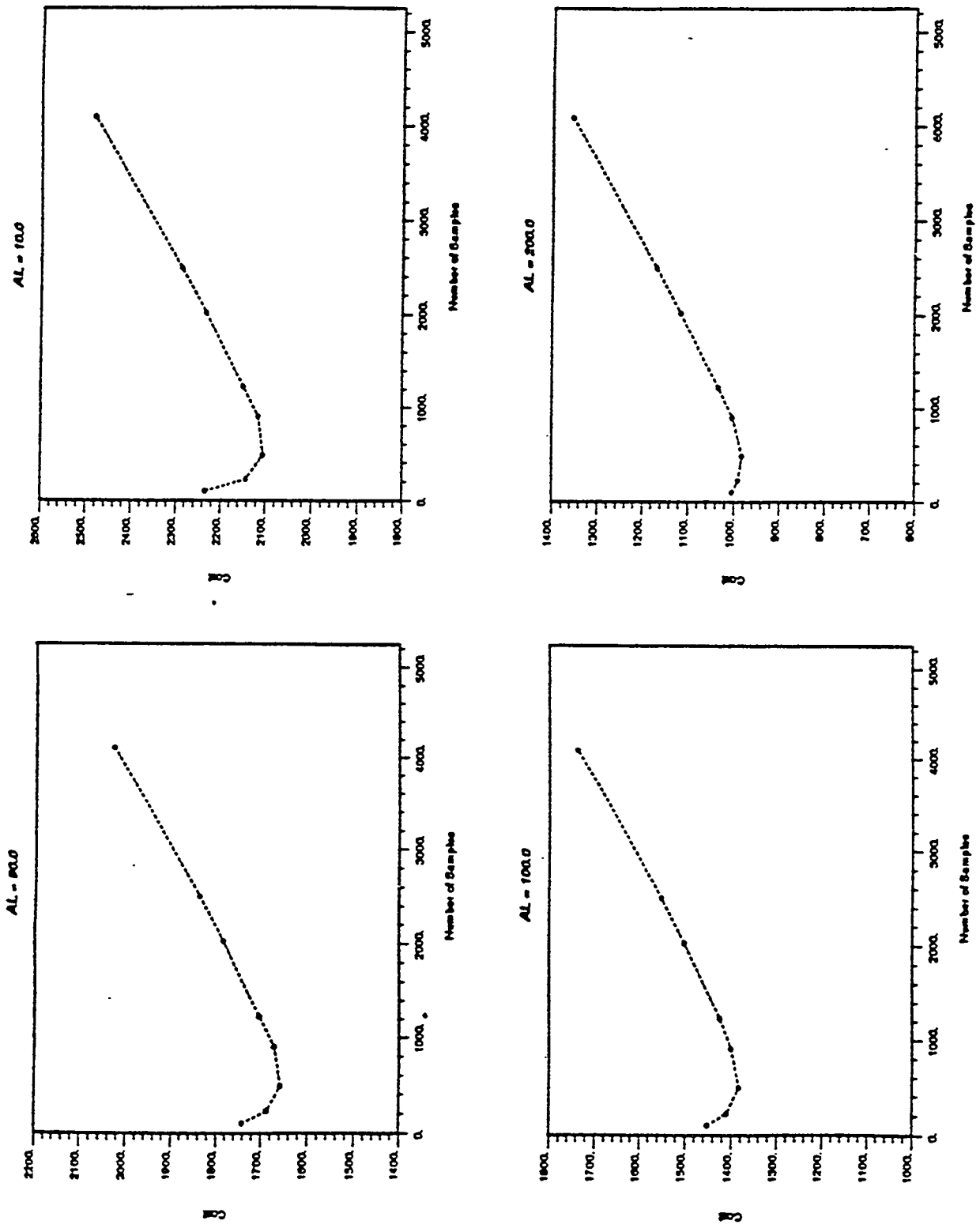


Fig. 3.87. Linear loss curves (AL = action level).

attempted. Because of the inherent difficulties encountered in recovering samples from 40.6 to 81 cm (16 to 32 in.) and 81 to 122 cm (32 to 48 in.), successful sample collection declined with depth. However, sufficient data were obtained to determine the vertical distribution of contaminants.

Soil samples taken along the transects and SLB in Phase Ib were analyzed by NAA. This method provided contaminant concentrations for the following analytes: arsenic, antimony, chromium, mercury, selenium, ^{235}U, ^{238}U, and zinc. This suite of analytes was chosen to define the contaminants of primary importance (mercury, arsenic, ^{235}U, and ^{238}U) and to provide results for other metals as well.

NAA is a method in which the bulk sample (1 g of soil) is irradiated with a neutron source (in this case, in the High Flux Isotope Reactor at ORNL), which creates unstable isotopes that undergo radioactive decay. Concentrations are determined by evaluating the gamma-ray spectrum of the sample during decay and correlating the intensity of a specific emission photopeak with a peak from a calibration standard.

Contaminant Distributions. Map 7 (4 sheets) is a presentation of the mercury values resulting from the transect sampling and NAA. Most locations display three numbers adjacent to the location symbol. These numbers represent mercury concentrations in parts per million (ppm = mg/kg) for the three layers: 0 to 40.6 cm (0 to 16 in.), 40.6 to 81 cm (16 to 32 in.), and 81 to 122 cm (32 to 48 in.). If the number is absent, the sample was not recovered. In some cases, an "R" is next to the sample results. This code conveys that the analytical results were rejected during the data validation process and that the data are not appropriate for use under Level IV qualification protocols. Other uses that have data quality objectives less strict than those necessary for the BRA may be valid. For the purposes of this report, they are used only to define extent of contamination.

Map 8 (4 sheets) is the same type of map as Map 7 but presents the values for total uranium activity. NAA results (in ppm) for ^{235}U and ^{238}U were converted to pCi/g (HEW 1970). An activity for ^{234}U (in pCi/g) was estimated (not analyzed by NAA) from the percent enrichment for materials enriched by the gaseous diffusion process (DOE 1988).

From a study of the maps, it becomes apparent that mercury and the other inorganic contaminants are situated in well-defined areas of the floodplain and not randomly scattered throughout its length. It was originally conceptualized that areas of the floodplain that are frequently inundated would show contaminant hot spots. A strong correlation was suspected

between contaminant levels and areas susceptible to frequent inundation (within the 10-year flood elevation as opposed to the 50- or 100-year flood elevation). Such areas would typically be the inside portion of creek meanders, flat low-lying areas adjacent to the creek, or portions upstream of constrictions (such as culverts and street underpasses). With the large number of years available for mass transport of particle-bound contaminants, it was anticipated that increased mercury concentrations would be seen throughout the entire 23 km of the EFPC. While this is partly true, it is not the primary case. Four main sections of the floodplain and several minor areas display increased mercury levels. The three study areas (NO, BR, and WA), noted in historical studies and the focus of intense study during the EFPC RI, are the largest contiguous areas of elevated mercury. A fourth area is observed along a reach of EFPC in the vicinity of the Grand Cove Subdivision.

Lastly, a consistent area of contamination is contained within a narrow zone juxtaposed to the creek. This ribbon of elevated mercury contamination is observed at the vast majority of sampling locations along the creek bank. Except where noted above, the adjacent samples, 20 m lateral from the creek bank, do not show increased concentrations. Contaminant levels appear to be a function of lateral distance from the creek. Supporting evidence for this observation is seen at soil Transect 10 (E 21,325). The set of sample points parallels the creek as it runs south to north. The unique positioning of the transect provides a series of contaminant concentrations located at varying distances from the creek. The distribution shows that even a few meters away from the edge of the creek the contamination decreases exponentially. In several of the samples, the mercury concentration is measured below the detection limit (labeled as 0 ppm) at a distance much less than 20 m from the creek. In addition, an overall declining gradient is seen progressively downstream within the ribbon of contamination.

While mercury has been the focus of discussion, the other inorganic contaminants generally have increased concentrations in the same areas. Comparison of the maps supplied for mercury (Map 7) and uranium (Map 8) provides the same picture of contaminant deposition seen for all inorganic analytes.

A second stage of sampling was proposed that employed a stratified sampling scheme based on the results of the initial stage. The original conceptualization that contaminant hot spots were present throughout the floodplain was not validated. The transects located every 100 m (328 ft) were to identify the hot spots, and the second stage of sampling would be to define the boundaries of the hot spot. After the first stage of sampling was complete, it was apparent that contaminant distribution was not as modeled. The second stage was utilized as a minor sampling event to fill in areas needing more definition.

Additional Phase Ib Sampling. To complement the NAA, conventional analysis (CLP, radiochemistry) was performed on a suite of soil samples (~60) collected from locations positioned throughout the floodplain. These sampling locations were established (see Fig. 3.85 or Map 4) in the various creek segments (see Maps 2 and 3 for present and future exposure segmentation) to provide extended coverage for organics, a comparison of metals and radionuclide concentrations with NAA, and to evaluate the correlation between mercury levels and other COCs.

SLB. The SLB was investigated with a modified but similar sampling design to that used for the floodplain soil sampling. The site model for the SLB is somewhat different from that for the EFPC floodplain. Soils were acquired from the floodplain and taken to the SLB to be used as topsoil fill. Contamination is either present within the upper 15 to 30 cm (6 to 12 in.) of the soil horizon or completely absent. No concentration gradient is obvious along the SLB. Sampling was conducted in the same manner as in the floodplain, with one exception. Instead of compositing a 0- to 40.6-cm (0- to 16-in.) interval for analysis, topsoil fill (noted by higher organic material and darker color) was segregated from the native construction backfill (noted by reddish clay and abundant rock fragments) before being placed into a sample jar. This practice ensured that the contaminant concentrations (in the floodplain soils exposed at the surface of the SLB) would not be diluted by mixing with noncontaminated construction fill.

Sampling was conducted along the entire length of the SLB except: 1) the portion of the SLB that lies within the EFPC floodplain, 2) the portion of the SLB that lies within the Oak Ridge Civic Center (which was sampled and remediated prior to the start of the EFPC RI), 3) any portions of the SLB that were covered by pavement or roadways, such as the Manhattan Place shopping center or Emory Valley Road, and 4) the SLB section along Warehouse Road (which was covered with fill materials and construction debris).

The sampling consisted of a two-staged event. The first stage involved sampling every 20 m (65 ft) along the length of the SLB and compositing three sequential samples for a single analysis. For every composite sample that exhibited mercury concentrations greater than 15 ppm, single samples were subsequently taken and analyzed across the hot spot on 20-m (65-ft) centers. Map 9 shows the composite sample locations and the composite mercury concentrations within adjacent boxes. For individual samples that delineate the hot spots, mercury concentrations are indicated next to the specific location. Three areas along the SLB demonstrate areas of elevated mercury concentrations: a small area at the intersection of Tulane Avenue and the Oak Ridge Turnpike, Fairbanks Road from Emory Valley Road to Warehouse Road, and Emory Valley Road west from the intersection with Fairbanks Road. Because a logical exposure scenario would

envision a person walking along the length of any of the three contaminated areas, each area will be considered as a unit to be evaluated individually. The concentrations for each analyte are presented by area in Table 3.28. The ranges of concentrations and related statistics for the SLB include values for noncontaminated portions of the SLB between the hot spots. For the purposes of site characterizations, analytical results recorded as less than the analytical detection limit were set to zero (as opposed to values incorporated into the risk assessment, which were set to one-half the detection limit).

The volume of mercury-contaminated soils was calculated for three areas along the SLB. Assumptions were made for the width (1.52 m/5 ft) and depth (0.152 m/6 in.) of EFPC soil used as topsoil cover. The contaminated length and volume of the SLB is as follows:

Site	Length (m) contaminated	Length (m) total	(%)	Volume (m^3)	Average concentration (mg/kg)
Tulane	15	91	17%	3.5	29
Fairbanks	396	1615	25%	92.0	61
Emory Valley	823	2438	34%	191.2	49
Total (m)	1234	4144		286 m^3	
Total (ft)	4048	13,596		10,125 ft^3	

Vertical Integration Study. The large-scale sampling (transect sampling) of the floodplain consisted of taking 16-in.-long soil cores and homogenizing the core before submitting it for analysis. It was recognized throughout this study that stratification of the contaminants occurs within the soil column as a natural result of the sedimentary process. This reflects the time-related deposition of the soil layers to the period of releases from the Y-12 Plant. A study was designed to determine the effects of stratification on the compositing of the sample and the degree to which this heterogeneity influenced the analytical results. Cores were obtained at four locations (with one duplicate) within the floodplain with the *Backsaver Zero Contamination Tube*. This device allows the extraction of a 2.5-cm (1-in.) soil core held in a clear acetate tube. The tube (18-in. long) was divided into 2.5-cm (1-in.) intervals, and the soil from each interval was submitted for NAA. The transect numbers represent the following locations:

Table 3.28. EFPC results for SLB soil summary of concentrations from 20-m sampling by SLB segment

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Emory Valley Beltway Segment									
Antimony	mg/kg	54/ 57	0.403	0.21	0.795	1.8	0.327	0.753	0.0189
Arsenic	mg/kg	57/ 57	.	2.6	8.69	27	3.5	8.69	0.113
Chromium	mg/kg	57/ 57	.	37	71.8	106	11.8	71.8	0.535
Mercury	mg/kg	32/ 53	2.79	4.4	56.7	162	45.5	34.2	0.429
Selenium	mg/kg	21/ 57	14.4	5.1	10.9	21	4.14	4.02	0.888
^{234}U	pCi/g	34/ 38	1.43	0.804	2.95	11	2.51	2.64	0.074
^{235}U	pCi/g	57/ 57	.	0.03	0.149	0.492	0.113	0.149	0.00322
^{238}U	pCi/g	34/ 38	1.14	1.1	4.02	13	3.16	3.59	0.097
Total uranium	pCi/g	34/ 38	2.61	1.94	7.1	24.5	5.75	6.35	0.173
Zinc	mg/kg	14/ 57	80.3	67	142	284	70	35	7.01
Fairbanks Beltway Segment									
Antimony	mg/kg	18/ 18	.	0.37	0.737	1.2	0.234	0.737	0.0271
Arsenic	mg/kg	36/ 37	2	6.1	10.5	18	2.68	10.2	0.162
Chromium	mg/kg	18/ 18	.	52	74.5	90	11.1	74.5	0.833
Mercury	mg/kg	12/ 22	3.14	4.5	56.3	158	50	30.7	0.471
Selenium	mg/kg	4/ 18	9.61	6.1	7.5	9.1	1.3	1.67	1.54
^{234}U	pCi/g	18/ 18	.	1.1	3.94	9.09	2.34	3.94	0.142
^{235}U	pCi/g	37/ 37	.	0.0407	0.15	0.449	0.105	0.15	0.00371
^{238}U	pCi/g	18/ 18	.	1.47	4.49	8.32	2.14	4.49	0.135
Total uranium	pCi/g	18/ 18	.	2.61	8.61	16.5	4.47	8.61	0.28
Zinc	mg/kg	15/ 18	65	60	109	194	37.6	90.5	4.17
Tulane Beltway Segment									
Antimony	mg/kg	5/ 7	0.35	0.57	1	1.8	0.49	0.716	0.0566
Arsenic	mg/kg	7/ 7	.	8.2	11.7	24	5.62	11.7	0.435
Chromium	mg/kg	7/ 7	.	49	70.3	95	15.5	70.3	1.2
Mercury	mg/kg	4/ 7	1.77	3.6	22.6	33	13.6	12.9	0.467
Selenium	mg/kg	1/ 7	9.65	12	12	12	.	1.71	4
^{234}U	pCi/g	7/ 7	.	1.12	1.68	2.71	0.555	1.68	0.183
^{235}U	pCi/g	7/ 7	.	0.0428	0.0734	0.131	0,0293	0.0734	0.00162

Table 3.28 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
^{238}U	pCi/g	7/ 7	.	1.57	2.14	2.7	0.412	2.14	0.182
Total uranium	pCi/g	7/ 7	.	2.92	3.9	5.2	0.919	3.9	0.364
Zinc	mg/kg	2/ 7	47.4	109	146	183	52.3	41.7	15.6

Results less than the detection limit were set to zero to compute grand mean.
Weight-based concentrations of uranium isotopes were converted to activity for this summary.
Source: EFPC Phase Ib validated results on January 11, 1993.

Transect	Location	Original sample mercury (ppm)	Wt. avg. 1 in. mercury (ppm)
E-20339	EFPC Confluence	98	177
E-37728	Grand Cove Subdiv.	49	205
E-53476	BR Study Site	898(R)	1023
E-53476	Bruner's Center (Duplicate)	898(R)	642
N-33468	NO Study Site	1320	986

(R)-results rejected in data validation

are they?

The results indicate that the mercury concentrations in the original (transect sampling) 0- to 16-in. samples are approximately equal to the weighted average of the 1-in. sample results. These results are within the range obtained by duplicate field samples. The weighted average results are surprisingly close when one considers that these cores were taken months later, and only in the general area of the original sample. The weighted average includes only the 0- to 16-in. sample values and omitted values for reject results. Table 3.29 presents the original (transect sampling) results for each analyte, and Table 3.30 contains the results for each 1-in. interval by location.

Figures 3.88 through 3.92 graphically portray the concentrations by horizon. Significant differences can be observed between sites. At the NO site, the highest concentrations of mercury are observed at a depth of 7 to 11 in., but very high concentrations also are observed at the surface. At the BR site, only minor concentrations of mercury exist at the surface, and a wide range in depth is observed for the "hot" zones. The duplicate sample for the BR site shows the highest concentration between 6 and 12 in. While the samples were taken < 2 ft apart, the initial sample exhibits the highest concentrations at a depth of 12 to 16 in. and the duplicate sample exhibits the highest concentrations at a depth of 6 to 12 in., a significant variation in distribution. Extreme variations in the depth of the highest contaminant concentrations such as those seen at the BR site can significantly impact the results obtained from a 0- to 16-in. composite analysis. Overall contaminant levels are much less at the Grand Cove site, and in this location, no appreciable contamination is detected until a depth of 15 to 16 in. From the irregular pattern of the transect sample results in the Grand Cove area, however, it is suspected that large variations take place within the site. The EFPC confluence sample is 700 m upstream from the actual confluence of EFPC with Poplar Creek. Concentrations here are similar to the Bruner's Center duplicate sample, where minimal concentrations were observed in the upper 7 in. and the highest concentrations were detected at a depth of 8 to 12 in.

Table 3.29. EFPC floodplain soil sampling original results

Location	Station	Depth (in.)	Mercury (mg/kg)	^{235}U (mg/kg)	^{238}U (mg/kg)	Arsenic (mg/kg)	Chromium (mg/kg)	Antimony (mg/kg)	Selenium (mg/kg)	Zinc (mg/kg)
E-20339	N-0	0-16	177.	0.42	48.	5.3	86.	0.82	<9.8 R	176.
E-37728	N-0	0-16	205.	0.28	34.	7.1	99.	1.0	<17.	<179.
		16-32	<3.7	0.028	6.6	5.9	53.	0.54	<13.	<150.
		32-48	<4.3	0.027	6.2	3.2	48.	0.38	<13.	<159.
E-53476	N-0	0-16	898. R	0.59	72.	16.	173.	1.3	<16.	<74.
		16-32	77. R	0.23	32.	8.8	73.	0.89	<11.	<54.
		32-48	47. R	0.097	14.	6.1	73.	0.66	<9.6	<44.
N-33468	E-0	0-16	1320.	0.60	98.	8.5	117.	1.1	<30.	<188.
		16-32	320.	0.19	38.	9.4	81.	0.75	<21.	<156.
		32-48	88.	0.31	45.	8.9	93.	0.83	<20.	<154.

Data qualifier code: R=rejected value.
Source: EFPC Phase Ib validated results on October 23, 1992.

Table 3.30. EFPC floodplain soil sampling results in 1-in. intervals

Location	Station	Depth (in.)	Mercury (mg/kg)	^{235}U (mg/kg)	^{238}U (mg/kg)	Arsenic (mg/kg)	Chromium (mg/kg)	Antimony (mg/kg)	Selenium (mg/kg)	Zinc (mg/kg)
E-20339	N-00-V	0-1	<3.9	0.10	16.	9.6 R	67.	0.94 R	<7.7	<49.
		1-2	14.	0.19	24.	9.9 R	104.	1.2 R	<10.	229.
		2-3	<4.0	0.21	24.	12. R	104.	1.2 R	13.	136.
		3-4	5.4	0.21	20.	9.9 R	107.	1.3 R	8.1	62.
		4-5	6.5	0.13	14.	11. R	75.	1.1 R	5.8	109.
		5-6		0.12						
		6-7		0.093						
		7-8	14.	0.092	12.	12. R	80.	1.6 R	<12.	89.
		8-9	63.	0.18	23.	11. R	80.	1.5 R	<11.	213.
		9-10	307.	0.38	44.	12. R	97.	1.5 R	<12.	222.
		10-11	425.	0.58	58.	9.8 R	93.	1.3 R	<15.	149.
		11-12	228.	0.63	98.	10.0 R	106.	1.5 R	<12.	196.
		12-13	117.	0.42	67.	8.3 R	133.	1.0 R	<11.	90.
		13-14	96.	0.40	63.	8.8 R	144.	1.3 R	<11.	131.
		14-15	56.	0.29	45.	6.7 R	112.	1.1 R	<9.9	136.
		15-16	45.	0.26	49.	7.8 R	106.	1.2 R	<11.	200.
		16-17		0.25						
		17-18	38.	0.21	34.	7.9 R	89.	1.0 R	<11.	101.
E-37728	N-04-V	0-1	<3.6	0.027	7.4	8.5 R	59.	0.88 R	7.7	110.
		1-2	<3.8	0.023	5.0	5.6 R	57.	1.0 R	7.3	<56.
		2-3	<1.4	0.020	<150.	<0.26 R	36.	<23. R	<3.6	<29.
		3-4	<1.5	0.022	<164.	<0.30 R	43.	<25. R	<4.0	<32.
		4-5	<1.5	0.023	<163.	<0.30 R	40.	<24. R	<3.9	<31.
		5-6	<1.5	0.023	<162.	<0.28 R	54.	<24. R	<3.9	<31.
		6-7	<2.1	0.00E+00	<239.	<0.27 R	119.	<36. R	<5.8	<47.
		7-8	<1.5	0.029	<166.	<0.28 R	52.	<26. R	<4.0	<34.
		8-9	<4.2	0.038	53.	<0.32 R	44.	<25. R	<4.0	<34.
		9-10	<5.3	0.038	66.	<0.40 R	62.	<30. R	<4.6	<41.
		10-11	12. R	0.060 R	48. R	<0.29 R	43. R	<24. R	<3.7 R	<32. R
		11-12	<1.4 R	0.024 R	<154. R	<0.32 R	37. R	<24. R	<3.6 R	<30. R

Data qualifier code: R=rejected value.

Table 3.30 (continued)

Location	Station	Depth (in.)	Mercury (mg/kg)	^{235}U (mg/kg)	^{238}U (mg/kg)	Arsenic (mg/kg)	Chromium (mg/kg)	Antimony (mg/kg)	Selenium (mg/kg)	Zinc (mg/kg)
		12-13	<3.4	0.029	43.	<0.26 R	36.	<22. R	<3.4	<29.
		13-14	9.9	0.051	50.	<0.30 R	56.	<27. R	<4.2	<36.
		14-15	10.	0.058	55.	<0.33 R	48.	<25. R	<3.8	101.
		15-16	49.	0.24	47.	<0.28 R	73.	<24. R	<3.9	142.
		16-17	53.	0.23	67.	<0.40 R	80.	<28. R	<4.5	137.
		17-18	39.	0.20	59.	<0.35 R	74.	<26. R	<4.1	173.
E-53476	N-OO-V	0-1	<1.7	0.16	<196.	<0.26 R	64.	<30. R	<4.6	<40.
		1-2	25.	0.23	52.	<0.31 R	81.	<36. R	<5.3	<47.
		2-3	<2.1	0.19	<238.	<0.29 R	70.	<35. R	<5.4	<43.
		3-4	32.	0.27	50.	<0.30 R	80.	<36. R	<6.0	<46.
		4-5	40.	0.25	<462. R	<0.24 R	76. R	<28. R	<6.5	<44. R
		5-6	492.	0.32	<470. R	<0.25 R	101. R	<30. R	<6.7	<50. R
		6-7	1740.	0.32	<642. R	<0.30 R	96. R	<35. R	<9.3	308. R
		7-8	2450.	0.69	<818. R	<0.35 R	171. R	<42. R	<12.	437. R
		8-9	2440.	0.50	<831. R	<0.37 R	127. R	<45. R	<12.	<69. R
		9-10	2740.	0.62	<972. R	<0.50 R	127. R	45. R	<14.	356. R
		10-11	3420.	0.60	<828. R	<0.31 R	110. R	<38. R	<12.	369. R
		11-12	1870.	1.5	<853. R	<0.38 R	161. R	<43. R	<12.	441. R
		12-13	292.	0.73	<627. R	<0.37 R	120. R	<41. R	<8.5	<69. R
		13-14	374.	0.72	<580. R	<0.28 R	122. R	<36. R	7.0	347. R
		14-15	295.	0.72	<599. R	<0.40 R	192. R	<39. R	<8.2	444. R
		15-16	168.	0.49	779. R	<0.36 R	221. R	<37. R	<7.6	441. R
		16-17	140.	0.47	<517. R	<0.32 R	191. R	<34. R	<6.9	419. R
		17-18		0.41						
E-53476	N-OO-VI-	0-1		0.11						
		1-2	29.	0.18	<406. R	<0.19 R	107. R	<28. R	<5.3	<43. R
		2-3	8.1	0.20	394. R	<0.20 R	74. R	<28. R	<5.3	<39. R
		3-4	71.	0.24	<446. R	<0.19 R	74. R	22. R	<5.8	<40. R
		4-5	1990.	0.45	<599. R	<0.22 R	95. R	<30. R	<8.2	279. R
		5-6	<3.6	0.058	<360. R	<0.19 R	68. R	<26. R	<4.7	<35. R
		6-7	<3.6	0.039	8.7	7.8 R	73.	0.69 R	9.1	<94.
		7-8	<3.3	0.049	11.	6.5 R	68.	0.66 R	<10.	<82.

Data qualifier code: R=rejected value.

Table 3.30 (continued)

Location	Station	Depth (in.)	Mercury (mg/kg)	^{233}U (mg/kg)	^{235}U (mg/kg)	Arsenic (mg/kg)	Chromium (mg/kg)	Antimony (mg/kg)	Selenium (mg/kg)	Zinc (mg/kg)
		8-9	<3.3	0.076	16.	8.1 R	73.	0.78 R	<11.	<84.
		9-10	<3.7	0.13	23.	8.3 R	82.	1.1 R	<12.	<92.
		10-11	<4.2	0.19	26.	11. R	73.	1.9 R	12.	<100.
		11-12	226.	0.26	37.	14. R	105.	1.6 R	<15.	<110.
		12-13	181.	0.27	30.	13. R	88.	1.7 R	<15.	<115.
		13-14	2080.	0.36	50.	21. R	84.	2.3 R	<20.	<132.
		14-15	2920.	0.67	70.	20. R	122.	2.3 R	<26.	<167.
		15-16	2130.	1.5	156.	27. R	194.	2.8 R	<26.	493.
		16-17	397.	0.71	95.	19. R	148.	1.8 R	<10.	332.
		17-18	298.	0.64	85.	18. R	206.	1.5 R	<8.8	370.
N-33468	E-02-V	0-1	451.	0.43	51.	9.5 R	77.	0.61 R	<6.3	137.
		1-2	593.	0.87	116.	11. R	117.	1.1 R	<7.9	153.
		2-3	642.	0.49	60.	11. R	98.	0.74 R	<8.1	<50.
		3-4	647.	0.47	57.	13. R	101.	0.72 R	<7.6	167.
		4-5	508. R	9.01E-05 R	55. R	7.9 R	76. R	0.69 R	<6.3 R	152. R
		5-6	227. R	0.21 R	25. R	7.6 R	63. R	0.48 R	<4.5 R	67. R
		6-7	510.	0.30	35.	11. R	94.	0.72 R	<6.9	205.
		7-8	1190.	0.35	132.	4.9 R	54.	0.56 R	<13.	137.
		8-9	1920.	0.26 R	<5.3 R	<0.27 R	77.	<509. R	<8.6	117.
		9-10	2870.	0.99 R	<6.2 R	<0.31 R	119.	<600. R	<11.	241.
		10-11	1950.	1.3 R	<5.7 R	<0.29 R	120.	<532. R	<9.2	244.
		11-12	203. R	1.5 R	<6.9 R	<0.35 R	195. R	<562. R	<7.5 R	404. R
		12-13	220. R	0.48 R	<5.1 R	<0.25 R	172. R	<438. R	<6.0 R	272. R
		13-14	318.	0.47 R	<7.3 R	<0.37 R	161.	<507. R	<7.1	251.
		14-15	306.	0.58 R	<6.5 R	<0.32 R	128.	<514. R	<6.9	235.
		15-16	436.	0.53 R	<5.7 R	<0.29 R	130.	<491. R	7.5	265.
		16-17	495.	0.65 R	<8.4 R	<0.42 R	97.	<615. R	<8.4	395.
		17-18	717.	0.59 R	<5.6 R	<0.28 R	91.	<472. R	<7.1	339.

Data qualifier code: R=rejected value.
Source: EFPC Phase Ib validated results on October 23, 1992.

Data qualifier code: R=rejected value.

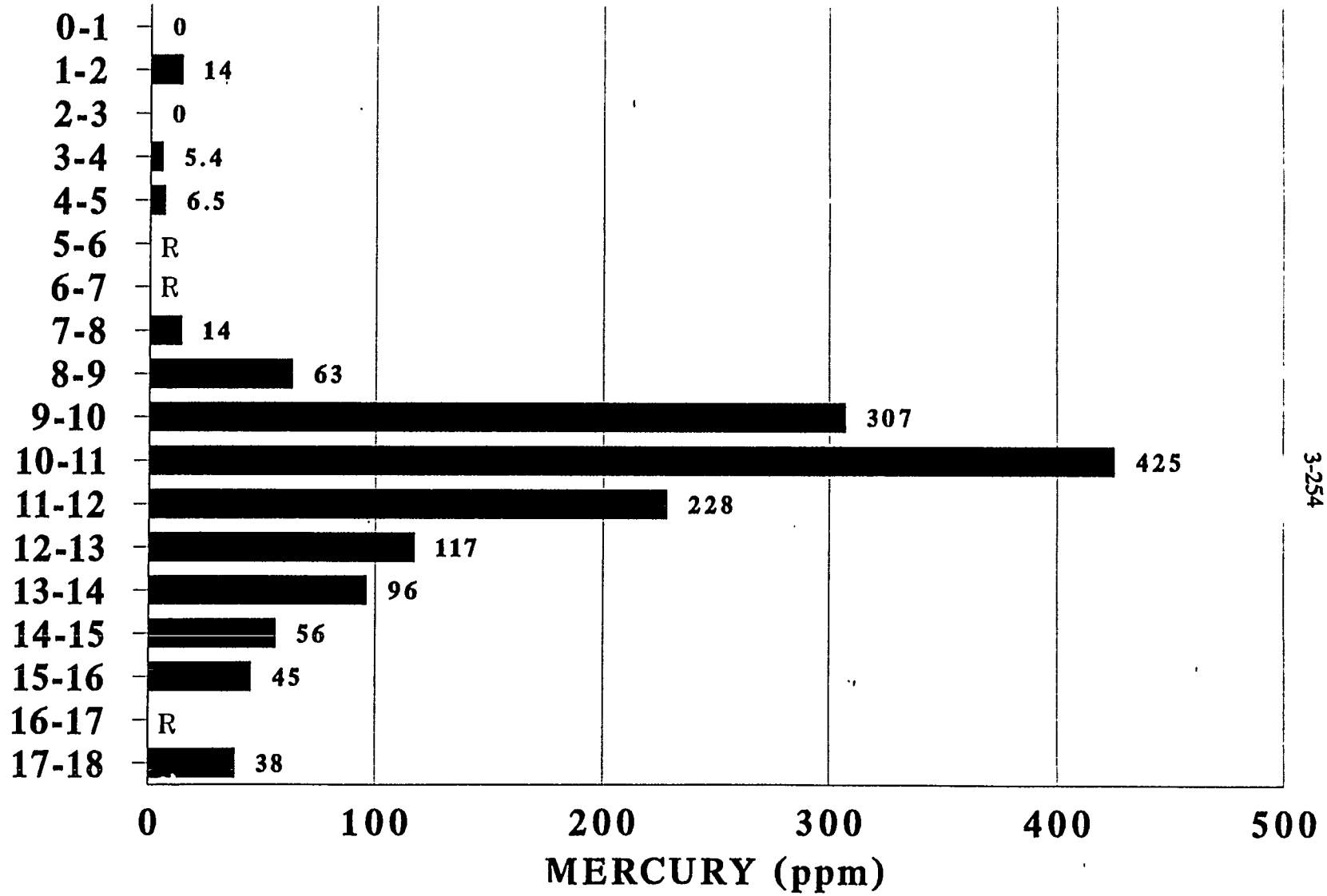


Fig. 3.88. Mercury concentrations for 1-in. intervals from 0 to 18 in. at Transect E-20339, Station N-00 (R represents rej).

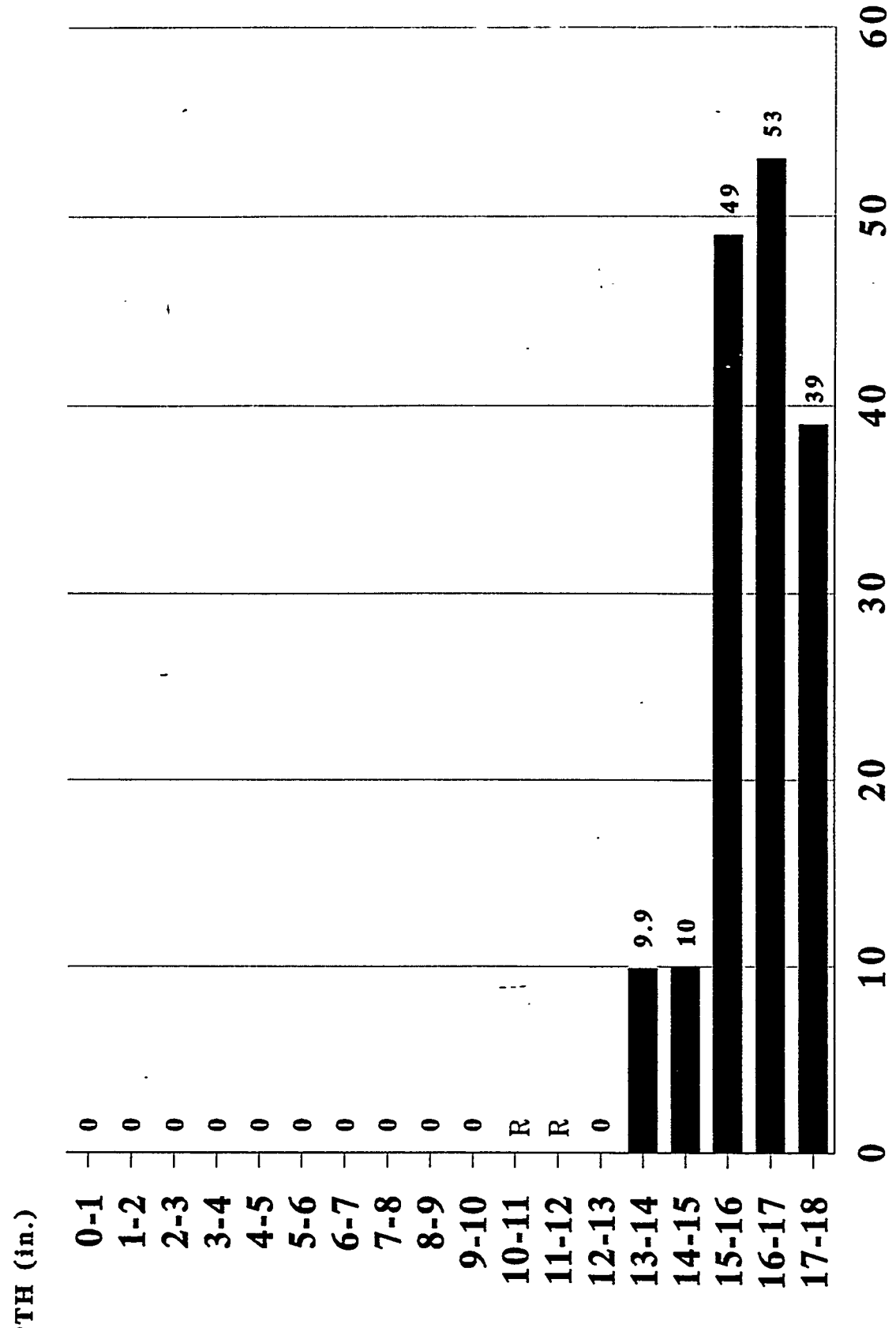


Fig. 3.89. Mercury concentrations in 1-in. intervals from 0 to 18 in. at Grand Cove Site - Transect E-37728, Station N-04 (R represents rej.)

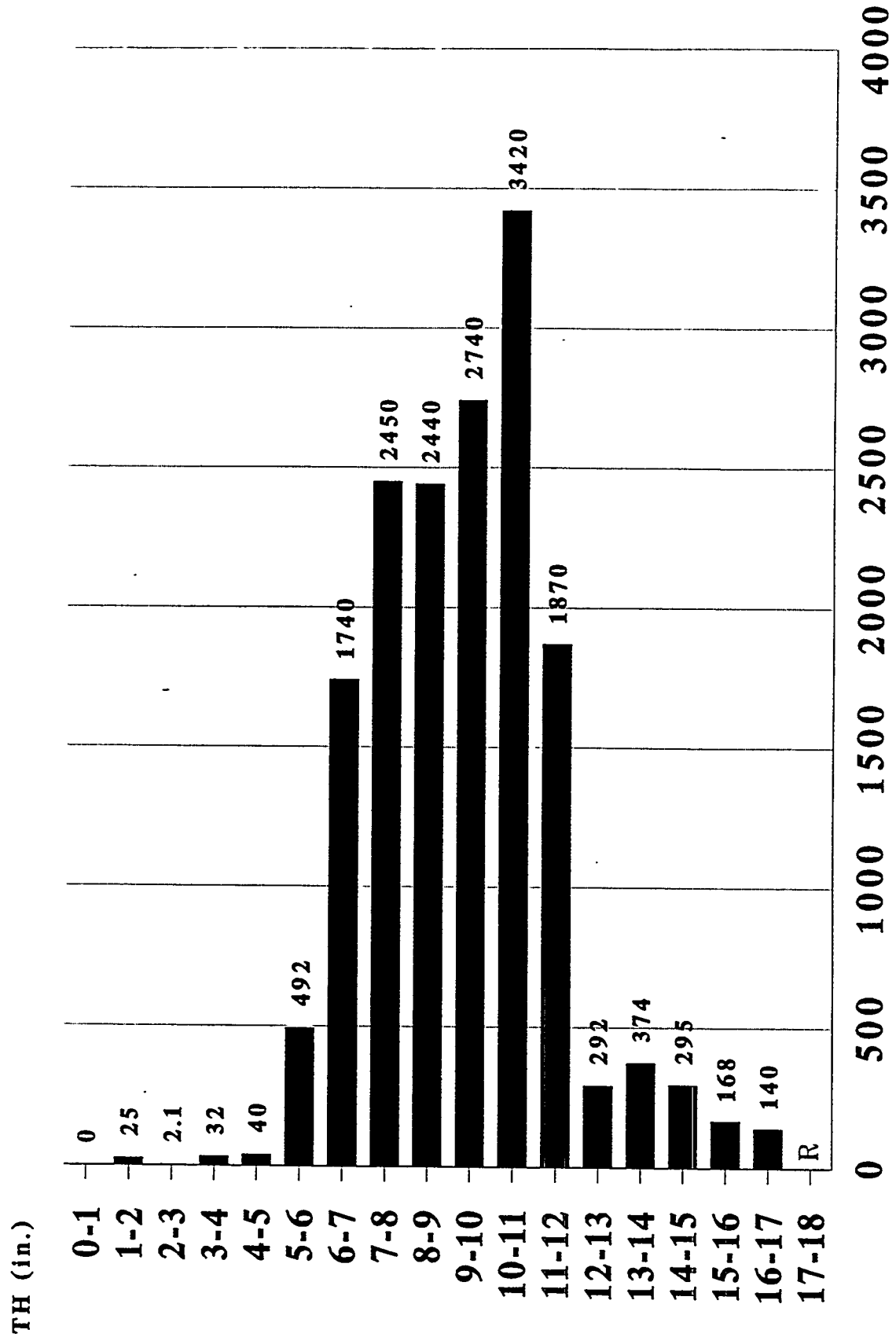


Fig. 3.90. Mercury concentrations in 1-in. intervals from 0 to 18 in, at BR Study Site - Transect E-53476, Station N-00 (R represents rej).

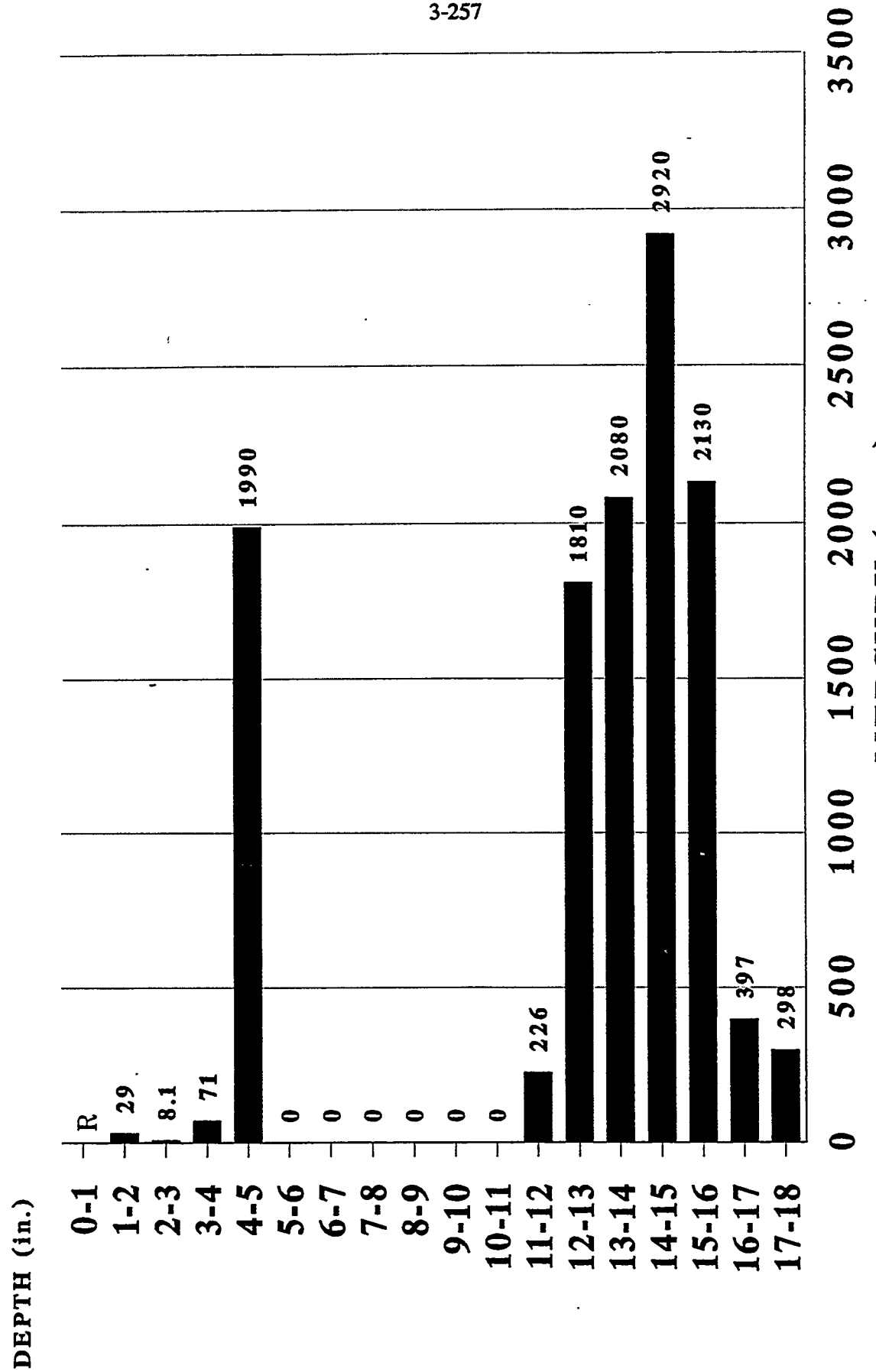


Fig. 3.91. Duplicate mercury concentrations in 1-in. intervals from 0 to 18 in. at BR Study Site - Transect E-53476, Station N-00D (R represents rej).

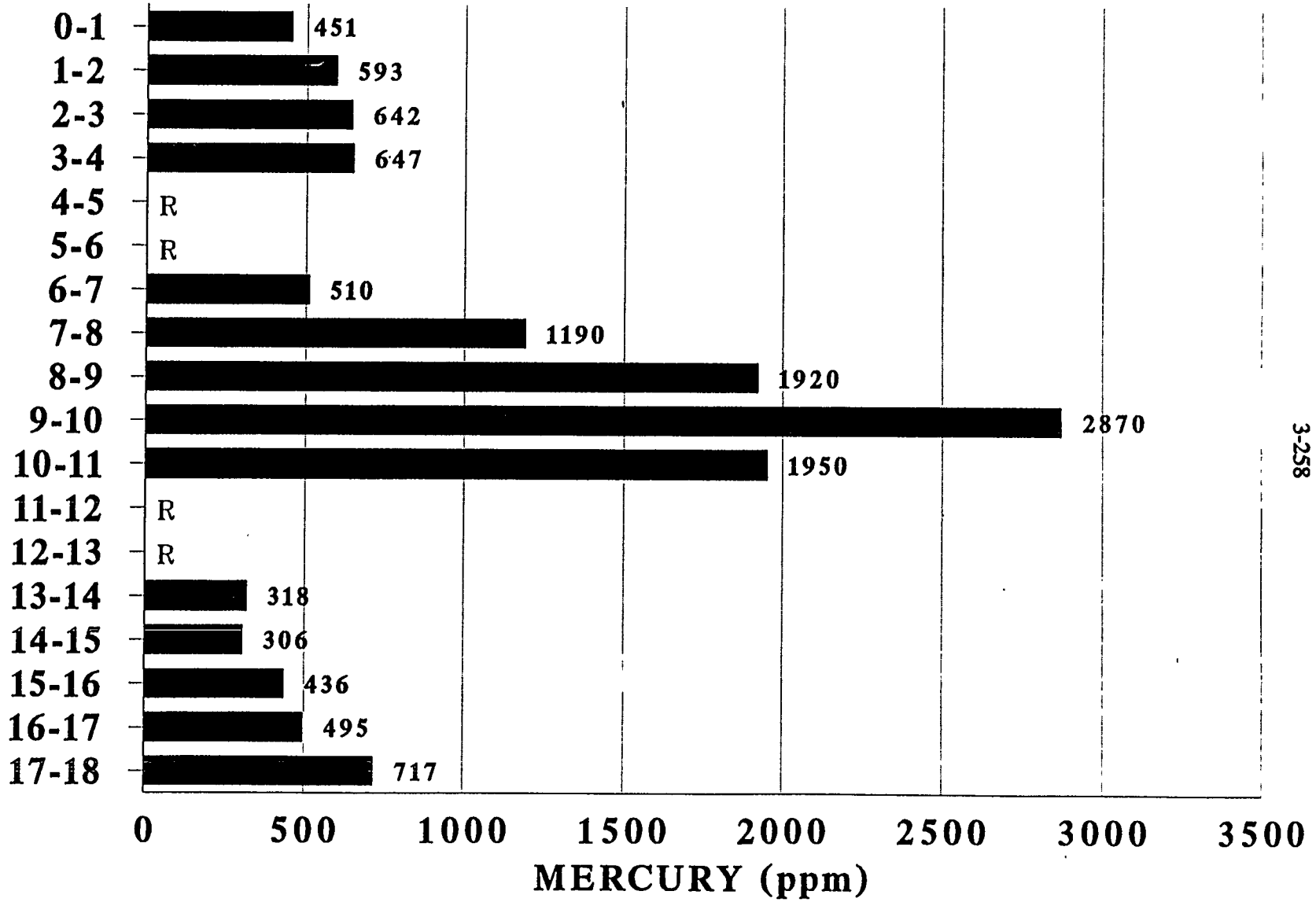


Fig. 3.92. Mercury concentrations in 1-in. intervals from 0 to 18 in. at NO Study Site - Transect N-33468, Station E-02 (R represents rej).

Generally, it appears that the largest mercury releases to EFPC occurred during the period when soil accumulated in the EFPC floodplain equivalent to a depth of about 1 ft. Only minor concentrations are observed within the surface intervals except at the NOAA site. This surface occurrence at NOAA is expected because the site is a depositional wetland immediately downstream of the Y-12 source. It is suggested that the migration of contamination from Y-12 is being trapped at this site.

Mercury Form. By virtue of its volume and proportionate toxicity, mercury is considered the principal contaminant within the EFPC floodplain. In addition, it displays unique chemical and toxicological properties. At environmental temperatures, elemental mercury possesses a high specific gravity, high vapor pressure, and high surface tension, and it is present in a liquid state. Furthermore, it can exist as an elemental, inorganic, or organometallic complex. The solubility, mobility, toxicity, and biological uptake of mercury change dramatically, depending upon its form. Even though processes at the Y-12 Plant utilized elemental mercury (Hg^0), conversion of mercury into other forms has taken place. Under natural conditions of temperature, pressure, pH, and oxidation potential (Eh) (e.g., in impoundment ponds and floodplain soils), very slow abiotic conversion of elemental mercury is expected. However, sulfate-reducing bacteria may alter elemental mercury to mercuric sulfide (HgS) or methylmercury (CH_3Hg^+).

Elemental mercury must first be oxidized to combine with sulfide to form mercuric sulfide. Likewise, the inorganic substrate that can be methylated is oxidized mercury (Hg^{++}). Most, if not virtually all, of the mercury in the EFPC floodplain soils probably left Y-12 in an oxidized state. Nitric acid was used to wash elemental mercury for the Colex process, and one opportunity for oxidation could have been this activity. Chlorine in chlorinated process and cooling water represents another opportunity for the oxidation of elemental mercury.

In a relative sense, mercury is present in large quantities as an environmental contaminant. Nonetheless, it occurs only in trace amounts compared to the soil/sediment mass. A 1000 mg/kg (ppm) mercury concentration is equivalent to only 0.1% by weight. The study of a particular compound in trace element quantities and the determination of the relative proportions of each compound is not a simple task. Direct investigative techniques for micron-sized particles are limited. The EFPC RI attempted several lines of investigation, and while general conclusions can be made, definitive evidence is not available.

Extraction Studies. Revis et al. (1989) reported results of sequential extraction studies of EFPC soils to determine relative amounts of inorganic, elemental, and methyl mercury compounds. The authors noted that most species and compounds of mercury, with the exception

of mercuric sulfide, are soluble in nitric acid (HNO_3) and that mercuric sulfide is completely soluble in a saturated solution of sodium sulfate (Na_2S). Elemental mercury was distinguished by the loss of mercury vapors after heating a sample for 5 days at 150°C and determining the remaining mercury by the cold vapor method. Methylmercury was estimated using the method described by Furutani and Rudd (1989). The results indicated the following distribution of the total mercury (Revis et al. 1989):

Hg^0	3-8%
HgS	84-98%
CH_3Hg^+	0.003-0.010%

The range of CH_3Hg was estimated from analyses of 72 samples; however, only seven had detectable levels. Concentrations ranged from 9.6-33 ng/g, and the detection limit was 10 ng/g.

Methylmercury Soils Analyses. To confirm reported methylmercury concentrations in soils, the EFPC RI sampled the three study areas (NO, WA, and BR with a duplicate at BR) and submitted the samples to Brooks-Rand, LTD., of Seattle, Washington. Total mercury and total methylmercury analyses were requested for each sample. Total mercury and total methylmercury were determined according to Brooks-Rand procedures: *Method BR-0002, Total Mercury in Solids by Cold Vapor Atomic Fluorescence,* and *Method BR-0001, Methylmercury in Tissues and Sediments.*

Results were as follows:

Sample #	Total Hg (µg/g-ppm)	Total CH_3Hg^+ (ng/g-ppb)	Total CH_3Hg^+ (Percent)
NO0103103	355	2.66	0.0008%
WA0404063	2099	41.45(3 reps)	0.0020%
BR0404078	2090	83.75	0.0040%
BR0404080(dup)	1494(3 reps)	65.33	0.0044%

Results from the Brooks-Rand analyses concur with published reports that methylmercury comprises a very small fraction (approximate average of 0.003%) of the total mercury present in EFPC soils.

In a gross sense, data obtained from the coral fish study (Appendix Q) for the ecological investigation can be used to assess the sediment concentrations of methymercury related to the particle-bound phase (that phase transported by suspension in surface waters). Concentrations of particulate methylmercury for flow into Lake Reality were examined as a percent of total mercury in the water column. These concentrations are expected to be higher than those observed within the creek because EFPC is considered to be a de-methylator of mercury. Total mercury for inflow into Lake Reality was recorded at 1.1 ± .05 μg/L (compared to 0.09 ± 0.02 ng/L for particulate methylmercury). Accordingly, methylmercury in the suspended particulate phase has been found to equal 0.008 percent of the total mercury in water (compared to 0.003 percent of the total mercury in soils).

TCLP. Sediment and soil samples from EFPC were subjected to the TCLP, and the extract was submitted for analysis of a suite of TCLP-specific analytes (including metals, semivolatile organic compounds, pesticides, and herbicides, but not VOCs). TCLP is used to characterize materials as hazardous or nonhazardous per RCRA guidelines. Although it is not a means to directly determine the form of the mercury, TCLP uses a weakly acidic extraction solution that is apparently ineffective on the form of mercury present in EFPC soils. A previously discussed (Sect. 3.2.2) sediment "ooze," which contained elevated mercury and PCB concentrations, was reported with all analyses above the analytical detection limit. Two samples (BR0404066 and NO010466) from the same study sites used for the methylmercury samples (BR and NO) showed analogous nondetects for metals, semivolatile organics, pesticides, and herbicides. Revis et al. (1989) noted the ineffectiveness of nitric acid on mercuric sulfide. The negative results for the TCLP tests may be due to the fact that mercury is present as mercuric sulfide and is not affected by the acidic extraction.

Microscopy Investigation. As part of the EFPC RI and with the assistance of the Material Science Section at the K-25 Plant, a supportive investigation with direct analytical techniques such as optical and electron microscopy and elemental microprobe analysis was undertaken. Objectives of the task were to: understand in what form the mercury presently exists, understand whether mercury forms vary within the floodplain, understand whether any observable differences or associations exist between areas of high and average mercury concentrations, determine the size of discrete mercury particles, and observe any strong associations or paragenetic relationship between mercury and other materials. A copy of the final report with photomicrographs is included in Appendix G. Mercury was found to be present in several forms—as discrete particles or globules, as coatings on mineral matter, and as fillings in pores and fissures in plant debris.

Discrete mercury particles are most often observed in the micron-size range. Mercury and sulfur have been found to coexist in all the mercury-rich entities. However, due to the small size, it cannot be confirmed whether mercury and sulfur have formed an actual compound or exist as an association of sulfur coating the mercury particles. Future work will require that the mercury be concentrated to allow for this determination. Except for relative levels of mercury, no change is noted throughout the floodplain, and no distinction has been observed for areas of high vs average concentrations. One notable association has been observed. Flyash and coal fragments were found to be more abundant in the mercury-rich samples and to be correspondingly less abundant in those samples that are poorer in mercury. No physical or chemical relationship could be established between the two constituents, and it is postulated that they are transported and deposited together in the same setting with no observable chemical or physical interaction.

3.2.5.4 Evaluation

The mercury and ^{238}U analyte maps (Maps 7 and 8) display contaminant concentrations at each sampling point by depth. A review of these maps reveals a large variation in concentrations between sampling locations within the same area. In general, however, concentrations are roughly within the same order of magnitude for a given area and increase or decrease in a similar manner along the floodplain. The heterogeneous nature of the soil is confirmed by the microscopy investigation, the vertical integration study, and the pilot soil study.

Assessment of the representative contaminant concentration for a given area is difficult. To incorporate this assessment into the risk assessment process or use this data for remedial action decisions is to assume a degree of uncertainty. Because one location could conceivably exhibit a range of concentrations as a function of the number of times it is sampled, the contaminant concentration is problematic. Each sample exemplifies contaminant concentrations for a specific point, but not over an area of interest. The interpolation between points can impart an even larger degree of uncertainty.

The EFPC RI employed two computer algorithms and one hand-drawn method to interpret the extent and concentration of contamination within the floodplain (as defined by mercury). Each computer algorithm, kriging (see below) and triangulation, has advantages and disadvantages. Kriging is attractive in that it provided an estimate of contaminant concentrations for discrete blocks between actual data points, but only for a single layer. Triangulation provided volumetric estimates for all depths, using interpolation of triangles formed between the data points regardless of depth, but did not estimate an average concentration for discrete areas. Both methods have the inherent disadvantage that the only input into the estimation process is the position (northing

and easting) and the concentration. Such factors as the direction of the creek and topographic height are not used in the processing. The distribution of contamination within the floodplain is a function of the manner in which EFPC floods and inundates the surrounding area, i.e., it is a function of the orientation of the creek and the lateral distance from the creek bank as well as the height of the surrounding topography. Problems were evident for certain segments of the creek using either computer method. Kriging could not adequately estimate the thin elongated ribbon of contamination along the creek bank, and triangulation formed triangles that did not follow creek orientation or provide reasonable shapes or patterns.

As a basis to qualify the computer estimates, a hand-drawn assessment of contaminant patterns was achieved using 50 and 200 ppm mercury for the contaminant boundaries (Maps 10 and 11). The 50 and 200 ppm concentration lines were estimated between bounding values along a single transect. The line connecting equal concentrations between transects was mapped by roughly following the same topographic elevation. In this manner, the 50 and 200 ppm concentrations are assumed (for a small area) to be a function of the topographic elevation. A decision was made to incorporate the analyses rejected for Level IV data use (as input into the risk assessment) into these maps for the sake of completeness. The use of these data for defining contaminant extent is in compliance with EPA's guidance for Level II data and above.

After reviewing the results from the three methods, it is judged that hand-contouring of the contaminant distribution patterns is most representative of the true extent of contamination. However, this method does not provide an estimate of discrete concentrations between sample points. To remedy this limiting factor, a combination of the hand-drawn interpretation and the kriging has been employed to gain the advantage from both methods.

Geostatistical Evaluation. The EFPC RI employed geostatistics for spatial evaluation of the contaminant concentrations. Geostatistics (EPA 1991) is a methodology for the analysis of spatially correlated data; its characteristic feature is the use of variograms or related techniques to quantify and model the spatial correlation structure. Variograms (which are plots of the variance of paired-sample measurements as a function of the distance between samples) provide a means of quantifying the commonly observed relationship in which samples close together will tend to have more similar values than samples farther apart. A variogram is developed to define the distance-variance relationship (i.e., spatial correlation structure) when an idealized mathematical function is fitted to a variogram constructed from a sample data set. Kriging is then implemented using the selected mathematical function as a weighted-moving average interpolator. The calculation of a point or average block concentration assigns a set of weights to surrounding

sample values, which minimizes the estimation variance. This is often referred to as best linear unbiased estimator (BLUE).

The structural analysis of the variograms and the data kriging were performed under the direction of Dr. Evan Englund of EPA's Environmental Monitoring Systems Laboratory (EMSL-Las Vegas) and Dr. A.K. Singh of the Environmental Research Center, University of Nevada, Las Vegas. A validated data set (without the rejected data) was supplied to EMSL from the NAA of Phase Ib soil transect samples. EFPC was subdivided into sections to compensate for the sinuous nature of the creek and to permit processing subsets of the 3000 ± samples. A nonparametric variogram model, which was used to compute block averages (20 × 20 m) of mercury concentrations within the EFPC floodplain, is a variant of Ordinary Kriging. In Ordinary Kriging, it is assumed that the concentration data have no spatial trends, and the variance of measurements is constant. The symmetry of the data distribution is an implicit assumption. Because the EFPC data were heavily skewed, log transformation was used to obtain a symmetric distribution. The estimates of block averages, obtained by using Ordinary Kriging on the log-data, were then back-transformed by a formula often employed in the geostatistical literature. The back-transformed block averages depend on the block averages of log-data and also on their kriging standard deviation. For this reason, the initial attempt at Ordinary Kriging with the EFPC data resulted in back-transformed block averages much higher than the observed maximum concentrations of mercury in some areas. The method of Rank-Order Kriging was used as an alternative. This method is a nonparametric geostatistical statistical method. More details of this method can be found in a forthcoming paper in Analytical Chimica Acta (1993) by Singh, Ananda, and Sparks. The method is accomplished by sorting the concentration data and replacing the concentration data by their ordered rank from 1 to n. A variogram model is fitted to the rank data, and Ordinary Kriging is performed using the fitted-model on the concentration data. The kriging standard deviation is multiplied by a correction factor (= variance of concentration data/variance of rank data). The variance of the concentration distribution is estimated from the raw concentration data.

Map 10 displays the average mercury concentrations in 20-m blocks overlain on the hand-drawn estimate of the distribution of mercury for 50 and 200 ppm levels (only Layer 1 was kriged). A summary of contaminated soil volumes is presented in Table 3.31. The class boundaries (i.e., cutoff) for mercury are taken from the human health PRGs. Mercury-contaminated soil volumes are calculated by segment for two classes (≥50, and ≥200). The ≥50 and ≥200 ppm mercury concentrations are based on the PRG for children and adults, respectively, using the incidental soil ingestion and dermal exposure pathways. The values of

Table 3.31. Mercury-contaminated soil volumes (cubic meters)

	Layer 1 (0-41 cm/0-16 in.) Hg (ppm)[a]		Layer 2 (41-82 cm/16-31 in.) Hg (ppm)[a]		Total Layers 1 and 2[b]	
	≥50	≥200	≥50	≥200	≥50	>200
1	20,246	4,222	3,343	3,343	23,589	7,565
2	5,117	0	787	0	5,904	0
3	3,744	0	2,233	1,147	5,977	1,147
4	29,073	13,231	14,214	4,051	43,287	17,282
5	8,901	2,081	1,657	0	10,558	2,256
6	4,174	0	0	0	4,174	0
7	15,953	0	1,268	0	17,221	0
8	9,841	3,864	1,315	0	11,156	3,864
9	26,722	182	1,605	873	28,327	1,055
Total (m^3)	123,771	23,580	26,422	9,589	150,193	33,169
Total (ft^3)	4,370,354	832,609	932,960	338,587	5,303,314	1,171,197

[a]Volume classes established or PRGs for mercury via soil ingestion and dermal exposure for children (58 ppm) and adults (198 ppm).
[b]Layer 3 is not presented in this table because it has no volumes greater than cutoffs.

50 and 200 have been rounded from the precise PRGs of 58 and 198. Total estimates for the three methods show agreement for the creek as a whole. The total volume estimates for mercury-contaminated soil ≥50 ppm are:

Method	Estimate (10^3 m^3/10^3 ft^3)
Contouring	140.5/4,960
Kriging	118.5/4,183
Triangulation	129.5/4,574

The contouring estimate includes volumes for layer 1 (0 to 41 cm) and layer 2 (41 to 82 cm). Only isolated samples within layer 3 (82 to123 cm) display concentrations greater than 50 ppm; therefore, no calculations were performed for this layer. The kriging estimate was performed for layer 1 only. The above kriging number includes the contouring estimate for layer 2 so that the numbers are comparable. While the triangulation estimate incorporates all three intervals, layer 3 contribution is insignificant.

Layer 1 contains the vast majority of the contaminated soil. Layer 2 has only about one-fifth as much contamination by volume, and segment 4 is the only area with an appreciable accumulation in the second layer. This is expected because most of the contaminant deposition is restricted to the upper 45 cm (18 in.). No estimates were compiled for layer 3 because only isolated sample points were observed to exceed the 50 ppm mercury concentration.

The region of the EFPC floodplain with the largest volume of contaminated soil is Segment 4 (which contains the BR study site). Segments 1, 7, 8, and 9 also contain relatively large volumes, but Segments 7 and 9 are much larger in total area than any of the other nine segments. Segments 7 and 9 do not have equivalent percentages of their total areas exceeding the cutoff levels.

Segment Evaluation. The complete data set for soil, including Phase Ia, Phase Ib, NAA, CLP, and conventional radiochemistry data, is compiled into Table 3.32 by creek segment. A comparison of contaminant levels by analyte and creek segment, including the reference site, is presented in Figs. 3.93 through 3.111. Most noticeable from these figures are the consistently high contaminant concentrations at Segments 1, 4, and (generally) 8. Segments 1 and 4 are expected to have high concentrations because they are the NO and BR sites. Segment 8, which is the Grand Cove area, was not anticipated to exhibit levels of contamination as high as were observed.

Table 3.32. Summary of contaminant concentrations in the surface layer of EFPC floodplain soils by creek segment.

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (< DL = 0)	Radiation counting uncertainty of mean
SEGMENT 1									
Arsenic	mg/kg	97/101	2.2	1.1	6.52	16	3.29	6.26	.
Aluminum	mg/kg	17/17	.	6640	14400	23200	4640	14400	.
Antimony	mg/kg	74/97	5.2	0.2	0.645	1.6	0.3	0.492	.
Barium	mg/kg	17/17	.	36	150	327	82.5	150	.
Beryllium	mg/kg	13/17	0.475	0.5	1.31	4.6	1.07	1	.
Cadmium	mg/kg	12/17	1.01	1.6	7.2	26	6.86	5.08	.
Chromium	mg/kg	91/91	.	9.4	64.6	117	25.2	64.6	.
Cobalt	mg/kg	16/17	7.9	1.8	12.1	25.7	5.84	11.4	.
Copper	mg/kg	17/17	.	4.1	80.1	176	56.3	80.1	.
Cyanide	mg/kg	7/12	0.724	0.62	0.84	1.3	0.26	0.49	.
Lead	mg/kg	17/17	.	10.6	40.2	66.2	17.6	40.2	.
Manganese	mg/kg	17/17	.	25.6	701	1560	468	701	.
Mercury	mg/kg	51/94	3.9	0.4	239	1590	390	129	.
Nickel	mg/kg	17/17	.	3.7	41.1	97.2	31	41.1	.
Selenium	mg/kg	15/99	11.7	5.3	26.7	110	28.3	4.04	.
Silver	mg/kg	9/17	1.95	2.2	7.17	13.2	4.24	3.79	.
Thallium	mg/kg	1/14	0.691	19.3	19.3	19.3	.	1.38	.
Vanadium	mg/kg	17/17	.	13.5	24.5	36.3	6.2	24.5	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Zinc	mg/kg	28/102	108	14.1	108	340	67	29.6	.
^{241}Am	pCi/g	10/12	0.132	-0.2105	-0.0479	0.1	0.0921	-0.0399	0.155
^{137}Cs	pCi/g	17/17	.	0.1325	1.34	8.24	1.92	1.34	0.0618
^{60}Co	pCi/g	15/15	.	-0.0443	0.00653	0.0548	0.0288	0.00653	0.0152
^{237}Np	pCi/g	12/12	.	-0.05	0.0045	0.0395	0.0261	0.0045	0.0529
^{233}Pa	pCi/g	5/5	.	-0.119	-0.0161	0.0984	0.0803	-0.0161	0.117
^{228}Th	pCi/g	1/1	.	2.542	2.54	2.54	.	2.54	0.183
^{230}Th	pCi/g	1/1	.	4.576	4.58	4.58	.	4.58	0.242
^{232}Th	pCi/g	1/1	.	1.898	1.9	1.9	.	1.9	0.162
^{234}U	pCi/g	85/88	1.89	0.31	6.77	28.4	6.51	6.54	0.0724
^{235}U	pCi/g	99/99	.	0.01	0.329	1.82	0.368	0.329	0.00601
^{238}U	pCi/g	83/86	1.51	0.21	7.42	32.6	6.47	7.16	0.0796
4,4'-DDD	µg/kg	1/17	22.7	0.22	0.22	0.22	.	0.0129	.
4,4'-DDE	µg/kg	2/17	23.8	9.9	12.5	15	3.61	1.47	.
4,4'-DDT	µg/kg	0/17	21.6	.	.	.	.	0	.
Aldrin	µg/kg	0/17	10.8	.	.	.	.	0	.
Aroclor-1254	µg/kg	1/17	203	800	800	800	.	47.1	.
Aroclor-1260	µg/kg	13/17	158	140	1400	2900	1080	1070	.
Dieldrin	µg/kg	0/17	21.6	.	.	.	.	0	.
Endosulfan I	µg/kg	0/17	10.8	.	.	.	.	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Endosulfan II	µg/kg	1/17	22.7	0.26	0.26	0.26	.	0.0153	.
Endosulfan sulfate	µg/kg	0/17	21.6	.	.	.	.	0	.
Endrin	µg/kg	1/17	22.7	0.15	0.15	0.15	.	0.00882	.
Endrin aldehyde	µg/kg	1/5	7.72	0.61	0.61	0.61	.	0.122	.
Endrin ketone	µg/kg	0/17	21.6	.	.	.	.	0	.
Heptachlor	µg/kg	1/17	11.4	0.13	0.13	0.13	.	0.00765	.
Heptachlor epoxide	µg/kg	0/17	10.8	.	.	.	.	0	.
alpha-Chlordane	µg/kg	3/17	119	0.28	10.9	24	12	1.93	.
delta-BHC	µg/kg	0/17	10.8	.	.	.	.	0	.
gamma-BHC (Lindane)	µg/kg	1/17	11.4	4.9	4.9	4.9	.	0.288	.
gamma-Chlordane	µg/kg	4/17	128	0.15	0.66	0.9	0.351	0.155	.
p,p'-Methoxychlor	µg/kg	0/17	108	.	.	.	.	0	.
2-Methylnaphthalene	µg/kg	8/17	616	48	198	500	150	93.2	.
4-Chloro-3-methylphenol	µg/kg	1/17	579	41	41	41	.	2.41	.
4-Nitrophenol	µg/kg	0/17	2420	.	.	.	.	0	.
Acenaphthene	µg/kg	5/17	578	63	417	1700	718	123	.
Acenaphthylene	µg/kg	5/17	542	43	85.2	160	45.5	25.1	.
Anthracene	µg/kg	9/17	527	63	384	2000	615	203	.
Benzo(a)anthracene	µg/kg	13/17	427	260	976	3400	921	746	.
Benzo(a)pyrene	µg/kg	13/17	427	220	890	2700	784	681	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Benzo(b)fluoranthene	µg/kg	14/17	403	120	1180	3900	978	975	.
Benzo(g,h,i)perylene	µg/kg	12/17	526	210	574	1800	417	405	.
Benzo(k)fluoranthene	µg/kg	14/17	403	120	943	3200	760	776	.
Benzoic acid	µg/kg	0/12	2540	.	.	.	.	0	.
Butylbenzylphthalate	µg/kg	1/17	554	82	82	82	.	4.82	.
Carbazole	µg/kg	3/5	465	96	152	260	93.5	91.2	.
Chrysene	µg/kg	13/17	427	240	961	3100	926	735	.
Di-n-butylphthalate	µg/kg	0/17	589	.	.	.	.	0	.
Di-n-octylphthalate	µg/kg	0/17	568	.	.	.	.	0	.
Dibenzo(a,h)anthracene	µg/kg	8/17	609	55	184	640	192	86.4	.
Dibenzofuran	µg/kg	5/17	578	52	201	700	280	59.1	.
Diethylphthalate	µg/kg	0/17	568	.	.	.	.	0	.
Fluoranthene	µg/kg	15/17	415	50	1920	8200	2210	1690	.
Fluorene	µg/kg	5/17	578	72	320	1200	493	94.1	.
Indeno(1,2,3-c,d)pyrene	µg/kg	12/17	526	180	569	1800	434	402	.
Naphthalene	µg/kg	6/17	579	95	412	1800	682	146	.
Pentachlorophenol	µg/kg	1/17	2440	67	67	67	.	3.94	.
Phenanthrene	µg/kg	13/17	427	210	1330	7800	2030	1010	.
Pyrene	µg/kg	15/17	415	48	1410	6500	1720	1240	.
bis(2-Ethylhexyl)phthalate	µg/kg	5/17	579	67	98	160	37.6	28.8	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Acetone	µg/kg	0/6	107	.	.	.	.	0	.
Methylene chloride	µg/kg	0/6	33.5	.	.	.	.	0	.
SEGMENT 2									
Aluminum	mg/kg	6/6	.	10200	13700	18800	3930	13700	.
Antimony	mg/kg	83/95	3.14	0.32	0.732	1.4	0.254	0.64	.
Arsenic	mg/kg	98/98	.	1.4	8.76	50	7.23	8.76	.
Barium	mg/kg	6/6	.	65.5	146	254	69.5	146	.
Beryllium	mg/kg	6/6	.	0.65	0.903	1.1	0.202	0.903	.
Cadmium	mg/kg	6/6	.	1.5	4.83	8.1	2.73	4.83	.
Chromium	mg/kg	92/92	.	15	65.5	117	17	65.5	.
Cobalt	mg/kg	6/6	.	8.7	11.4	14.1	2.37	11.4	.
Copper	mg/kg	6/6	.	12.2	152	350	126	152	.
Lead	mg/kg	6/6	.	23.6	43	65.8	15.7	43	.
Manganese	mg/kg	6/6	.	721	815	882	55.3	815	.
Mercury	mg/kg	27/83	3.49	0.6	64.1	443	96	20.9	.
Nickel	mg/kg	6/6	.	9.9	39.3	59	21.2	39.3	.
Selenium	mg/kg	31/98	11.3	6.1	27.4	59	15.1	8.68	.
Silver	mg/kg	3/6	2.47	3.1	3.43	3.8	0.351	1.72	.
Thallium	mg/kg	0/6	0.777	.	.	.	.	0	.
Vanadium	mg/kg	6/6	.	18.3	22.7	30.6	5.09	22.7	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Zinc	mg/kg	40/98	97	39	1250	7640	2240	511	.
^{137}Cs	pCi/g	6/6	.	0.0792	0.761	1.58	0.566	0.761	0.0699
^{60}Co	pCi/g	6/6	.	-0.102	0.0183	0.0885	0.0704	0.0183	0.0404
^{237}Np	pCi/g	6/6	.	0.004	0.0152	0.06	0.0222	0.0152	0.0123
^{233}Pa	pCi/g	6/6	.	-0.0934	0.0165	0.15	0.0838	0.0165	0.0861
^{228}Th	pCi/g	3/3	.	1.142	1.52	2.11	0.519	1.52	0.0855
^{230}Th	pCi/g	3/3	.	3.402	4.56	6.51	1.7	4.56	0.147
^{232}Th	pCi/g	3/3	.	0.918	1.31	1.74	0.414	1.31	0.0785
^{234}U	pCi/g	80/87	1.31	1.0397984	3.32	11.4	2.85	3.05	0.0482
^{235}U	pCi/g	94/94	.	0.02568	0.135	0.535	0.126	0.135	0.00405
^{238}U	pCi/g	78/85	1.05	1.2654	3.68	11.3	2.5	3.38	0.0533
4,4'-DDD	µg/kg	0/6	4.12	.	.	.	.	0	.
4,4'-DDE	µg/kg	4/6	4.2	0.15	1.45	3.6	1.51	0.968	.
4,4'-DDT	µg/kg	0/6	4.12	.	.	.	.	0	.
Aldrin	µg/kg	5/6	1.8	0.081	0.196	0.33	0.0958	0.164	.
Aroclor-1254	µg/kg	0/6	41.2	.	.	.	.	0	.
Aroclor-1260	µg/kg	6/6	.	3	367	860	340	367	.
Dieldrin	µg/kg	0/6	4.12	.	.	.	.	0	.
Endosulfan I	µg/kg	0/6	2.12	.	.	.	.	0	.
Endosulfan II	µg/kg	0/6	4.12	.	.	.	.	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Endosulfan sulfate	µg/kg	0/6	4.12	.	.	.	.	0	.
Endrin	µg/kg	0/6	4.12	.	.	.	.	0	.
Endrin aldehyde	µg/kg	0/6	4.12	.	.	.	.	0	.
Endrin ketone	µg/kg	0/6	4.12	.	.	.	.	0	.
Heptachlor	µg/kg	1/6	2.14	0.082	0.082	0.082	.	0.0137	.
Heptachlor epoxide	µg/kg	0/6	2.12	.	.	.	.	0	.
alpha-Chlordane	µg/kg	4/6	2.15	0.11	2.76	6	2.94	1.84	.
delta-BHC	µg/kg	0/6	2.12	.	.	.	.	0	.
gamma-BHC (Lindane)	µg/kg	0/6	2.12	.	.	.	.	0	.
gamma-Chlordane	µg/kg	3/6	2.03	0.56	1.49	2.8	1.17	0.743	.
p,p'-Methoxychlor	µg/kg	0/6	21.2	.	.	.	.	0	.
2-Methylnaphthalene	µg/kg	5/6	340	82	127	260	75.5	105	.
4-Chloro-3-methylphenol	µg/kg	0/6	413	.	.	.	.	0	.
4-Nitrophenol	µg/kg	0/6	1010	.	.	.	.	0	.
Acenaphthene	µg/kg	2/6	405	47	56	65	12.7	18.7	.
Acenaphthylene	µg/kg	1/6	412	130	130	130	.	21.7	.
Anthracene	µg/kg	4/6	365	59	108	150	43.6	72.3	.
Benzo(a)anthracene	µg/kg	6/6	.	140	847	2200	795	847	.
Benzo(a)pyrene	µg/kg	6/6	.	140	632	1600	539	632	.
Benzo(b)fluoranthene	µg/kg	6/6	.	400	1230	2800	896	1230	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (< DL = 0)	Radiation counting uncertainty of mean
Benzo(g,h,i)perylene	µg/kg	6/6	.	110	490	1200	398	490	.
Benzo(k)fluoranthene	µg/kg	6/6	.	400	1230	2800	896	1230	.
Butylbenzylphthalate	µg/kg	0/6	413	.	.	.	.	0	.
Carbazole	µg/kg	4/6	365	55	107	150	49.7	71.7	.
Chrysene	µg/kg	6/6	.	190	618	1400	467	618	.
Di-n-butylphthalate	µg/kg	1/6	428	110	110	110	.	18.3	.
Di-n-octylphthalate	µg/kg	0/6	413	.	.	.	.	0	.
Dibenzo(a,h)anthracene	µg/kg	4/6	365	50	177	360	142	118	.
Dibenzofuran	µg/kg	2/6	398	53	58.5	64	7.78	19.5	.
Diethylphthalate	µg/kg	0/6	413	.	.	.	.	0	.
Fluoranthene	µg/kg	6/6	.	370	1300	2900	974	1300	.
Fluorene	µg/kg	2/6	405	66	67	68	1.41	22.3	.
Indeno(1,2,3-c,d)pyrene	µg/kg	6/6	.	120	528	1300	432	528	.
Naphthalene	µg/kg	5/6	340	54	89.2	180	51.8	74.3	.
Pentachlorophenol	µg/kg	0/6	1010	.	.	.	.	0	.
Phenanthrene	µg/kg	6/6	.	130	580	1200	438	580	.
Pyrene	µg/kg	6/6	.	250	1020	2500	889	1020	.
bis(2-Ethylhexyl)phthalate	µg/kg	3/6	433	53	70.7	98	24	35.3	.
SEGMENT 3									
Arsenic	mg/kg	64/65	2.5	2.4	8.97	24	3.65	8.83	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Aluminum	mg/kg	14/14	.	8190	15600	27100	5820	15600	.
Antimony	mg/kg	51/60	8.27	0.38	1.1	11	1.49	0.933	.
Barium	mg/kg	14/14	.	60.8	99.9	173	33.6	99.9	.
Beryllium	mg/kg	8/14	1.08	0.61	0.804	0.95	0.117	0.459	.
Cadmium	mg/kg	8/14	1.09	1.6	3.61	7.4	2.25	2.06	.
Chromium	mg/kg	66/66	.	16.4	68.5	217	31.6	68.5	.
Cobalt	mg/kg	14/14	.	6.6	13.7	20.3	3.9	13.7	.
Copper	mg/kg	14/14	.	8.3	43.6	124	36.5	43.6	.
Cyanide	mg/kg	0/6	0.648	.	.	.	.	0	.
Lead	mg/kg	13/13	.	26.5	69.1	177	41.4	69.1	.
Manganese	mg/kg	14/14	.	398	1020	1910	359	1020	.
Mercury	mg/kg	36/67	2.8	0.17	73.4	868	147	39.4	.
Nickel	mg/kg	14/14	.	8.9	28.7	62.8	17.3	28.7	.
Selenium	mg/kg	23/66	8.89	12	29.3	60	12.6	10.2	.
Silver	mg/kg	5/14	1.85	1.4	5.16	8.5	2.98	1.84	.
Thallium	mg/kg	0/14	0.768	.	.	.	.	0	.
Vanadium	mg/kg	14/14	.	16.3	27.6	42.8	7.58	27.6	.
Zinc	mg/kg	42/66	100	55.1	923	6830	1960	587	.
^{241}Am	pCi/g	23/23	.	-0.1899	0.0328	0.338	0.115	0.0328	0.083
^{137}Cs	pCi/g	33/33	.	0	0.676	3.17	0.81	0.676	0.0176

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
^{60}Co	pCi/g	34/34	.	-0.0541	0.00957	0.184	0.0367	0.00957	0.00954
^{237}Np	pCi/g	29/29	.	-0.0526	0.00785	0.143	0.0506	0.00785	0.0166
^{233}Pa	pCi/g	7/7	.	-0.0563	0.042	0.163	0.0839	0.042	0.0811
^{228}Th	pCi/g	3/3	.	1.622	2.1	2.36	0.417	2.1	0.116
^{230}Th	pCi/g	3/3	.	1.763	2.37	3.16	0.713	2.37	0.122
^{232}Th	pCi/g	3/3	.	1.246	1.5	1.9	0.353	1.5	0.102
^{234}U	pCi/g	72/79	1.96	0.38	3.48	12	3.37	3.17	0.0489
^{235}U	pCi/g	92/92	.	0.01	0.149	1.15	0.187	0.149	0.00407
^{238}U	pCi/g	71/78	1.57	0.23	3.4	15.7	3.21	3.09	0.0475
4,4'-DDD	µg/kg	3/12	13.3	0.16	0.58	0.9	0.38	0.145	.
4,4'-DDE	µg/kg	3/12	13.3	2	3.2	5.5	1.99	0.8	.
4,4'-DDT	µg/kg	1/12	11.7	7.3	7.3	7.3	.	0.608	.
Aldrin	µg/kg	1/12	5.75	0.11	0.11	0.11	.	0.00917	.
Aroclor-1254	µg/kg	5/32	165	190	406	670	171	63.4	.
Aroclor-1260	µg/kg	14/32	182	87	390	1700	417	171	.
Dieldrin	µg/kg	4/12	12.4	4.1	59.2	200	94.5	19.7	.
Endosulfan I	µg/kg	1/12	5.75	0.15	0.15	0.15	.	0.0125	.
Endosulfan II	µg/kg	1/12	11.7	0.39	0.39	0.39	.	0.0325	.
Endosulfan sulfate	µg/kg	0/12	11	.	.	.	.	0	.
Endrin	µg/kg	1/12	11.7	0.26	0.26	0.26	.	0.0217	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Endrin aldehyde	µg/kg	0/7	4.17	.	.	.	.	0	.
Endrin ketone	µg/kg	1/12	11.7	0.32	0.32	0.32	.	0.0267	.
Heptachlor	µg/kg	1/12	5.76	0.14	0.14	0.14	.	0.0117	.
Heptachlor epoxide	µg/kg	1/12	5.05	11	11	11	.	0.917	.
alpha-Chlordane	µg/kg	4/12	63.8	0.19	2.1	4.4	1.95	0.702	.
delta-BHC	µg/kg	1/12	5.75	0.085	0.085	0.085	.	0.00708	.
gamma-BHC (Lindane)	µg/kg	0/12	5.46	.	.	.	.	0	.
gamma-Chlordane	µg/kg	5/12	72.6	0.1	1.53	3.4	1.38	0.636	.
p,p'-Methoxychlor	µg/kg	1/12	57.6	0.98	0.98	0.98	.	0.0817	.
2-Methylnaphthalene	µg/kg	3/9	580	59	177	410	202	59.1	.
4-Chloro-3-methylphenol	µg/kg	0/9	526	.	.	.	.	0	.
4-Nitrophenol	µg/kg	0/9	1750	.	.	.	.	0	.
Acenaphthene	µg/kg	1/9	540	900	900	900	.	100	.
Acenaphthylene	µg/kg	1/9	539	57	57	57	.	6.33	.
Anthracene	µg/kg	4/9	608	48	330	1000	452	147	.
Benzo(a)anthracene	µg/kg	7/9	910	55	778	2900	1040	605	.
Benzo(a)pyrene	µg/kg	6/9	740	87	831	2600	1010	554	.
Benzo(b)fluoranthene	µg/kg	7/9	910	91	1340	5200	1880	1050	.
Benzo(g,h,i)perylene	µg/kg	5/9	655	170	642	1500	587	357	.
Benzo(k)fluoranthene	µg/kg	6/9	740	93	1470	5200	2020	979	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Benzoic acid	µg/kg	0/2	4350	.	.	.	.	0	.
Butylbenzylphthalate	µg/kg	4/9	612	55	118	200	60.9	52.4	.
Carbazole	µg/kg	2/7	412	51	101	150	70	28.7	.
Chrysene	µg/kg	7/9	910	54	875	3500	1260	681	.
Di-n-butylphthalate	µg/kg	1/9	546	73	73	73	.	8.11	.
Di-n-octylphthalate	µg/kg	0/9	526	.	.	.	.	0	.
Dibenzo(a,h)anthracene	µg/kg	4/9	608	53	197	370	167	87.4	.
Dibenzofuran	µg/kg	1/9	540	470	470	470	.	52.2	.
Diethylphthalate	µg/kg	1/9	416	12000	12000	12000	.	1330	.
Fluoranthene	µg/kg	7/9	910	130	1750	7300	2590	1360	.
Fluorene	µg/kg	2/9	557	57	418	780	511	93	.
Indeno(1,2,3-c,d)pyrene	µg/kg	6/9	740	47	569	1500	589	380	.
Naphthalene	µg/kg	2/9	557	46	293	540	349	65.1	.
Pentachlorophenol	µg/kg	0/9	1750	.	.	.	.	0	.
Phenanthrene	µg/kg	7/9	910	62	1090	5100	1830	848	.
Pyrene	µg/kg	7/9	910	95	1360	5100	1880	1060	.
bis(2-Ethylhexyl)phthalate	µg/kg	5/9	665	60	150	350	126	83.6	.
SEGMENT 4									
Aluminum	mg/kg	9/9	.	14400	19400	27900	4460	19400	.
Antimony	mg/kg	88/100	6.13	0.19	0.892	2	0.313	0.785	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Arsenic	mg/kg	100/100	.	2.9	10.1	40.5	4.25	10.1	.
Barium	mg/kg	9/9	.	99	228	454	108	228	.
Beryllium	mg/kg	4/9	1.15	0.81	1.7	2.2	0.617	0.757	.
Cadmium	mg/kg	8/9	1.3	1.8	14.7	41.3	12.3	13.1	.
Chromium	mg/kg	104/104	.	9.8	82.4	180	33.5	82.4	.
Cobalt	mg/kg	9/9	.	13.1	15.5	18.4	1.71	15.5	.
Copper	mg/kg	9/9	.	28.2	184	397	126	184	.
Cyanide	mg/kg	6/9	0.647	0.79	4.75	17.1	6.41	3.17	.
Lead	mg/kg	7/7	.	34.1	103	155	43.6	103	.
Manganese	mg/kg	9/9	.	701	1140	1740	290	1140	.
Mercury	mg/kg	69/109	3.69	5.5	243	1290	272	154	.
Nickel	mg/kg	9/9	.	24.1	87.6	174	47	87.6	.
Selenium	mg/kg	13/103	13.6	4.6	11.6	17	3.54	1.47	.
Silver	mg/kg	7/9	1.75	9.9	15.7	29.7	7.01	12.2	.
Thallium	mg/kg	0/8	0.54	.	.	.	.	0	.
Vanadium	mg/kg	9/9	.	27.9	33.7	44.9	5.68	33.7	.
Zinc	mg/kg	34/104	117	46	194	392	81.7	63.3	.
^{241}Am	pCi/g	7/8	0.436	-0.2571	0.0382	0.462	0.237	0.0334	0.315
^{137}Cs	pCi/g	8/8	.	0.5844	2.04	3.86	1.05	2.04	0.0497
^{60}Co	pCi/g	7/7	.	-0.0127	0.0271	0.0769	0.0364	0.0271	0.0199

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
^{237}Np	pCi/g	7/7	.	-0.0759	0.0369	0.108	0.0658	0.0369	0.0534
^{234}U	pCi/g	84/94	1.76	0.26	8.65	28.6	7.92	7.73	0.112
^{235}U	pCi/g	95/95	.	0.02	0.367	1.35	0.376	0.367	0.00617
^{238}U	pCi/g	84/94	1.41	0.15	8.4	27.6	7.1	7.51	0.102
4,4'-DDD	µg/kg	0/9	34.1	.	.	.	.	0	.
4,4'-DDE	µg/kg	0/8	25.9	.	.	.	.	0	.
4,4'-DDT	µg/kg	0/9	34.1	.	.	.	.	0	.
Aldrin	µg/kg	0/9	17.3	.	.	.	.	0	.
Aroclor-1254	µg/kg	3/9	398	1900	2370	3000	569	789	.
Aroclor-1260	µg/kg	7/9	210	800	1900	3800	993	1480	.
Dieldrin	µg/kg	0/9	34.1	.	.	.	.	0	.
Endosulfan I	µg/kg	0/9	17.3	.	.	.	.	0	.
Endosulfan II	µg/kg	0/9	34.1	.	.	.	.	0	.
Endosulfan sulfate	µg/kg	0/9	34.1	.	.	.	.	0	.
Endrin	µg/kg	0/9	34.1	.	.	.	.	0	.
Endrin ketone	µg/kg	0/9	34.1	.	.	.	.	0	.
Heptachlor	µg/kg	0/9	17.3	.	.	.	.	0	.
Heptachlor epoxide	µg/kg	0/9	17.3	.	.	.	.	0	.
alpha-Chlordane	µg/kg	0/9	173	.	.	.	.	0	.
delta-BHC	µg/kg	0/9	17.3	.	.	.	.	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
gamma-BHC (Lindane)	µg/kg	0/9	17.3	.	.	.	.	0	.
gamma-Chlordane	µg/kg	0/9	173	.	.	.	.	0	.
p,p'-Methoxychlor	µg/kg	0/9	173	.	.	.	.	0	.
2-Methylnaphthalene	µg/kg	5/9	735	43	71	120	30.2	39.4	.
4-Chloro-3-methylphenol	µg/kg	1/9	591	52	52	52	.	5.78	.
4-Nitrophenol	µg/kg	1/9	2870	390	390	390	.	43.3	.
Acenaphthene	µg/kg	1/9	591	60	60	60	.	6.67	.
Acenaphthylene	µg/kg	2/9	613	52	52.5	53	0.707	11.7	.
Anthracene	µg/kg	7/9	695	53	99.3	170	43.9	77.2	.
Benzo(a)anthracene	µg/kg	9/9	.	300	544	910	224	544	.
Benzo(a)pyrene	µg/kg	9/9	.	340	568	940	217	568	.
Benzo(b)fluoranthene	µg/kg	9/9	.	490	970	1700	430	970	.
Benzo(g,h,i)perylene	µg/kg	3/9	523	170	377	640	240	126	.
Benzo(k)fluoranthene	µg/kg	9/9	.	170	908	1700	507	908	.
Benzoic acid	µg/kg	0/9	2300	.	.	.	.	0	.
Butylbenzylphthalate	µg/kg	1/9	585	49	49	49	.	5.44	.
Chrysene	µg/kg	9/9	.	360	652	1200	297	652	.
Di-n-butylphthalate	µg/kg	2/9	600	51	70.5	90	27.6	15.7	.
Di-n-octylphthalate	µg/kg	0/9	571	.	.	.	.	0	.
Dibenzo(a,h)anthracene	µg/kg	0/9	571	.	.	.	.	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (< DL = 0)	Radiation counting uncertainty of mean
Dibenzofuran	µg/kg	0/9	571	.	.	.	.	0	.
Diethylphthalate	µg/kg	0/9	571	.	.	.	.	0	.
Fluoranthene	µg/kg	9/9	.	620	1230	2300	602	1230	.
Fluorene	µg/kg	1/9	591	73	73	73	.	8.11	.
Indeno(1,2,3-c,d)pyrene	µg/kg	5/9	580	49	268	640	226	149	.
Naphthalene	µg/kg	3/9	632	52	63	84	18.2	21	.
Pentachlorophenol	µg/kg	1/9	2870	300	300	300	.	33.3	.
Phenanthrene	µg/kg	9/9	.	220	510	860	243	510	.
Pyrene	µg/kg	9/9	.	490	1010	2200	588	1010	.
bis(2-Ethylhexyl)phthalate	µg/kg	6/9	820	79	130	250	67	86.9	.
Acetone	µg/kg	1/3	34.5	2200	2200	2200	.	733	.
Methylene chloride	µg/kg	0/3	47.7	.	.	.	.	0	.
SEGMENT 5									
Aluminum	mg/kg	6/6	.	13000	14500	16200	1320	14500	.
Antimony	mg/kg	61/69	3.24	0.27	0.768	1.3	0.243	0.679	.
Arsenic	mg/kg	72/72	.	3.4	8.7	33	3.63	8.7	.
Barium	mg/kg	6/6	.	74.7	104	130	18.4	104	.
Beryllium	mg/kg	0/6	0.693	.	.	.	.	0	.
Cadmium	mg/kg	5/6	0.8	2.1	5.04	8.4	3.07	4.2	.
Chromium	mg/kg	72/72	.	17.7	71.1	128	20.8	71.1	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Cobalt	mg/kg	5/6	8.6	12.9	14.9	16.1	1.2	12.4	.
Copper	mg/kg	6/6	.	17.2	87.9	220	72.3	87.9	.
Cyanide	mg/kg	1/6	0.628	62.6	62.6	62.6	.	10.4	.
Lead	mg/kg	6/6	.	26.2	58.8	72.2	17.9	58.8	.
Manganese	mg/kg	6/6	.	602	1050	1300	236	1050	.
Mercury	mg/kg	35/72	3.81	6.7	87.5	352	82.9	42.5	.
Nickel	mg/kg	6/6	.	13.4	36	62.1	17.7	36	.
Selenium	mg/kg	20/72	13.2	10	17.6	25	4.93	4.89	.
Silver	mg/kg	4/6	1.7	2.6	5.37	9.1	2.77	3.58	.
Thallium	mg/kg	0/6	0.503	.	.	.	.	0	.
Vanadium	mg/kg	6/6	.	21.1	27.7	31.2	3.97	27.7	.
Zinc	mg/kg	16/72	108	48.5	180	389	96.2	39.9	.
^{241}Am	pCi/g	6/6	.	-0.1282	0.059	0.405	0.185	0.059	0.137
^{137}Cs	pCi/g	6/6	.	0.2892	0.912	1.52	0.426	0.912	0.029
^{60}Co	pCi/g	6/6	.	-0.0361	0.000433	0.0253	0.0221	0.000433	0.013
^{237}Np	pCi/g	6/6	.	-0.0886	0.0272	0.0769	0.0627	0.0272	0.0308
^{234}U	pCi/g	64/70	1.66	1.0133896	4.79	19.7	4.25	4.38	0.076
^{235}U	pCi/g	70/70	.	0.04066	0.203	0.963	0.195	0.203	0.0061
^{238}U	pCi/g	65/71	1.33	1.2321	4.97	16.3	3.64	4.55	0.0736
4,4'-DDD	µg/kg	0/4	20.3	.	.	.	. .	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
4,4'-DDE	µg/kg	0/4	20.3	.	.	.	.	0	.
4,4'-DDT	µg/kg	0/4	20.3	.	.	.	.	0	.
Aldrin	µg/kg	0/4	9.87	.	.	.	.	0	.
Aroclor-1254	µg/kg	0/4	203	.	.	.	.	0	.
Aroclor-1260	µg/kg	2/4	200	310	340	370	42.4	170	.
Dieldrin	µg/kg	0/4	20.3	.	.	.	.	0	.
Endosulfan I	µg/kg	0/4	9.87	.	.	.	.	0	.
Endosulfan II	µg/kg	0/4	20.3	.	.	.	.	0	.
Endosulfan sulfate	µg/kg	0/4	20.3	.	.	.	.	0	.
Endrin	µg/kg	0/4	20.3	.	.	.	.	0	.
Endrin ketone	µg/kg	0/4	20.3	.	.	.	.	0	.
Heptachlor	µg/kg	0/4	9.87	.	.	.	.	0	.
Heptachlor epoxide	µg/kg	0/4	9.87	.	.	.	.	0	.
alpha-Chlordane	µg/kg	0/4	98.7	.	.	.	.	0	.
delta-BHC	µg/kg	0/4	9.87	.	.	.	.	0	.
gamma-BHC (Lindane)	µg/kg	0/4	9.87	.	.	.	.	0	.
gamma-Chlordane	µg/kg	0/4	98.7	.	.	.	.	0	.
p,p'-Methoxychlor	µg/kg	0/4	98.7	.	.	.	.	0	.
2-Methylnaphthalene	µg/kg	2/4	410	45	50	55	7.07	25	.
4-Chloro-3-methylphenol	µg/kg	0/4	417	.	.	.	.	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
4-Nitrophenol	µg/kg	0/4	2050	.	.	.	.	0	.
Acenaphthene	µg/kg	0/4	417	.	.	.	.	0	.
Acenaphthylene	µg/kg	1/4	417	90	90	90	.	22.5	.
Anthracene	µg/kg	2/4	410	110	155	200	63.6	77.5	.
Benzo(a)anthracene	µg/kg	4/4	.	120	458	820	364	458	.
Benzo(a)pyrene	µg/kg	4/4	.	140	497	940	395	497	.
Benzo(b)fluoranthene	µg/kg	4/4	.	290	980	1800	784	980	.
Benzo(g,h,i)perylene	µg/kg	4/4	.	100	410	730	331	410	.
Benzo(k)fluoranthene	µg/kg	4/4	.	290	980	1800	784	980	.
Benzoic acid	µg/kg	2/4	2100	45	72.5	100	38.9	36.2	.
Butylbenzylphthalate	µg/kg	0/4	417	.	.	.	.	0	.
Chrysene	µg/kg	4/4	.	160	592	1100	493	592	.
Di-n-butylphthalate	µg/kg	1/4	176	71	71	71	.	17.7	.
Di-n-octylphthalate	µg/kg	0/4	417	.	.	.	.	0	.
Dibenzo(a,h)anthracene	µg/kg	2/4	410	180	180	180	0	90	.
Dibenzofuran	µg/kg	0/4	417	.	.	.	.	0	.
Diethylphthalate	µg/kg	0/4	417	.	.	.	.	0	.
Fluoranthene	µg/kg	4/4	.	260	1070	2100	926	1070	.
Fluorene	µg/kg	1/4	417	53	53	53	.	13.3	.
Indeno(1,2,3-c,d)pyrene	µg/kg	4/4	.	83	358	640	292	358	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Naphthalene	µg/kg	0/4	417	.	.	.	.	0	.
Pentachlorophenol	µg/kg	0/4	2050	.	.	.	.	0	.
Phenanthrene	µg/kg	4/4	.	110	420	800	353	420	.
Pyrene	µg/kg	4/4	.	230	825	1500	669	825	.
bis(2-Ethylhexyl)phthalate	µg/kg	2/4	410	120	135	150	21.2	67.5	.
SEGMENT 6									
Aluminum	mg/kg	7/7	.	4550	12700	18200	4680	12700	.
Antimony	mg/kg	54/61	7.35	0.32	0.625	1.2	0.185	0.553	.
Arsenic	mg/kg	62/62	.	1.7	6.88	13	2.41	6.88	.
Barium	mg/kg	7/7	.	33.7	62.9	94.5	23.7	62.9	.
Beryllium	mg/kg	4/7	0.587	0.36	0.63	0.81	0.191	0.36	.
Cadmium	mg/kg	2/7	1.2	3.3	3.95	4.6	0.919	1.13	.
Chromium	mg/kg	63/63	.	11.4	64.3	112	21.5	64.3	.
Cobalt	mg/kg	5/7	5.1	5	14	27.1	8.16	10	.
Copper	mg/kg	6/7	6.7	7.4	28.6	78	27.1	24.5	.
Cyanide	mg/kg	2/3	0.6	1.1	1.3	1.5	0.283	0.867	.
Lead	mg/kg	7/7	.	11.3	23.8	41.2	11.6	23.8	.
Manganese	mg/kg	7/7	.	62.1	733	1990	672	733	.
Mercury	mg/kg	28/63	2.54	0.21	41.7	207	47.7	18.6	.
Nickel	mg/kg	6/7	8.4	7.4	18.3	38.1	12.2	15.7	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Selenium	mg/kg	32/63	9.99	4.9	38.9	58	14.1	19.8	.
Silver	mg/kg	1/7	2.05	2.9	2.9	2.9	.	0.414	.
Thallium	mg/kg	0/7	0.617	.	.	.	.	0	.
Vanadium	mg/kg	7/7	.	9.6	23.2	31	7.05	23.2	.
Zinc	mg/kg	36/63	104	15	101	393	91.9	57.9	.
^{241}Am	pCi/g	1/1	.	0	0	0	.	0	0.699
^{137}Cs	pCi/g	5/5	.	0.0122	0.507	1.08	0.511	0.507	0.0616
^{60}Co	pCi/g	5/5	.	-0.0353	0.0147	0.0566	0.036	0.0147	0.0322
^{237}Np	pCi/g	1/1	.	0	0	0	.	0	0.0723
^{233}Pa	pCi/g	4/4	.	-0.0795	-0.00893	0.0163	0.0471	-0.00893	0.0999
^{228}Th	pCi/g	2/2	.	1.19	2.23	3.26	1.47	2.23	0.155
^{230}Th	pCi/g	1/1	.	7.913	7.91	7.91	.	7.91	0.403
^{232}Th	pCi/g	2/2	.	0.623	1.8	2.98	1.67	1.8	0.148
^{234}U	pCi/g	55/60	1.55	0.46	3.96	18.5	3.58	3.63	0.0768
^{235}U	pCi/g	59/59	.	0.02	0.173	0.877	0.174	0.173	0.00634
^{238}U	pCi/g	54/59	1.24	0.36	4.17	17.6	3.1	3.82	0.0719
4,4'-DDD	µg/kg	1/7	11.8	0.34	0.34	0.34	.	0.0486	.
4,4'-DDE	µg/kg	0/7	10.7	.	.	.	.	0	.
4,4'-DDT	µg/kg	0/7	10.7	.	.	.	.	0	.
Aldrin	µg/kg	0/7	5.37	.	.	.	.	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (< DL = 0)	Radiation counting uncertainty of mean
Aroclor-1254	µg/kg	1/7	118	57	57	57	.	8.14	.
Aroclor-1260	µg/kg	4/7	197	5.2	77	150	73.5	44	.
Dieldrin	µg/kg	0/7	10.7	.	.	.	.	0	.
Endosulfan I	µg/kg	1/7	5.9	0.1	0.1	0.1	.	0.0143	.
Endosulfan II	µg/kg	0/7	10.7	.	.	.	.	0	.
Endosulfan sulfate	µg/kg	0/7	10.7	.	.	.	.	0	.
Endrin	µg/kg	0/7	10.7	.	.	.	.	0	.
Endrin aldehyde	µg/kg	0/4	4.03	.	.	.	.	0	.
Endrin ketone	µg/kg	0/7	10.7	.	.	.	.	0	.
Heptachlor	µg/kg	0/7	5.37	.	.	.	.	0	.
Heptachlor epoxide	µg/kg	0/7	5.37	.	.	.	.	0	.
alpha-Chlordane	µg/kg	1/7	49.8	1.3	1.3	1.3	.	0.186	.
delta-BHC	µg/kg	1/7	5.9	0.12	0.12	0.12	.	0.0171	.
gamma-BHC (Lindane)	µg/kg	0/7	5.37	.	.	.	.	0	.
gamma-Chlordane	µg/kg	1/7	49.8	0.83	0.83	0.83	.	0.119	.
p,p'-Methoxychlor	µg/kg	0/7	53.7	.	.	.	.	0	.
2-Methylnaphthalene	µg/kg	0/7	404	.	.	.	.	0	.
4-Chloro-3-methylphenol	µg/kg	0/7	404	.	.	.	.	0	.
4-Nitrophenol	µg/kg	0/7	1400	.	.	.	.	0	.
Acenaphthene	µg/kg	0/7	404	.	.	.	.	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Acenaphthylene	µg/kg	0/7	404	.	.	.	.	0	.
Anthracene	µg/kg	0/7	404	.	.	.	.	0	.
Benzo(a)anthracene	µg/kg	3/7	400	46	209	300	141	89.4	.
Benzo(a)pyrene	µg/kg	3/7	400	50	160	240	98.5	68.6	.
Benzo(b)fluoranthene	µg/kg	3/7	400	76	309	430	202	132	.
Benzo(g,h,i)perylene	µg/kg	2/7	400	270	290	310	28.3	82.9	.
Benzo(k)fluoranthene	µg/kg	3/7	400	49	126	250	108	54	.
Benzoic acid	µg/kg	0/3	1970	.	.	.	.	0	.
Butylbenzylphthalate	µg/kg	0/7	404	.	.	.	.	0	.
Carbazole	µg/kg	0/4	405	.	.	.	.	0	.
Chrysene	µg/kg	3/7	400	58	209	290	131	89.7	.
Di-n-butylphthalate	µg/kg	0/7	427	.	.	.	.	0	.
Di-n-octylphthalate	µg/kg	0/7	404	.	.	.	.	0	.
Dibenzo(a,h)anthracene	µg/kg	2/7	400	57	66	75	12.7	18.9	.
Dibenzofuran	µg/kg	0/7	404	.	.	.	.	0	.
Diethylphthalate	µg/kg	0/7	404	.	.	.	.	0	.
Fluoranthene	µg/kg	3/7	400	110	460	690	308	197	.
Fluorene	µg/kg	0/7	404	.	.	.	.	0	.
Indeno(1,2,3-c,d)pyrene	µg/kg	2/7	400	270	285	300	21.2	81.4	.
Naphthalene	µg/kg	0/7	404	.	.	.	.	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Pentachlorophenol	µg/kg	0/7	1400	.	.	.	.	0	.
Phenanthrene	µg/kg	2/7	400	230	250	270	28.3	71.4	.
Pyrene	µg/kg	3/7	400	93	324	510	212	139	.
bis(2-Ethylhexyl)phthalate	µg/kg	1/7	403	75	75	75	.	10.7	.
Acetone	µg/kg	0/3	43.3	.	.	.	.	0	.
Methylene chloride	µg/kg	0/3	34.7	.	.	.	.	0	.
SEGMENT 7									
Antimony	mg/kg	263/283	0.402	0.3	0.772	3.6	0.419	0.717	.
Arsenic	mg/kg	289/291	3.1	1.7	7.82	21	2.48	7.76	.
Aluminum	mg/kg	8/8	.	7490	10100	13300	2120	10100	.
Barium	mg/kg	8/8	.	44.2	106	208	52	106	.
Beryllium	mg/kg	8/8	.	0.51	0.747	1.1	0.166	0.747	.
Cadmium	mg/kg	4/8	1.2	2.1	5.6	9.3	3.4	2.8	.
Chromium	mg/kg	330/330	.	12.4	67	175	22.2	67	.
Cobalt	mg/kg	8/8	.	7.1	13.6	37.1	9.78	13.6	.
Copper	mg/kg	8/8	.	6	68.6	199	71.3	68.6	.
Lead	mg/kg	8/8	.	21.3	35	55.8	13	35	.
Manganese	mg/kg	8/8	.	537	1250	3390	888	1250	.
Mercury	mg/kg	84/326	3	0.39	44.9	278	53.5	11.6	.
Nickel	mg/kg	7/8	7.1	9.3	28.3	59.8	20.6	24.7	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Selenium	mg/kg	166/331	11.7	3.6	20.9	68	16.5	10.5	.
Silver	mg/kg	2/8	2.42	3.7	4.05	4.4	0.495	1.01	.
Thallium	mg/kg	0/8	0.73	.	.	.	.	0	.
Vanadium	mg/kg	8/8	.	15.8	18.9	23	2.4	18.9	.
Zinc	mg/kg	125/330	77.1	24.3	490	7640	1380	186	.
^{137}Cs	pCi/g	8/8	.	0.0793	0.619	2.08	0.7	0.619	0.0558
^{60}Co	pCi/g	8/8	.	-0.0114	0.017	0.0551	0.0217	0.017	0.0345
^{237}Np	pCi/g	3/3	.	0.012	0.0483	0.11	0.0537	0.0483	0.0154
^{233}Pa	pCi/g	8/8	.	-0.1105	-0.0149	0.127	0.073	-0.0149	0.0758
^{228}Th	pCi/g	2/2	.	1.076	1.54	2	0.656	1.54	0.0997
^{230}Th	pCi/g	2/2	.	1.774	7.38	13	7.92	7.38	0.209
^{232}Th	pCi/g	2/2	.	0.354	1.01	1.67	0.928	1.01	0.081
^{234}U	pCi/g	279/308	1.52	0.8237671	3.44	19.7	3.73	3.12	0.0335
^{235}U	pCi/g	335/335	.	0.02568	0.15	0.963	0.177	0.15	0.00214
^{238}U	pCi/g	290/319	1.21	1.1322	3.56	24.3	3.18	3.23	0.0297
4,4'-DDD	µg/kg	0/8	4.09	.	.	.	.	0	.
4,4'-DDE	µg/kg	6/8	4	0.16	0.672	1.9	0.745	0.504	.
4,4'-DDT	µg/kg	2/8	4.1	0.31	1	1.7	0.983	0.251	.
Aldrin	µg/kg	1/8	2.1	0.082	0.082	0.082	.	0.0103	.
Aroclor-1254	µg/kg	0/8	40.9	.	.	.	.	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Aroclor-1260	µg/kg	5/8	39.7	17	120	270	116	74.9	.
Dieldrin	µg/kg	2/8	4.05	0.2	0.445	0.69	0.347	0.111	.
Endosulfan I	µg/kg	0/8	2.1	.	.	.	.	0	.
Endosulfan II	µg/kg	1/8	4.1	0.38	0.38	0.38	.	0.0475	.
Endosulfan sulfate	µg/kg	1/8	4.06	0.7	0.7	0.7	.	0.0875	.
Endrin	µg/kg	2/8	4.15	0.13	0.325	0.52	0.276	0.0812	.
Endrin aldehyde	µg/kg	2/8	4.1	0.27	1.64	3	1.93	0.409	.
Endrin ketone	µg/kg	0/8	4.09	.	.	.	.	0	.
Heptachlor	µg/kg	4/8	2.12	0.1	0.172	0.26	0.0797	0.0862	.
Heptachlor epoxide	µg/kg	1/8	2.09	0.24	0.24	0.24	.	0.03	.
alpha-Chlordane	µg/kg	7/8	2.1	0.11	0.804	2.8	1.04	0.704	.
delta-BHC	µg/kg	0/8	2.1	.	.	.	.	0	.
gamma-BHC (Lindane)	µg/kg	1/8	2.09	0.43	0.43	0.43	.	0.0537	.
gamma-Chlordane	µg/kg	6/8	2.05	0.087	0.23	0.35	0.0861	0.172	.
p,p'-Methoxychlor	µg/kg	4/8	21.2	0.3	1.45	2.8	1.03	0.725	.
2-Methylnaphthalene	µg/kg	0/8	410	.	.	.	.	0	.
4-Chloro-3-methylphenol	µg/kg	0/8	410	.	.	.	.	0	.
4-Nitrophenol	µg/kg	0/8	979	.	.	.	.	0	.
Acenaphthene	µg/kg	0/8	410	.	.	.	.	0	.
Acenaphthylene	µg/kg	0/8	410	.	.	.	.	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (< DL = 0)	Radiation counting uncertainty of mean
Anthracene	µg/kg	2/8	407	51	68	85	24	17	.
Benzo(a)anthracene	µg/kg	4/8	395	270	330	380	53.5	165	.
Benzo(a)pyrene	µg/kg	4/8	395	240	305	370	64.5	152	.
Benzo(b)fluoranthene	µg/kg	6/8	400	41	475	750	336	356	.
Benzo(g,h,i)perylene	µg/kg	4/8	395	170	263	400	106	131	.
Benzo(k)fluoranthene	µg/kg	4/8	395	630	690	750	51.6	345	.
Butylbenzylphthalate	µg/kg	0/8	410	.	.	.	.	0	.
Carbazole	µg/kg	2/8	407	50	53.5	57	4.95	13.4	.
Chrysene	µg/kg	4/8	395	270	313	380	49.9	156	.
Di-n-butylphthalate	µg/kg	3/8	406	61	344	510	246	129	.
Di-n-octylphthalate	µg/kg	2/8	410	52	64	76	17	16	.
Dibenzo(a,h)anthracene	µg/kg	3/8	398	53	66.3	86	17.4	24.9	.
Dibenzofuran	µg/kg	0/8	410	.	.	.	.	0	.
Diethylphthalate	µg/kg	0/8	410	.	.	.	.	0	.
Fluoranthene	µg/kg	5/8	397	62	576	830	300	360	.
Fluorene	µg/kg	0/8	410	.	.	.	.	0	.
Indeno(1,2,3-c,d)pyrene	µg/kg	4/8	395	190	263	370	78.9	131	.
Naphthalene	µg/kg	0/8	410	.	.	.	.	0	.
Pentachlorophenol	µg/kg	0/8	979	.	.	.	.	0	.
Phenanthrene	µg/kg	4/8	395	220	297	420	93.2	149	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (< DL = 0)	Radiation counting uncertainty of mean
Pyrene	µg/kg	5/8	397	45	401	640	224	251	.
bis(2-Ethylhexyl)phthalate	µg/kg	5/8	397	77	183	370	121	115	.
SEGMENT 8									
Antimony	mg/kg	69/77	0.448	0.32	0.702	1.3	0.213	0.629	.
Aluminum	mg/kg	8/8	.	9470	13000	18600	3140	13000	.
Arsenic	mg/kg	85/85	.	2	7.24	13	2.33	7.24	.
Barium	mg/kg	8/8	.	74.5	116	186	37.1	116	.
Beryllium	mg/kg	8/8	.	0.67	0.806	1	0.143	0.806	.
Cadmium	mg/kg	6/8	1.3	1.5	4.17	9.3	3.04	3.13	.
Chromium	mg/kg	85/85	.	17.1	70.6	161	27.6	70.6	.
Cobalt	mg/kg	8/8	.	9.1	11.8	20	3.65	11.8	.
Copper	mg/kg	8/8	.	10.3	115	382	126	115	.
Lead	mg/kg	8/8	.	14.1	52.4	131	38	52.4	.
Manganese	mg/kg	8/8	.	503	857	1430	326	857	.
Mercury	mg/kg	37/85	3.46	4.2	79.7	417	97	34.7	.
Nickel	mg/kg	8/8	.	11.8	33.5	72.3	22.2	33.5	.
Selenium	mg/kg	11/85	11.9	6.5	10.4	17	3.2	1.35	.
Silver	mg/kg	4/8	2.55	4.9	7.35	12.3	3.43	3.67	.
Thallium	mg/kg	0/8	0.755	.	.	.	.	0	.
Vanadium	mg/kg	8/8	.	17.1	22.6	34.8	6	22.6	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (< DL = 0)	Radiation counting uncertainty of mean
Zinc	mg/kg	16/85	117	41.2	408	4160	1010	76.8	.
^{137}Cs	pCi/g	8/8	.	0.0519	1.24	3.13	1.22	1.24	0.116
^{60}Co	pCi/g	8/8	.	0.0067	0.0467	0.082	0.0225	0.0467	0.0243
^{237}Np	pCi/g	4/4	.	0.002	0.123	0.406	0.191	0.123	0.0232
^{233}Pa	pCi/g	8/8	.	-0.111	0.0648	0.319	0.139	0.0648	0.0718
^{229}Th	pCi/g	3/3	.	1.136	1.74	2.3	0.584	1.74	0.0818
^{232}Th	pCi/g	3/3	.	0.615	1.09	1.61	0.499	1.09	0.0614
^{234}U	pCi/g	65/73	1.32	0.9833602	5.85	25.4	6.34	5.21	0.0885
^{235}U	pCi/g	81/81	.	0.0428	0.238	1.24	0.291	0.238	0.00565
^{238}U	pCi/g	65/73	1.06	1.0989	5.47	21	4.93	4.87	0.0785
4,4'-DDD	µg/kg	0/8	4.25	.	.	.	.	0	.
4,4'-DDE	µg/kg	8/8	.	0.2	0.676	1.5	0.506	0.676	.
4,4'-DDT	µg/kg	1/8	4.2	0.56	0.56	0.56	.	0.07	.
Aldrin	µg/kg	2/8	2.23	0.088	0.179	0.27	0.129	0.0448	.
Aroclor-1254	µg/kg	0/8	42.5	.	.	.	.	0	.
Aroclor-1260	µg/kg	8/8	.	6.1	126	360	136	126	.
Dieldrin	µg/kg	1/8	4.2	0.44	0.44	0.44	.	0.055	.
Endosulfan I	µg/kg	0/8	2.2	.	.	.	.	0	.
Endosulfan II	µg/kg	0/8	4.25	.	.	.	.	0	.
Endosulfan sulfate	µg/kg	0/8	4.25	.	.	.	.	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Endrin	µg/kg	2/8	4.23	0.24	0.46	0.68	0.311	0.115	.
Endrin aldehyde	µg/kg	0/8	4.25	.	.	.	.	0	.
Endrin ketone	µg/kg	0/8	4.25	.	.	.	.	0	.
Heptachlor	µg/kg	3/8	2.28	0.075	0.108	0.14	0.0325	0.0406	.
Heptachlor epoxide	µg/kg	3/8	2.18	0.15	0.327	0.48	0.166	0.123	.
alpha-Chlordane	µg/kg	6/8	2.2	0.17	2.35	4.8	2.01	1.76	.
delta-BHC	µg/kg	0/8	2.2	.	.	.	.	0	.
gamma-BHC (Lindane)	µg/kg	1/8	2.2	3.8	3.8	3.8	.	0.475	.
gamma-Chlordane	µg/kg	6/8	2.2	0.077	3.17	8.3	3.17	2.37	.
p,p'-Methoxychlor	µg/kg	0/8	22	.	.	.	.	0	.
2-Methylnaphthalene	µg/kg	1/8	430	53	53	53	.	6.62	.
4-Chloro-3-methylphenol	µg/kg	0/8	426	.	.	.	.	0	.
4-Nitrophenol	µg/kg	0/8	1030	.	.	.	.	0	.
Acenaphthene	µg/kg	0/8	426	.	.	.	.	0	.
Acenaphthylene	µg/kg	0/8	426	.	.	.	.	0	.
Anthracene	µg/kg	0/8	426	.	.	.	.	0	.
Benzo(a)anthracene	µg/kg	5/8	437	44	99.6	140	35.9	62.2	.
Benzo(a)pyrene	µg/kg	4/8	427	92	114	150	27.4	56.9	.
Benzo(b)fluoranthene	µg/kg	7/8	400	76	163	310	83.9	143	.
Benzo(g,h,i)perylene	µg/kg	1/8	426	100	100	100	.	12.5	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Benzo(k)fluoranthene	µg/kg	7/8	400	76	176	310	84.9	154	.
Butylbenzylphthalate	µg/kg	0/8	426	.	.	.	.	0	.
Carbazole	µg/kg	0/8	426	.	.	.	.	0	.
Chrysene	µg/kg	5/8	437	54	113	150	41	70.7	.
Di-n-butylphthalate	µg/kg	1/8	430	50	50	50	.	6.25	.
Di-n-octylphthalate	µg/kg	0/8	426	.	.	.	.	0	.
Dibenzo(a,h)anthracene	µg/kg	0/8	426	.	.	.	.	0	.
Dibenzofuran	µg/kg	0/8	426	.	.	.	.	0	.
Diethylphthalate	µg/kg	0/8	426	.	.	.	.	0	.
Fluoranthene	µg/kg	7/8	400	64	176	310	95.6	154	.
Fluorene	µg/kg	0/8	426	.	.	.	.	0	.
Indeno(1,2,3-c,d)pyrene	µg/kg	3/8	422	82	124	180	50.5	46.5	.
Naphthalene	µg/kg	0/8	426	.	.	.	.	0	.
Pentachlorophenol	µg/kg	0/8	1030	.	.	.	.	0	.
Phenanthrene	µg/kg	5/8	437	45	88.2	120	28.5	55.1	.
Pyrene	µg/kg	7/8	400	50	128	230	67.5	112	.
bis(2-Ethylhexyl)phthalate	µg/kg	6/8	425	55	72.7	99	17.8	54.5	.
SEGMENT 9									
Arsenic	mg/kg	315/320	4.8	1.7	7.04	27	2.93	6.93	.
Aluminum	mg/kg	18/18	.	6880	11100	23300	3960	11100	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Antimony	mg/kg	538/652	1.23	0.14	0.69	2.9	0.264	0.569	.
Barium	mg/kg	18/18	.	76.6	101	133	12.8	101	.
Beryllium	mg/kg	17/18	0.5	0.57	0.753	1.1	0.111	0.711	.
Cadmium	mg/kg	14/18	1.23	1.6	2.51	3.7	0.647	1.95	.
Chromium	mg/kg	691/691	.	6.9	59.7	182	17.7	59.7	.
Cobalt	mg/kg	18/18	.	8.8	10.9	14.3	1.25	10.9	.
Copper	mg/kg	18/18	.	7.4	42	63.5	14.1	42	.
Lead	mg/kg	18/18	.	21.2	35.4	66.8	11.7	35.4	.
Manganese	mg/kg	18/18	.	674	941	1180	134	941	.
Mercury	mg/kg	153/698	3.64	2.6	44.3	216	42.7	9.72	.
Nickel	mg/kg	18/18	.	10.7	24.6	32.5	5.57	24.6	.
Selenium	mg/kg	112/700	11.1	1.7	15.5	66	13.9	2.48	.
Silver	mg/kg	3/18	2.64	2.6	2.97	3.2	0.322	0.494	.
Thallium	mg/kg	0/18	0.78	.	.	.	.	0	.
Vanadium	mg/kg	18/18	.	13.7	18.3	32.6	4.59	18.3	.
Zinc	mg/kg	112/677	95.1	26	102	321	54.4	16.9	.
^{137}Cs	pCi/g	17/17	.	0.169	0.988	2.25	0.579	0.988	0.0705
^{60}Co	pCi/g	17/17	.	-0.0781	0.0566	0.127	0.0512	0.0566	0.0217
^{237}Np	pCi/g	7/7	.	0.003	0.104	0.57	0.206	0.104	0.047
^{233}Pa	pCi/g	15/15	.	-0.129	0.00931	0.292	0.115	0.00931	0.0555

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
^{228}Th	pCi/g	8/8	.	0.728	1.59	2.35	0.481	1.59	0.0578
^{230}Th	pCi/g	6/6	.	1.278	2.72	3.81	0.948	2.72	0.0886
^{232}Th	pCi/g	8/8	.	0.664	1.01	1.68	0.381	1.01	0.0457
^{234}U	pCi/g	515/683	1.71	0.9300551	3.54	21.3	3.63	2.67	0.0294
^{235}U	pCi/g	724/724	.	0.03424	0.134	1.03	0.157	0.134	0.0013
^{238}U	pCi/g	522/690	1.36	0.9657	3.89	20.3	3.1	2.94	0.0269
4,4'-DDD	µg/kg	1/18	4.33	0.14	0.14	0.14	.	0.00778	.
4,4'-DDE	µg/kg	9/18	4.34	0.29	0.921	1.5	0.393	0.461	.
4,4'-DDT	µg/kg	0/18	4.33	.	.	.	.	0	.
Aldrin	µg/kg	0/18	2.23	.	.	.	.	0	.
Aroclor-1254	µg/kg	1/18	43.3	34	34	34	.	1.89	.
Aroclor-1260	µg/kg	17/18	41	12	82.2	260	71.6	77.6	.
Dieldrin	µg/kg	2/18	4.3	0.15	0.625	1.1	0.672	0.0694	.
Endosulfan I	µg/kg	0/18	2.23	.	.	.	.	0	.
Endosulfan II	µg/kg	1/18	4.35	0.43	0.43	0.43	.	0.0239	.
Endosulfan sulfate	µg/kg	0/18	4.33	.	.	.	.	0	.
Endrin	µg/kg	2/18	4.35	0.82	3.11	5.4	3.24	0.346	.
Endrin aldehyde	µg/kg	1/18	4.35	0.65	0.65	0.65	.	0.0361	.
Endrin ketone	µg/kg	0/18	4.33	.	.	.	.	0	.
Heptachlor	µg/kg	7/18	2.21	0.081	0.114	0.17	0.0303	0.0443	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Heptachlor epoxide	µg/kg	2/18	2.22	0.2	0.205	0.21	0.00707	0.0228	.
alpha-Chlordane	µg/kg	10/18	2.26	0.16	1.18	4.6	1.32	0.657	.
delta-BHC	µg/kg	2/18	2.24	0.061	0.0855	0.11	0.0347	0.0095	.
gamma-BHC (Lindane)	µg/kg	0/18	2.23	.	.	.	.	0	.
gamma-Chlordane	µg/kg	5/18	2.21	0.26	1.58	4.2	1.7	0.439	.
p,p'-Methoxychlor	µg/kg	1/18	22.4	1.1	1.1	1.1	.	0.0611	.
2-Methylnaphthalene	µg/kg	0/18	435	.	.	.	.	0	.
4-Chloro-3-methylphenol	µg/kg	0/18	435	.	.	.	.	0	.
4-Nitrophenol	µg/kg	0/18	1060	.	.	.	.	0	.
Acenaphthene	µg/kg	0/18	435	.	.	.	.	0	.
Acenaphthylene	µg/kg	0/18	435	.	.	.	.	0	.
Anthracene	µg/kg	0/18	435	.	.	.	.	0	.
Benzo(a)anthracene	µg/kg	9/18	422	49	73.6	100	16.9	36.8	.
Benzo(a)pyrene	µg/kg	8/18	424	53	71.7	99	17.5	31.9	.
Benzo(b)fluoranthene	µg/kg	14/18	425	54	125	220	51.6	97.1	.
Benzo(g,h,i)perylene	µg/kg	2/18	435	61	80.5	100	27.6	8.94	.
Benzo(k)fluoranthene	µg/kg	11/18	426	52	127	220	53.7	77.3	.
Butylbenzylphthalate	µg/kg	1/18	413	67	67	67	.	3.72	.
Carbazole	µg/kg	0/18	435	.	.	.	.	0	.
Chrysene	µg/kg	9/18	424	44	78.9	110	21.1	39.4	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Di-n-butylphthalate	µg/kg	2/18	439	98	139	180	58	15.4	.
Di-n-octylphthalate	µg/kg	0/18	435	.	.	.	.	0	.
Dibenzo(a,h)anthracene	µg/kg	0/18	435	.	.	.	.	0	.
Dibenzofuran	µg/kg	0/18	435	.	.	.	.	0	.
Diethylphthalate	µg/kg	0/18	435	.	.	.	.	0	.
Fluoranthene	µg/kg	15/18	423	60	123	220	52.9	103	.
Fluorene	µg/kg	0/18	435	.	.	.	.	0	.
Indeno(1,2,3-c,d)pyrene	µg/kg	2/18	436	79	85.5	92	9.19	9.5	.
Naphthalene	µg/kg	0/18	435	.	.	.	.	0	.
Pentachlorophenol	µg/kg	0/18	1060	.	.	.	.	0	.
Phenanthrene	µg/kg	7/18	430	49	63.3	79	12	24.6	.
Pyrene	µg/kg	15/18	423	55	102	210	48.4	84.9	.
bis(2-Ethylhexyl)phthalate	µg/kg	6/18	433	45	72.5	110	26.8	24.2	.
Hinds Creek Reference Site									
Aluminum	mg/kg	12/12	.	7950	12400	19900	3490	12400	.
Antimony	mg/kg	0/7	7.49	.	.	.	.	0	.
Arsenic	mg/kg	12/12	.	1.5	2.54	3.9	0.711	2.54	.
Barium	mg/kg	12/12	.	69.2	112	165	36	112	.
Beryllium	mg/kg	12/12	.	0.4	0.675	0.95	0.174	0.675	.
Cadmium	mg/kg	0/12	0.743	.	.	.	.	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Chromium	mg/kg	12/12	.	12.9	20.2	29.8	5.21	20.2	.
Cobalt	mg/kg	12/12	.	3.6	9.21	13	2.88	9.21	.
Copper	mg/kg	12/12	.	4.3	8.65	12.4	2.43	8.65	.
Cyanide	mg/kg	0/11	0.619	.	.	.	.	0	.
Lead	mg/kg	12/12	.	9.2	12.6	18.2	2.8	12.6	.
Manganese	mg/kg	12/12	.	138	509	1170	287	509	.
Mercury	mg/kg	1/12	0.117	0.13	0.13	0.13	.	0.0108	.
Nickel	mg/kg	12/12	.	7.2	13.9	20.5	4.26	13.9	.
Selenium	mg/kg	0/12	0.743	.	.	.	.	0	.
Silver	mg/kg	0/12	1.74	.	.	.	.	0	.
Thallium	mg/kg	0/12	0.497	.	.	.	.	0	.
Vanadium	mg/kg	12/12	.	13.2	19.5	25.5	4.08	19.5	.
Zinc	mg/kg	11/12	33.5	19.3	34.8	46	8.7	31.9	.
^{241}Am	pCi/g	12/12	.	-0.1446	0.00128	0.305	0.127	0.00128	0.101
^{137}Cs	pCi/g	12/12	.	0.0769	0.38	1.29	0.337	0.38	0.032
^{60}Co	pCi/g	12/12	.	-0.0395	-0.00471	0.0366	0.0252	-0.00471	0.0109
^{237}Np	pCi/g	12/12	.	-0.0843	0.00208	0.135	0.0599	0.00208	0.0255
^{234}U	pCi/g	9/9	.	0.23	0.264	0.31	0.0283	0.264	0.00916
^{235}U	pCi/g	9/9	.	0	0.0144	0.04	0.0113	0.0144	0.00378
^{238}U	pCi/g	9/9	.	0.18	0.214	0.27	0.0305	0.214	0.00831

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
4,4'-DDD	µg/kg	0/11	19.7	.	.	.	.	0	.
4,4'-DDE	µg/kg	0/11	19.7	.	.	.	.	0	.
4,4'-DDT	µg/kg	0/11	19.7	.	.	.	.	0	.
Aldrin	µg/kg	0/11	9.85	.	.	.	.	0	.
Aroclor-1254	µg/kg	0/11	197	.	.	.	.	0	.
Aroclor-1260	µg/kg	0/11	197	.	.	.	.	0	.
Dieldrin	µg/kg	0/11	19.7	.	.	.	.	0	.
Endosulfan I	µg/kg	0/11	9.85	.	.	.	.	0	.
Endosulfan II	µg/kg	0/11	19.7	.	.	.	.	0	.
Endosulfan sulfate	µg/kg	0/11	19.7	.	.	.	.	0	.
Endrin	µg/kg	0/11	19.7	.	.	.	.	0	.
Endrin ketone	µg/kg	0/11	19.7	.	.	.	.	0	.
Heptachlor	µg/kg	0/11	9.85	.	.	.	.	0	.
Heptachlor epoxide	µg/kg	0/11	9.85	.	.	.	.	0	.
alpha-Chlordane	µg/kg	0/11	98.5	.	.	.	.	0	.
delta-BHC	µg/kg	0/11	9.85	.	.	.	.	0	.
gamma-BHC (Lindane)	µg/kg	0/11	9.85	.	.	.	.	0	.
gamma-Chlordane	µg/kg	0/11	98.5	.	.	.	.	0	.
p,p'-Methoxychlor	µg/kg	0/11	98.5	.	.	.	.	0	.
2-Methylnaphthalene	µg/kg	0/11	411	.	.	.	.	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation of results > detection limit	Grand mean (< DL = 0)	Radiation counting uncertainty of mean
4-Chloro-3-methylphenol	µg/kg	0/11	411	.	.	.	.	0	.
4-Nitrophenol	µg/kg	0/11	2000	.	.	.	.	0	.
Acenaphthene	µg/kg	0/11	411	.	.	.	.	0	.
Acenaphthylene	µg/kg	0/11	411	.	.	.	.	0	.
Anthracene	µg/kg	0/11	411	.	.	.	.	0	.
Benzo(a)anthracene	µg/kg	0/11	411	.	.	.	.	0	.
Benzo(a)pyrene	µg/kg	0/11	411	.	.	.	.	0	.
Benzo(b)fluoranthene	µg/kg	0/11	411	.	.	.	.	0	.
Benzo(g,h,i)perylene	µg/kg	0/11	411	.	.	.	.	0	.
Benzo(k)fluoranthene	µg/kg	0/11	411	.	.	.	.	0	.
Benzoic acid	µg/kg	2/11	1700	58	929	1800	1230	169	.
Butylbenzylphthalate	µg/kg	0/11	411	.	.	.	.	0	.
Chrysene	µg/kg	0/11	411	.	.	.	.	0	.
Di-n-butylphthalate	µg/kg	0/11	411	.	.	.	.	0	.
Di-n-octylphthalate	µg/kg	0/11	411	.	.	.	.	0	.
Dibenzo(a,h)anthracene	µg/kg	0/11	411	.	.	.	.	0	.
Dibenzofuran	µg/kg	0/11	411	.	.	.	.	0	.
Diethylphthalate	µg/kg	0/11	411	.	.	.	.	0	.
Fluoranthene	µg/kg	0/11	411	.	.	.	.	0	.
Fluorene	µg/kg	0/11	411	.	.	.	.	0	.

Table 3.32 (continued)

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation of results >detection limit	Grand mean (<DL=0)	Radiation counting uncertainty of mean
Indeno(1,2,3-c,d)pyrene	µg/kg	0/11	411	.	.	.	.	0	.
Naphthalene	µg/kg	0/11	411	.	.	.	.	0	.
Pentachlorophenol	µg/kg	0/11	2000	.	.	.	.	0	.
Phenanthrene	µg/kg	0/11	411	.	.	.	.	0	.
Pyrene	µg/kg	0/11	411	.	.	.	.	0	.
bis(2-Ethylhexyl)phthalate	µg/kg	2/11	413	330	430	530	141	78.2	.

Results less than the detection limit were set to zero to compute grand mean.
Weight-based concentrations of uranium isotopes were converted to activity for this summary.
Source: EFPC Phase Ia and Ib validated results on January 11, 1993.

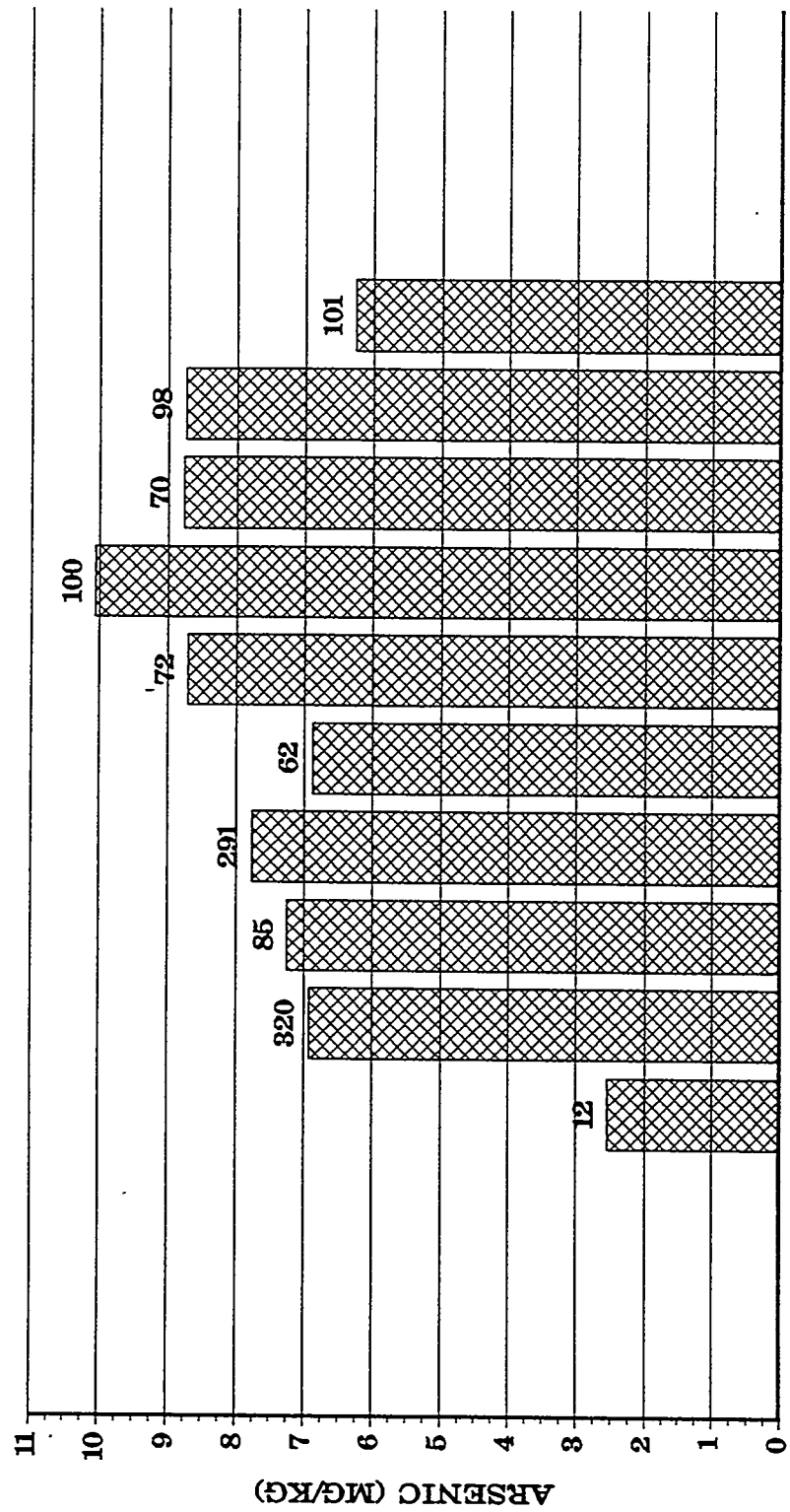


Fig. 3.93. Mean *Arsenic* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2) and HC refers to the Hinds Creek reference site.

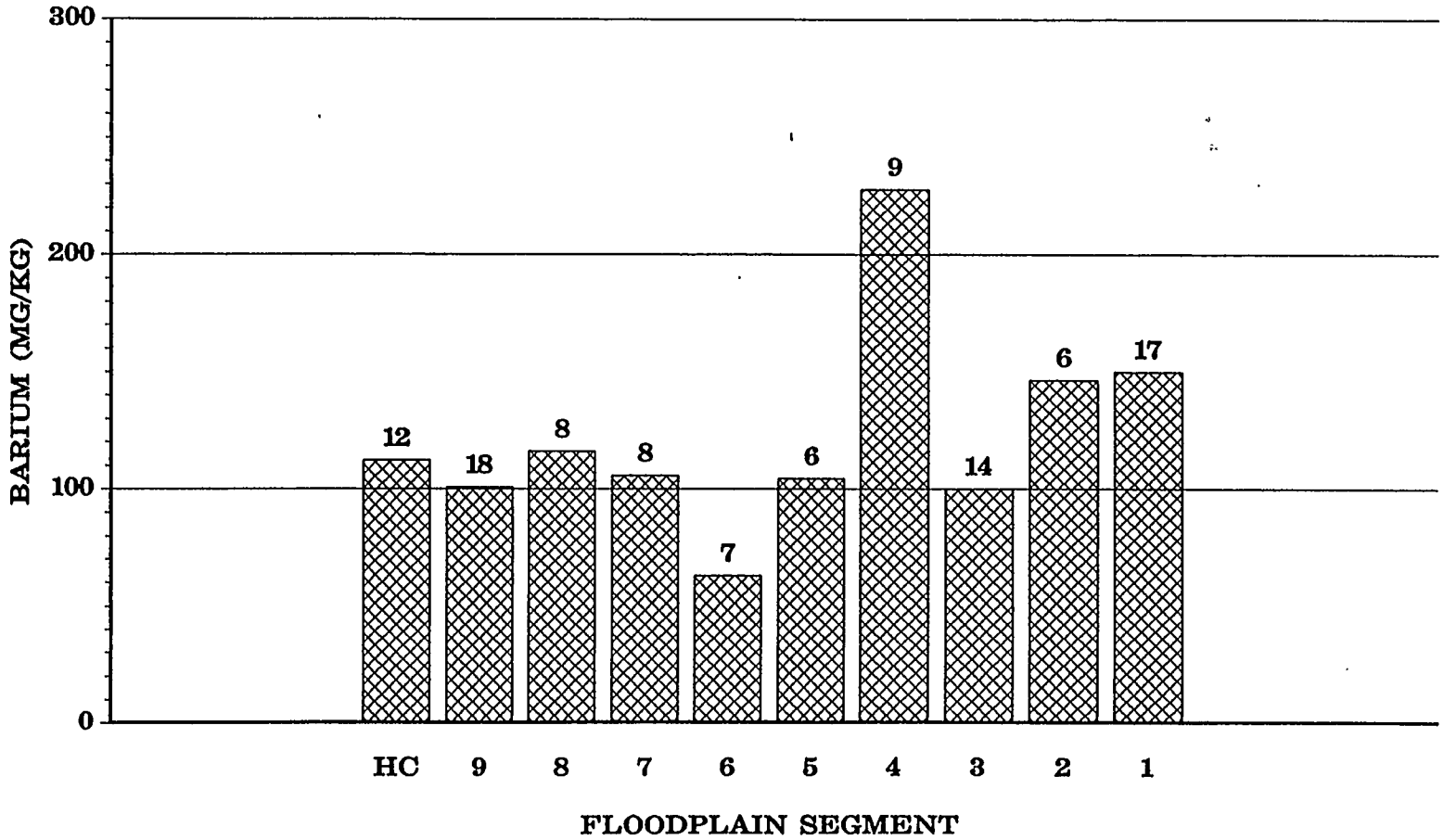


Fig. 3.94. Mean *Barium* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

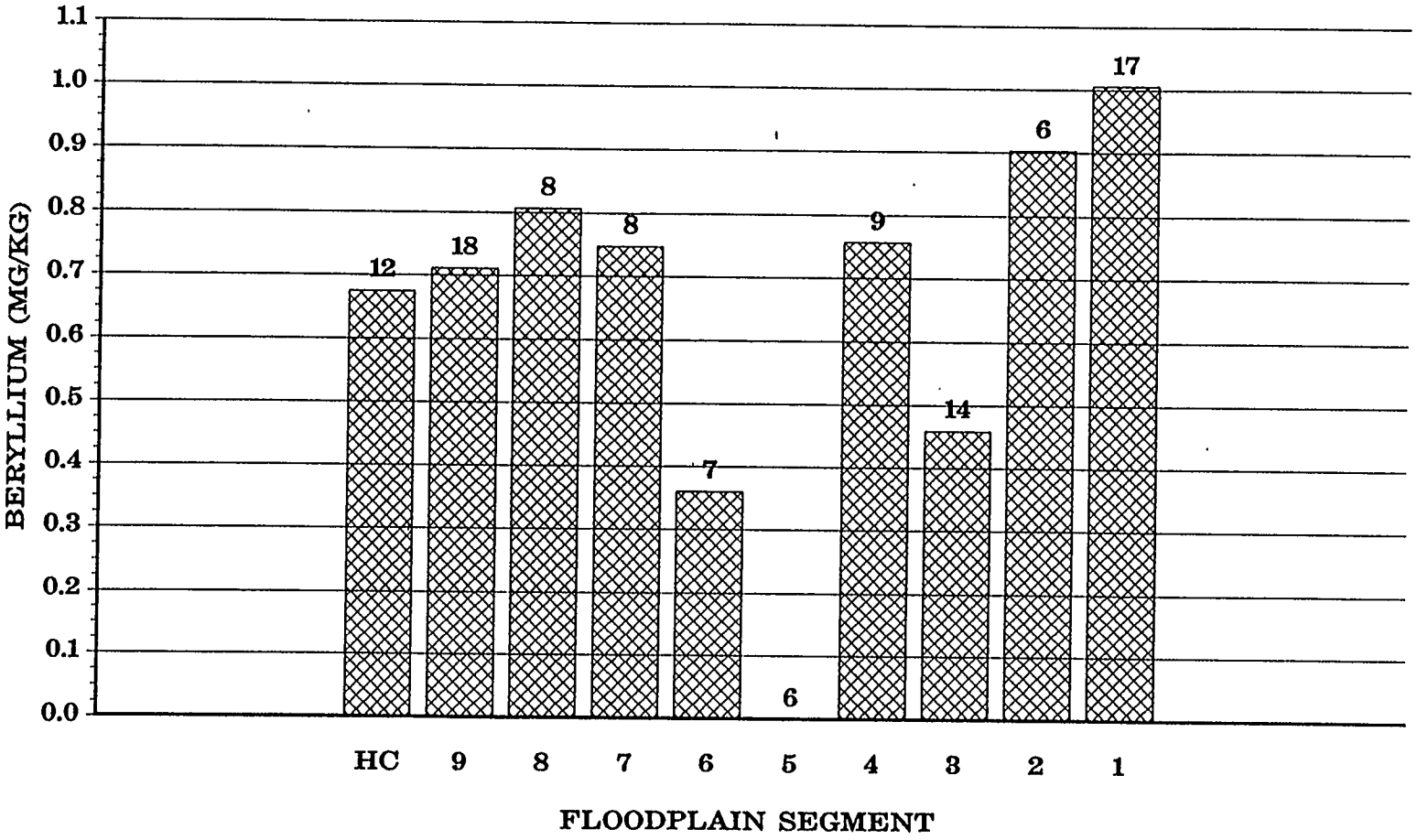


Fig. 3.95. Mean *Beryllium* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

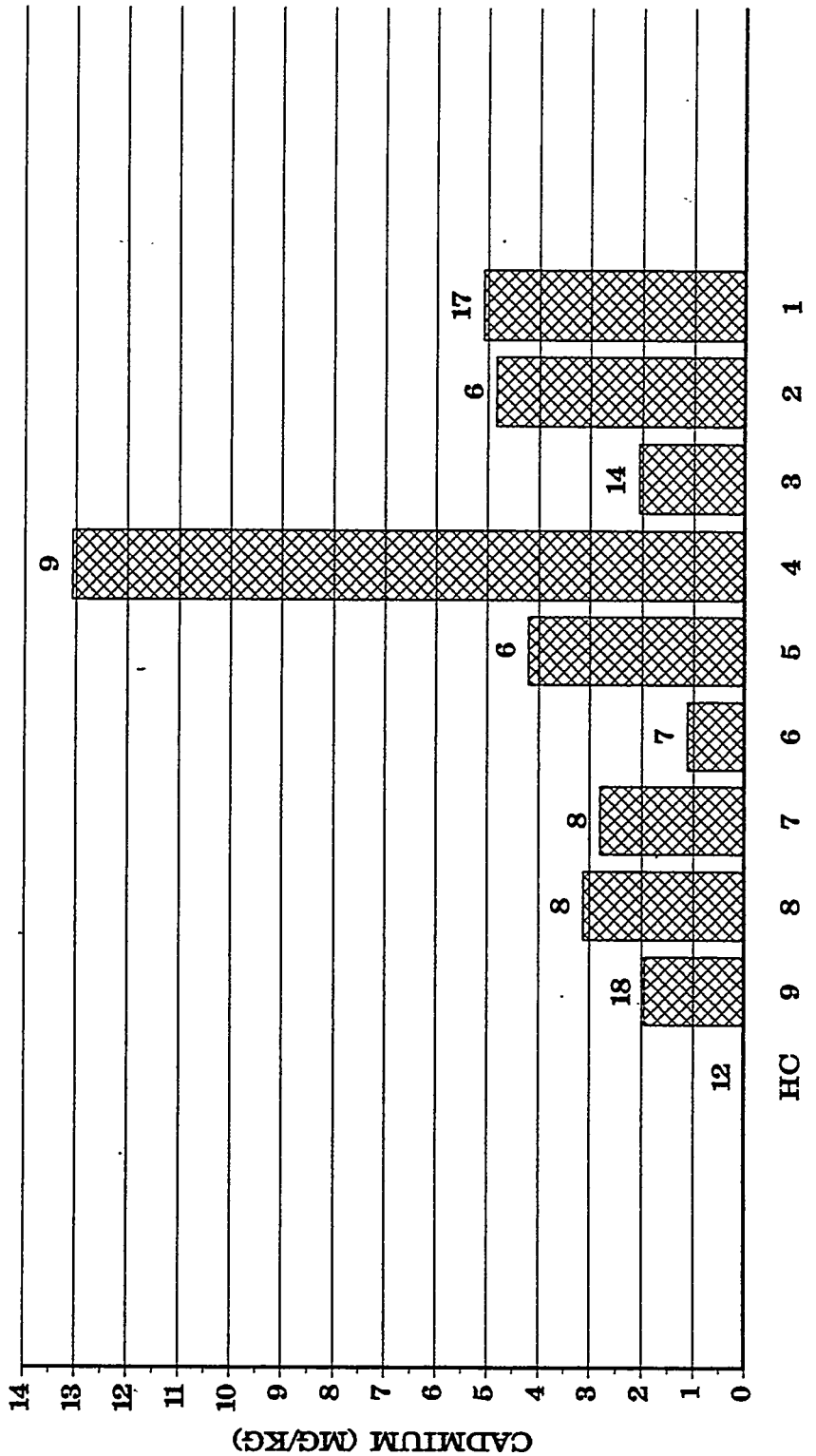


Fig. 3.96. Mean *Cadmium* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

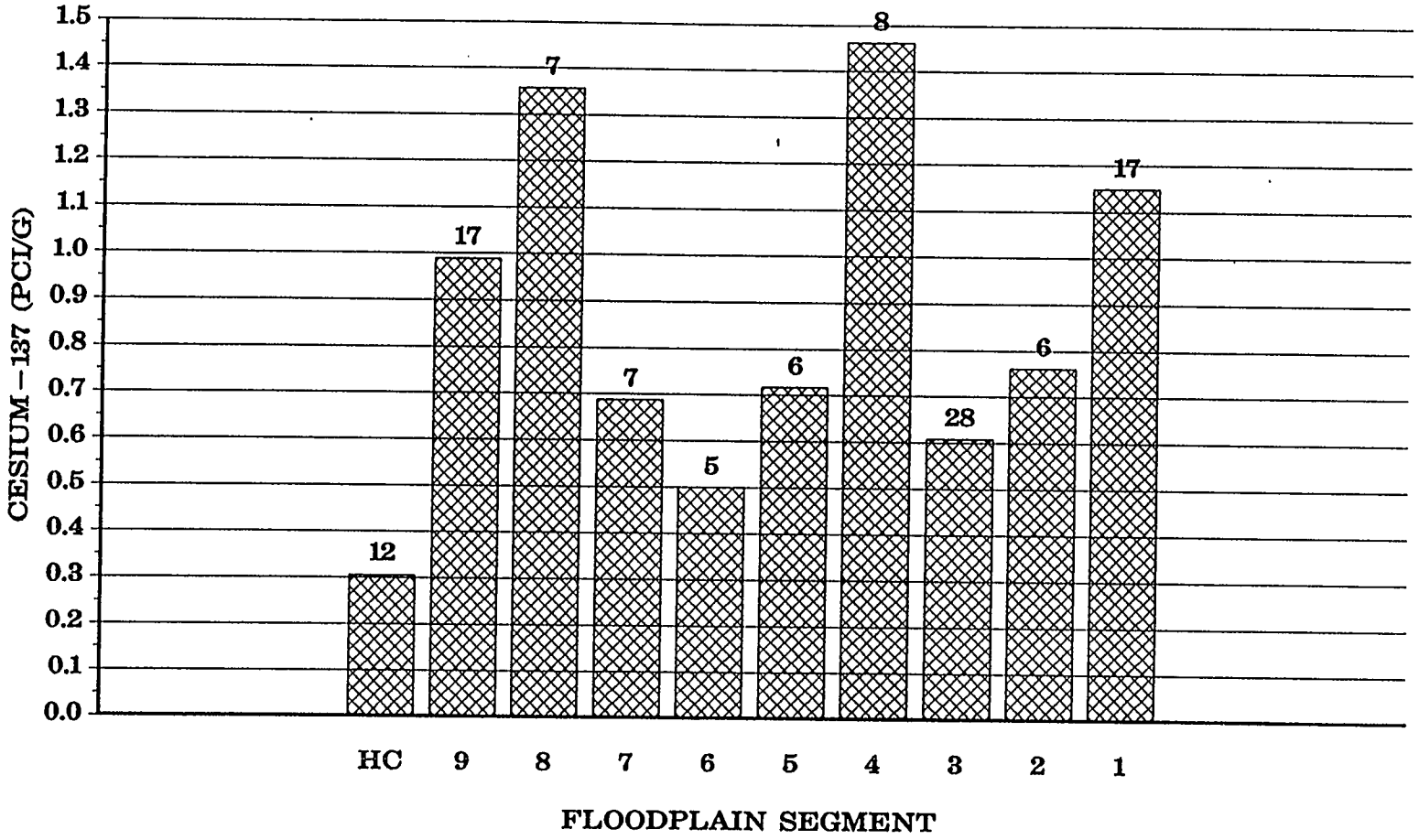


Fig. 3.97. Mean ^{137}Cs concentrations (pCi/g) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

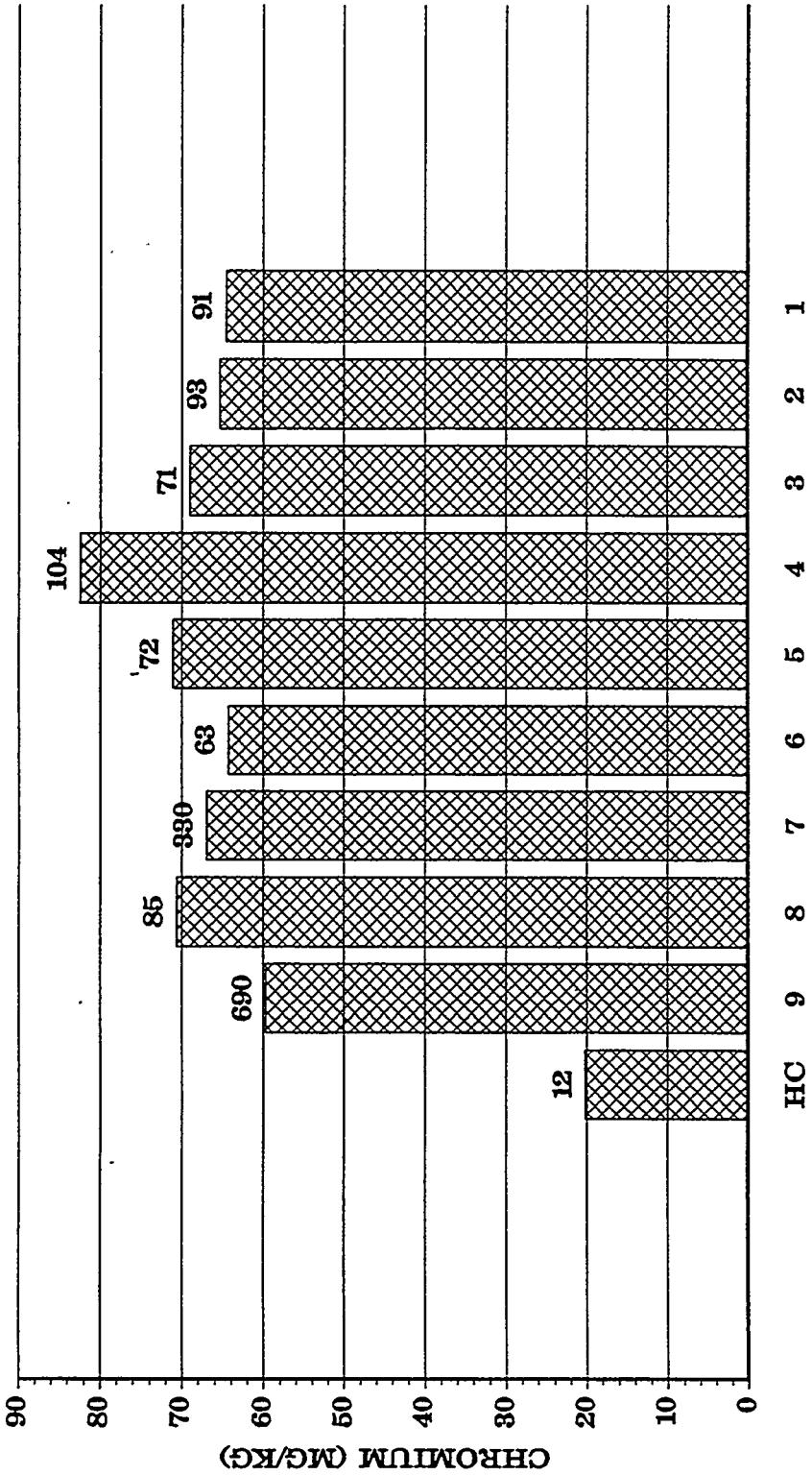


Fig. 3.98. Mean *Chromium* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

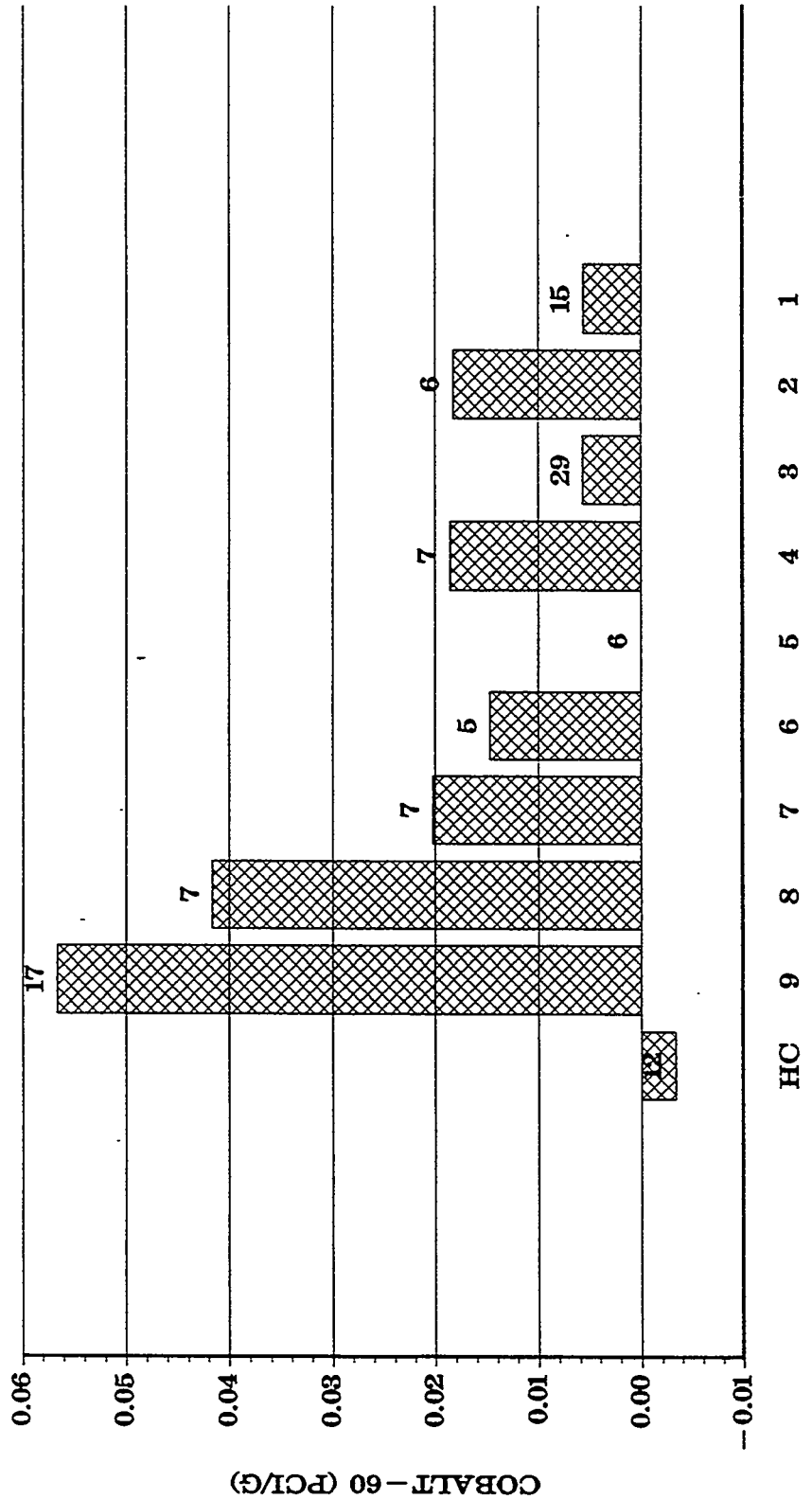


Fig. 3.99. Mean ^{60}Co concentrations (pCi/g) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

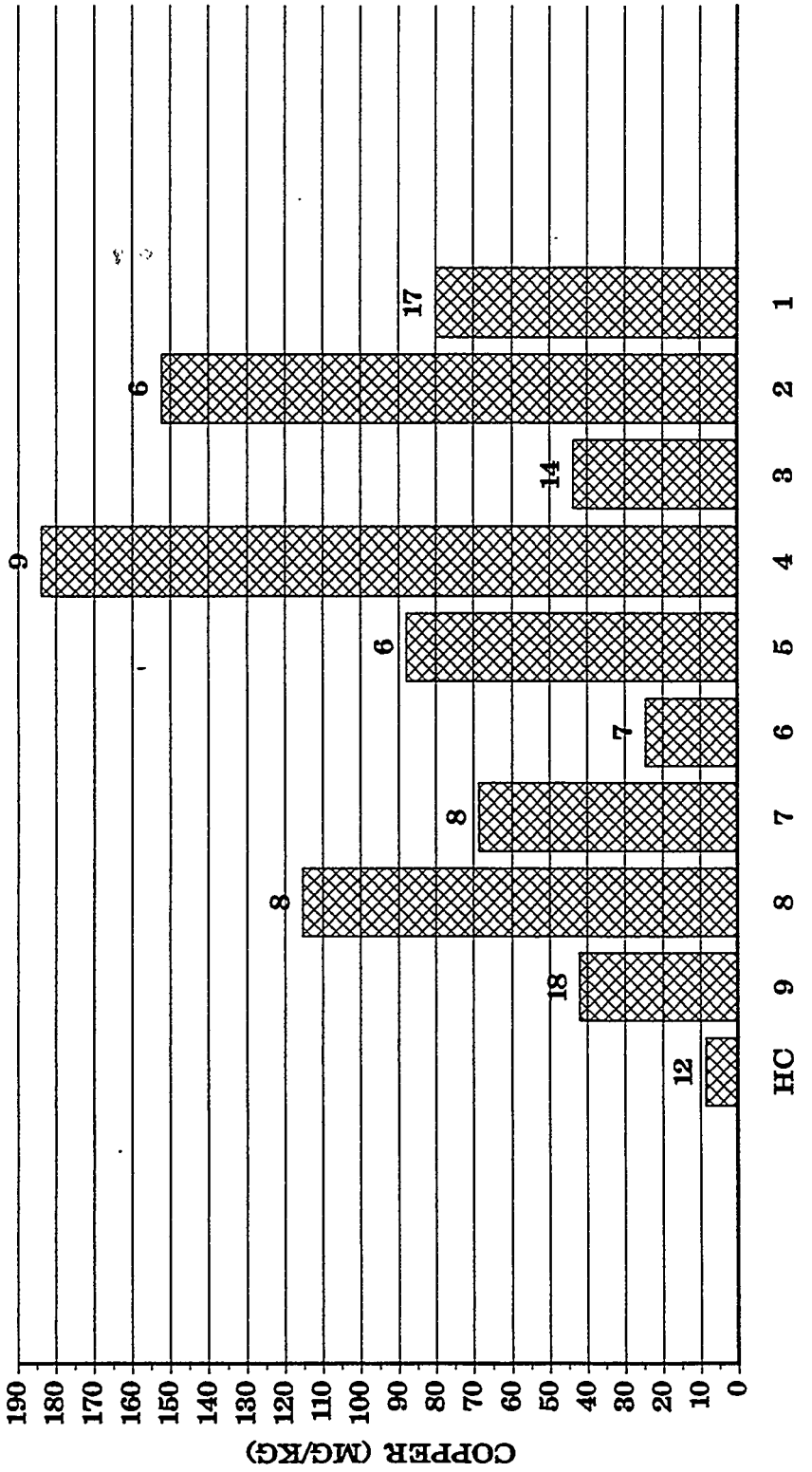


Fig. 3.100. Mean *Copper* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

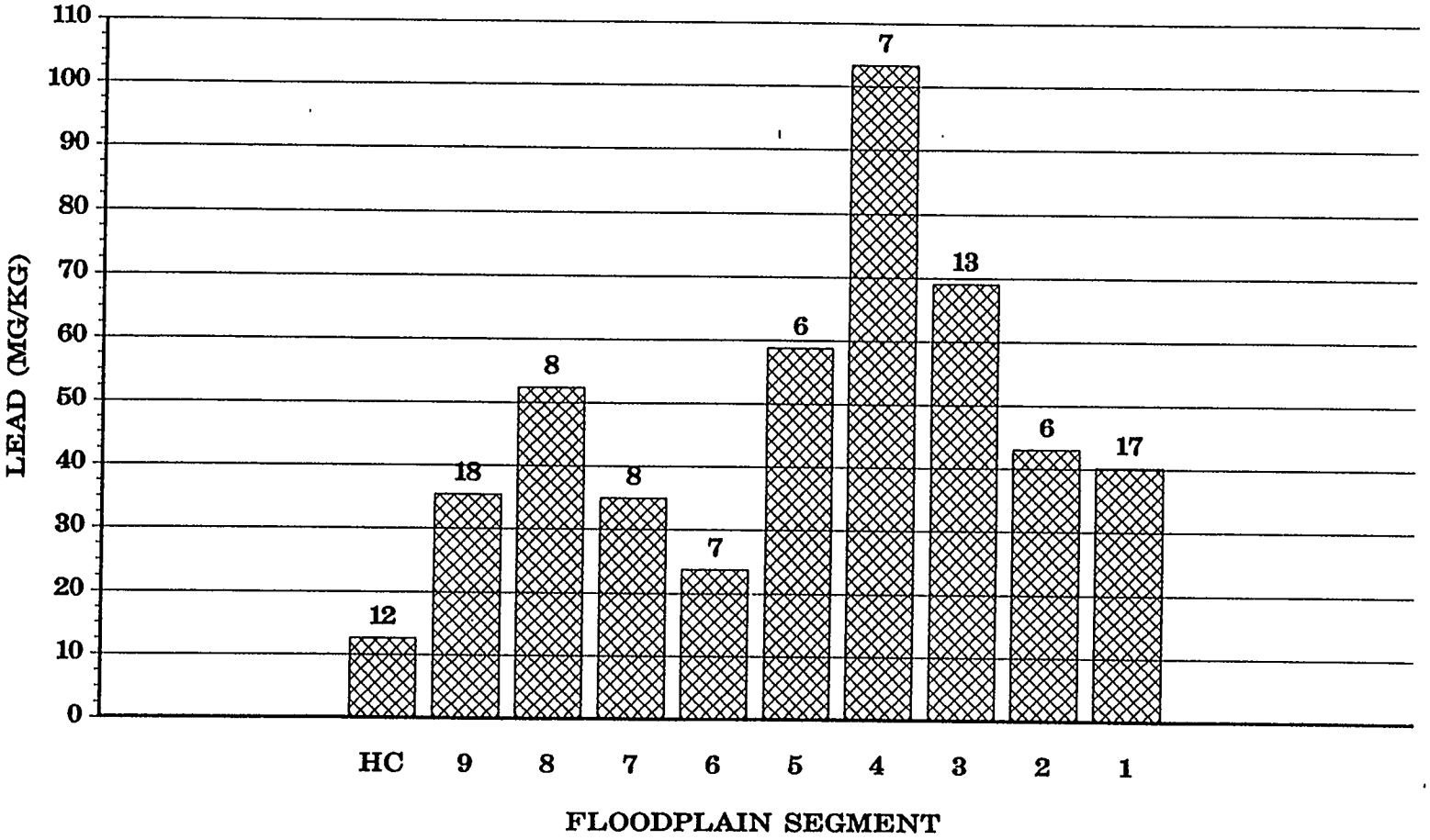


Fig. 3.101. Mean *Lead* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

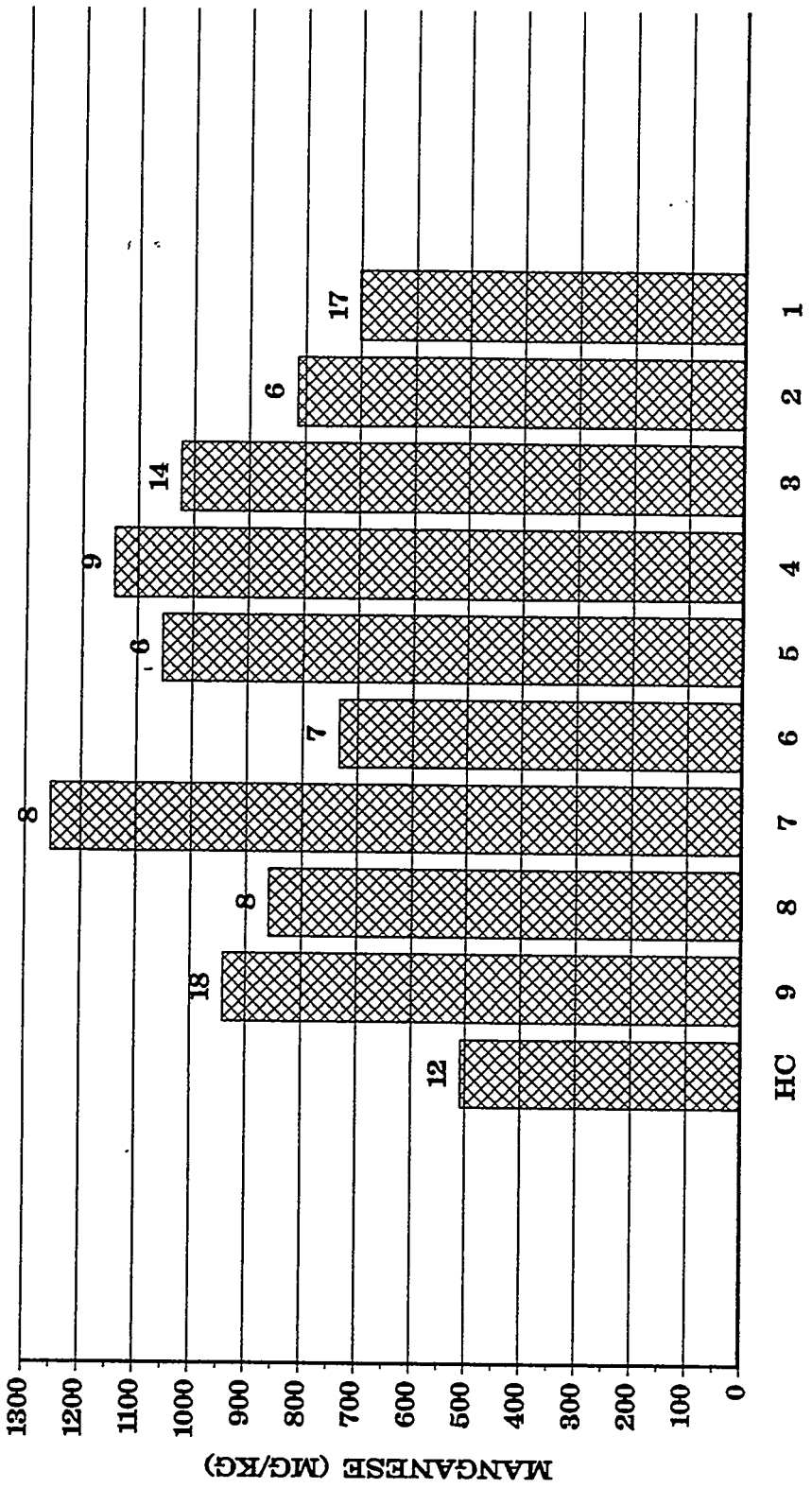


Fig. 3.102. Mean *Manganese* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

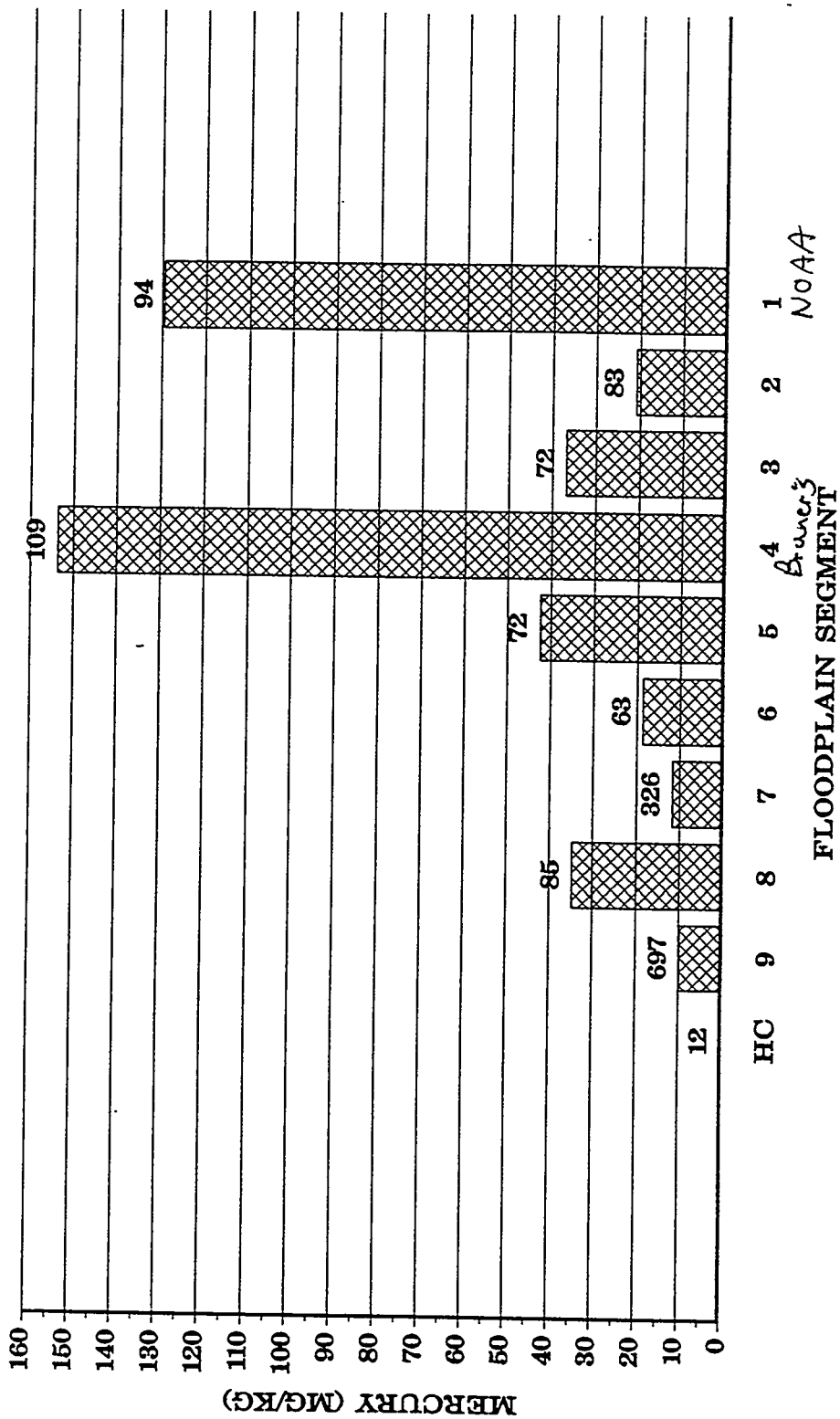


Fig. 3.103. Mean *Mercury* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

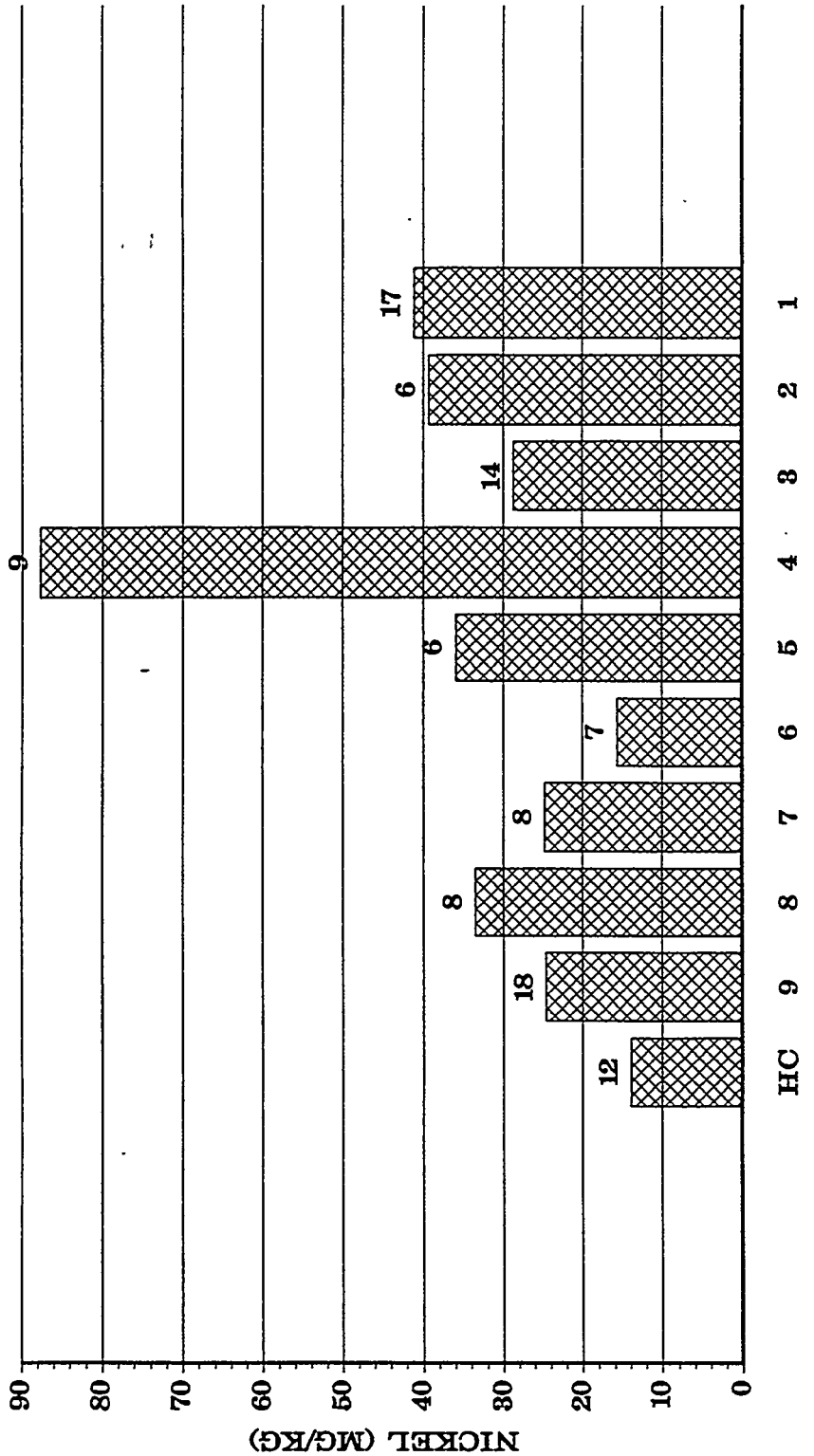


Fig. 3.104. Mean *Nickel* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

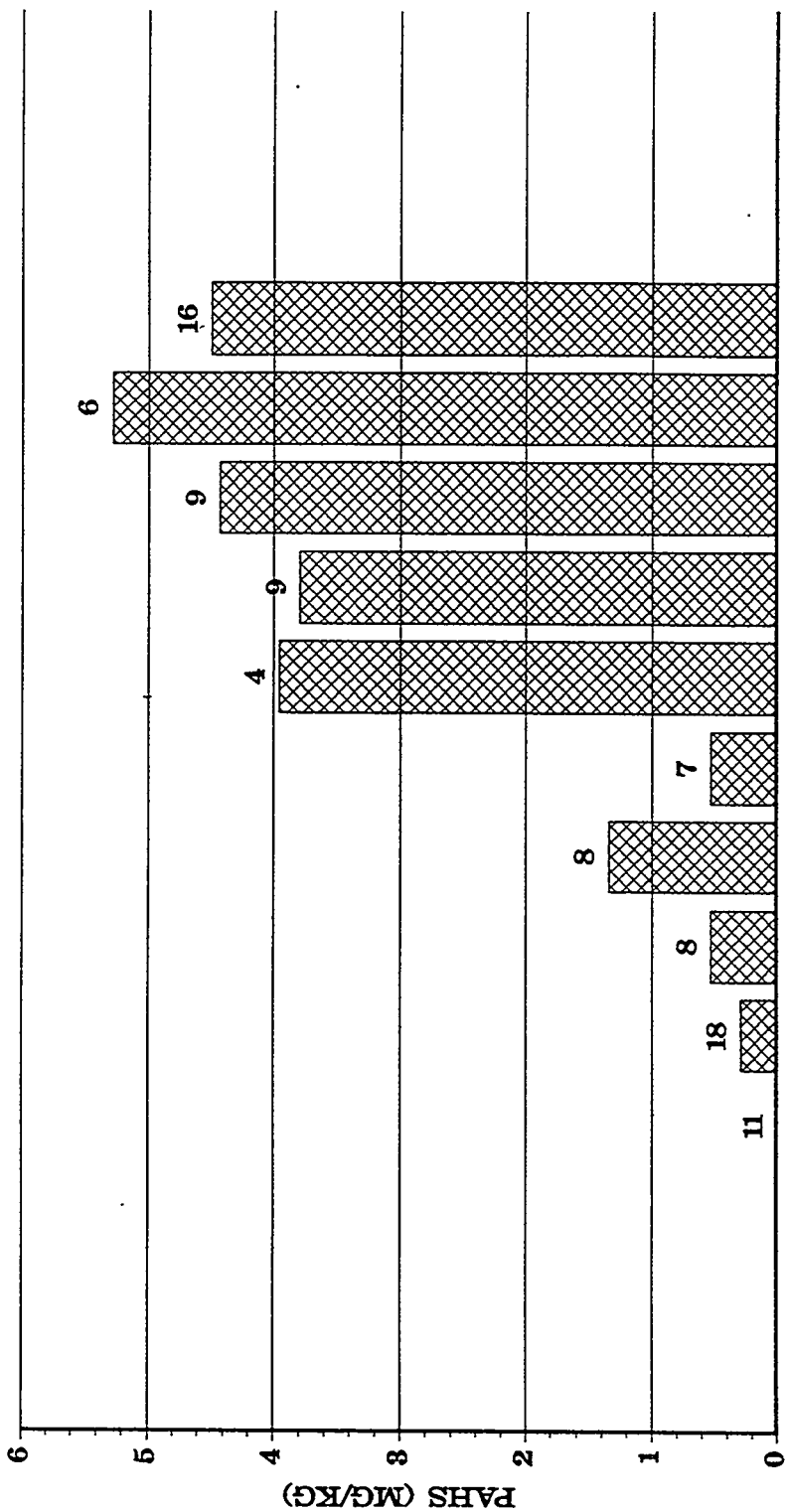


Fig. 3.105. Mean *PAH* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

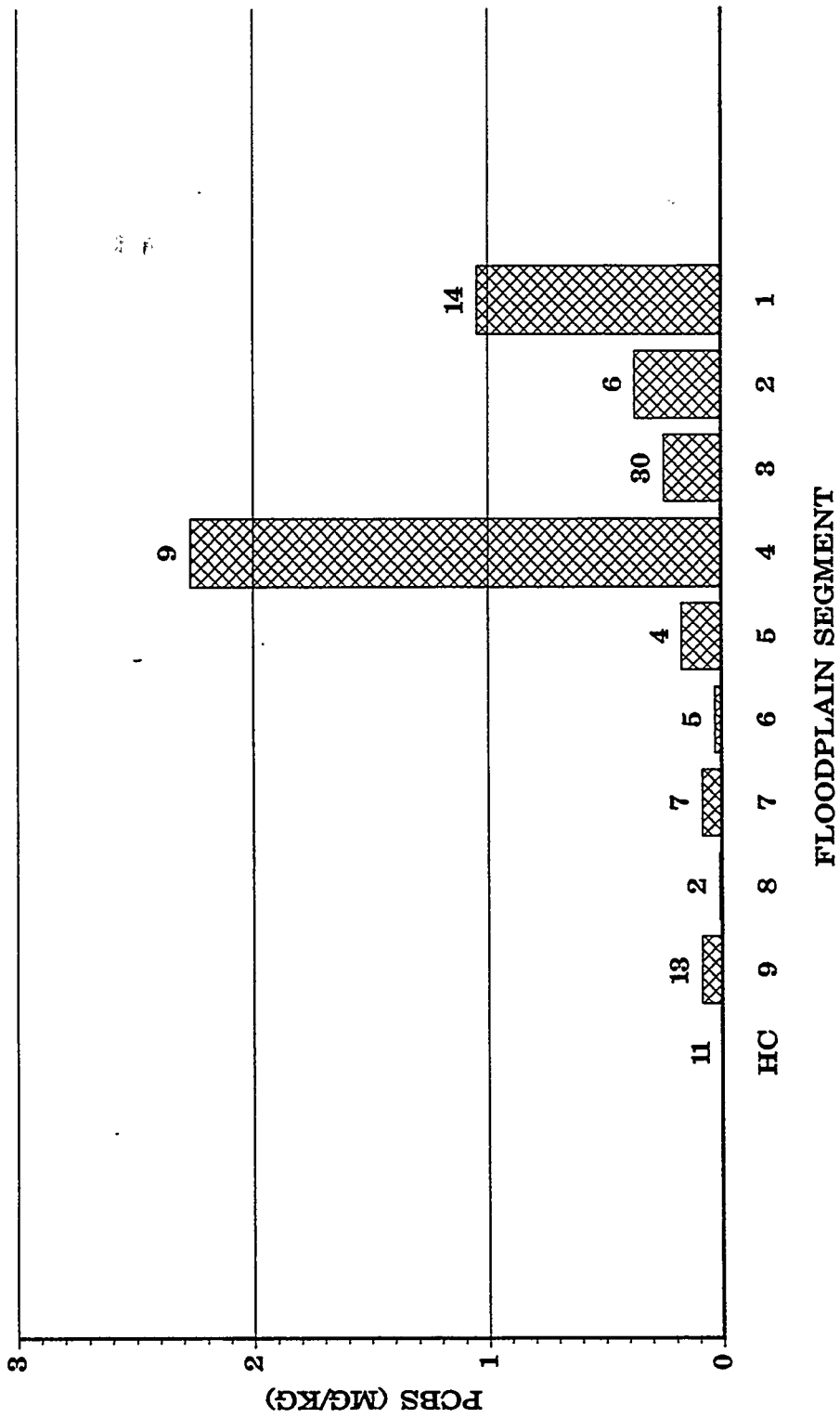


Fig. 3.106. Mean *PCB* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

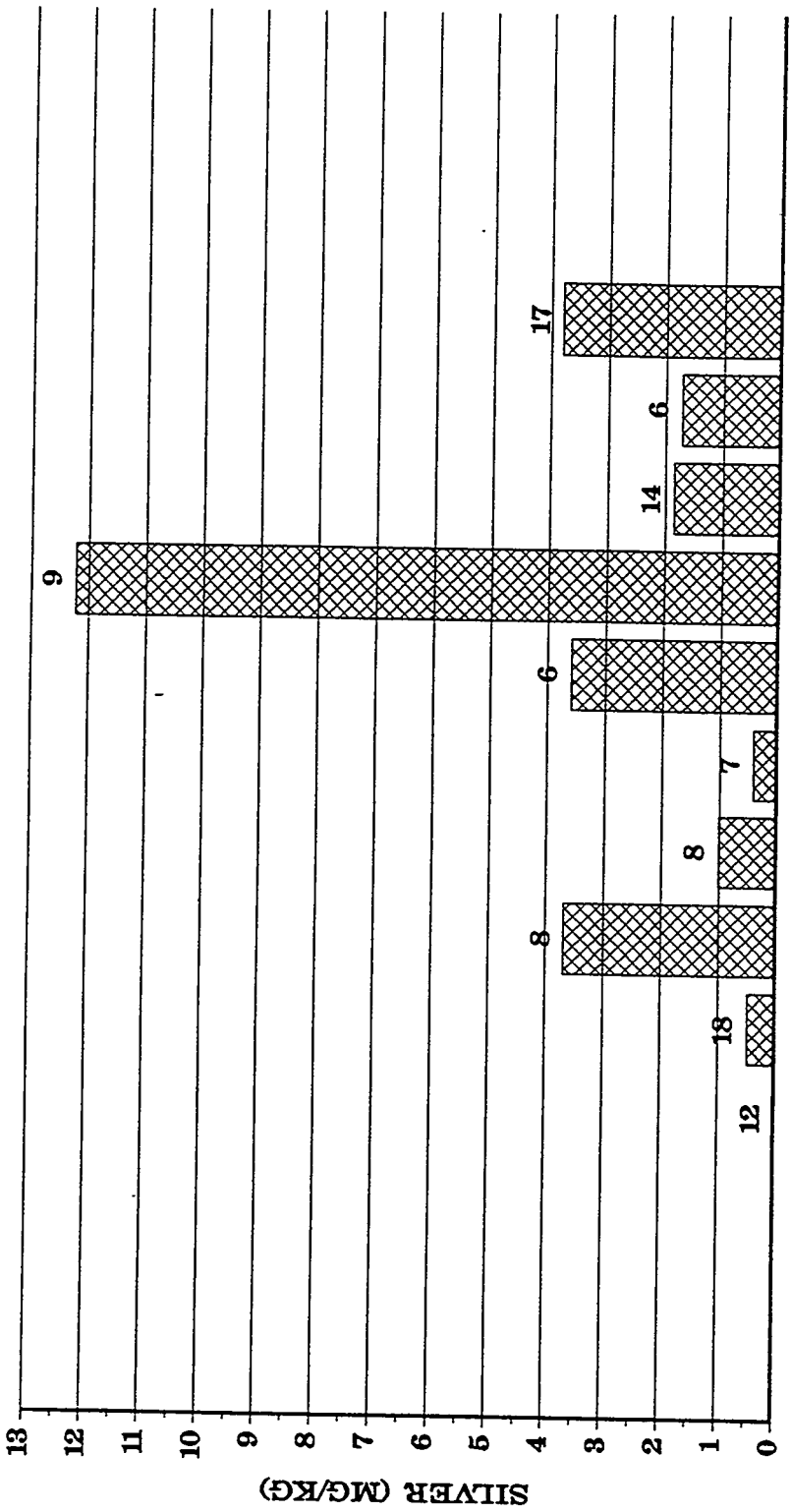


Fig. 3.107. Mean *Silver* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

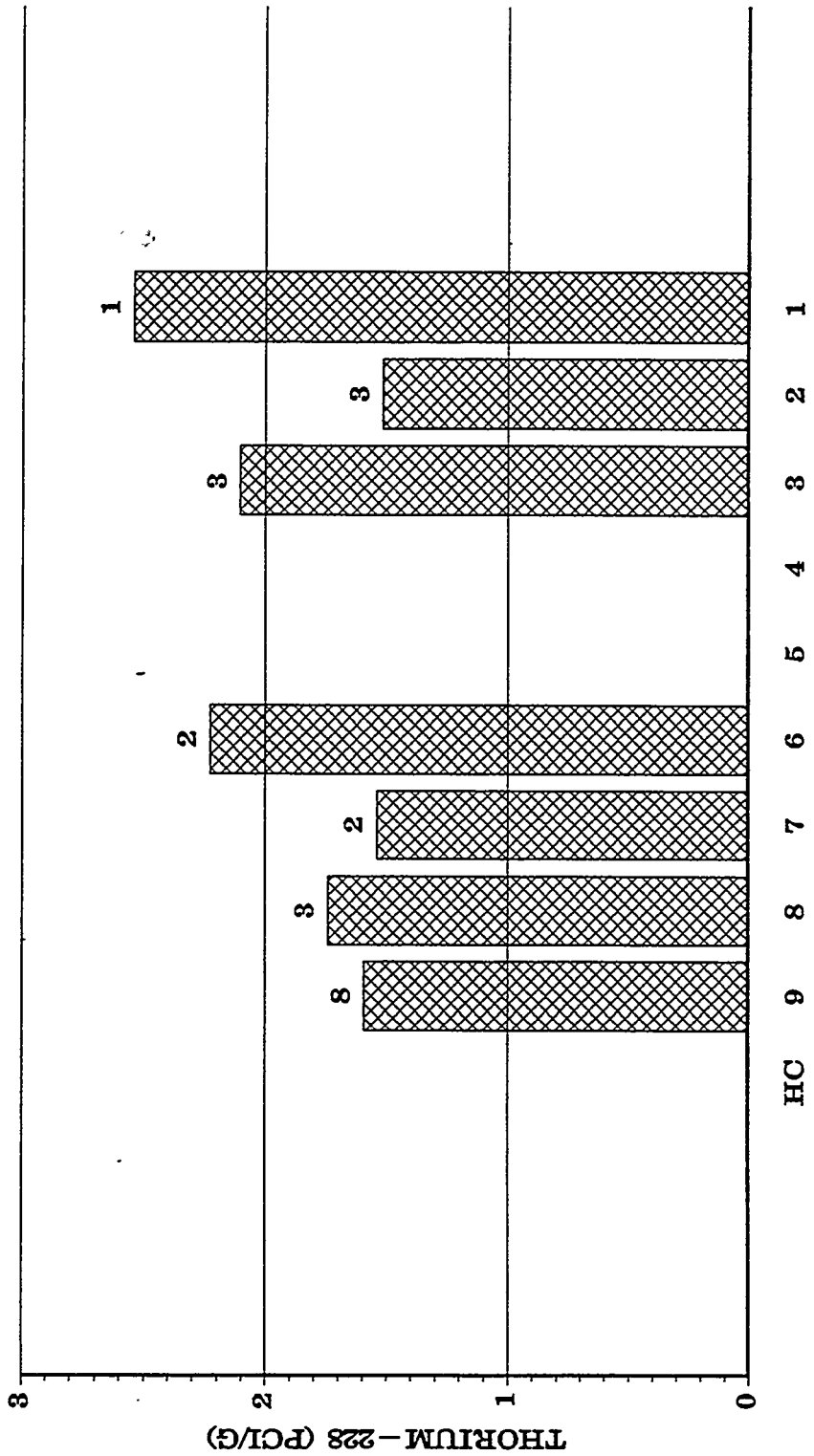


Fig. 3.108. Mean *Total Thorium* concentrations (pCi/L) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

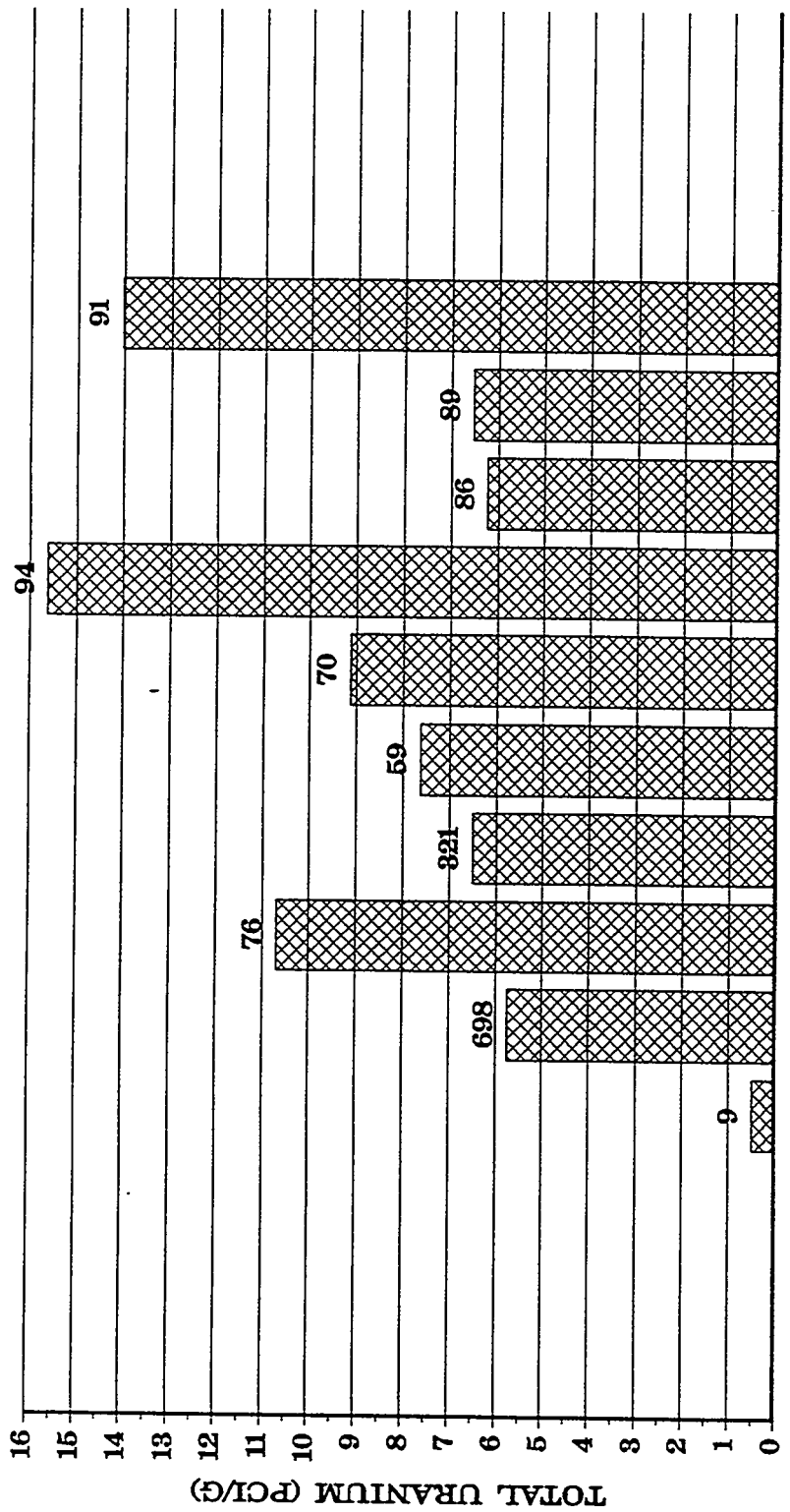


Fig. 3.109. Mean *Total Uranium* concentrations (pCi/g) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

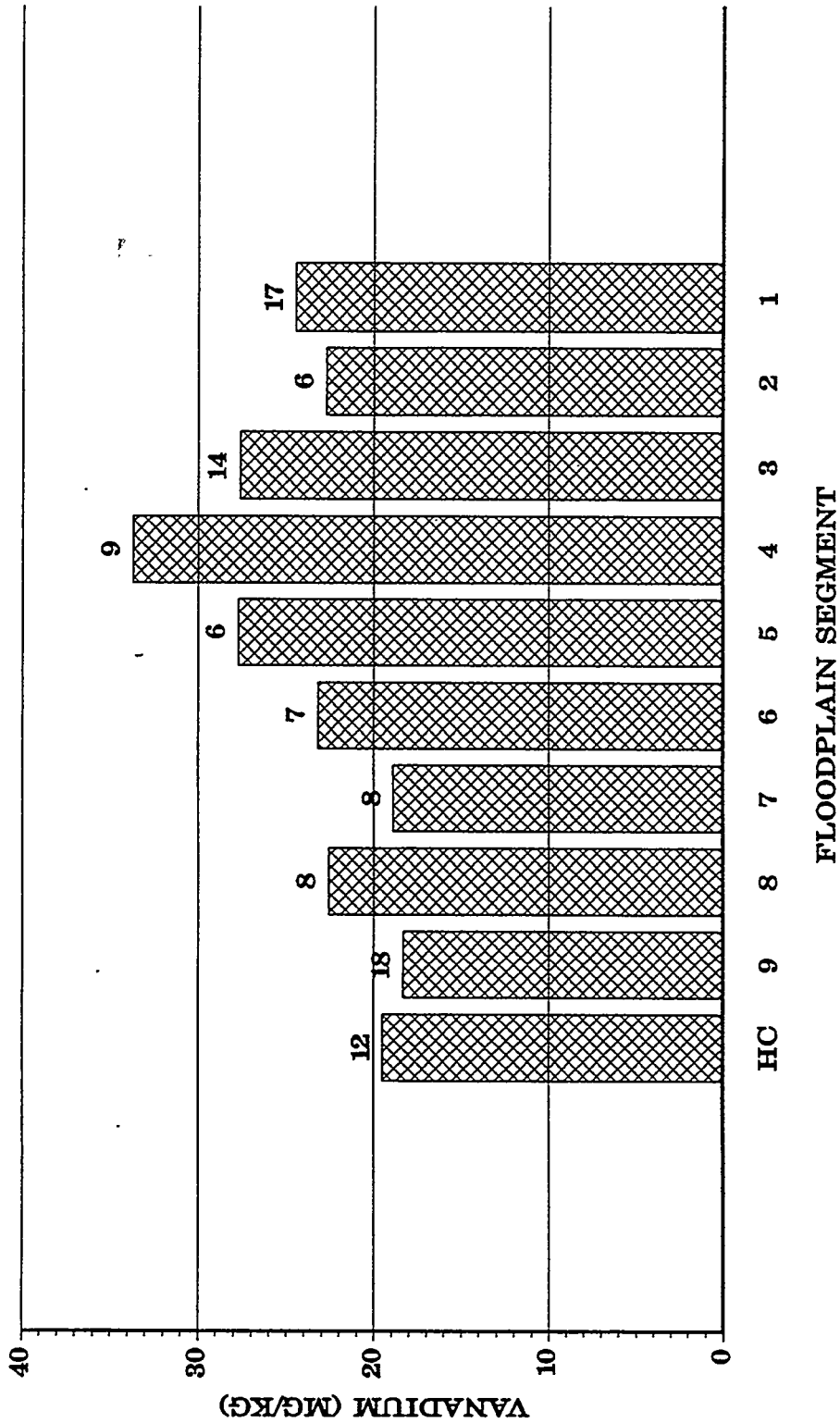


Fig. 3.110. Mean *Vanadium* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

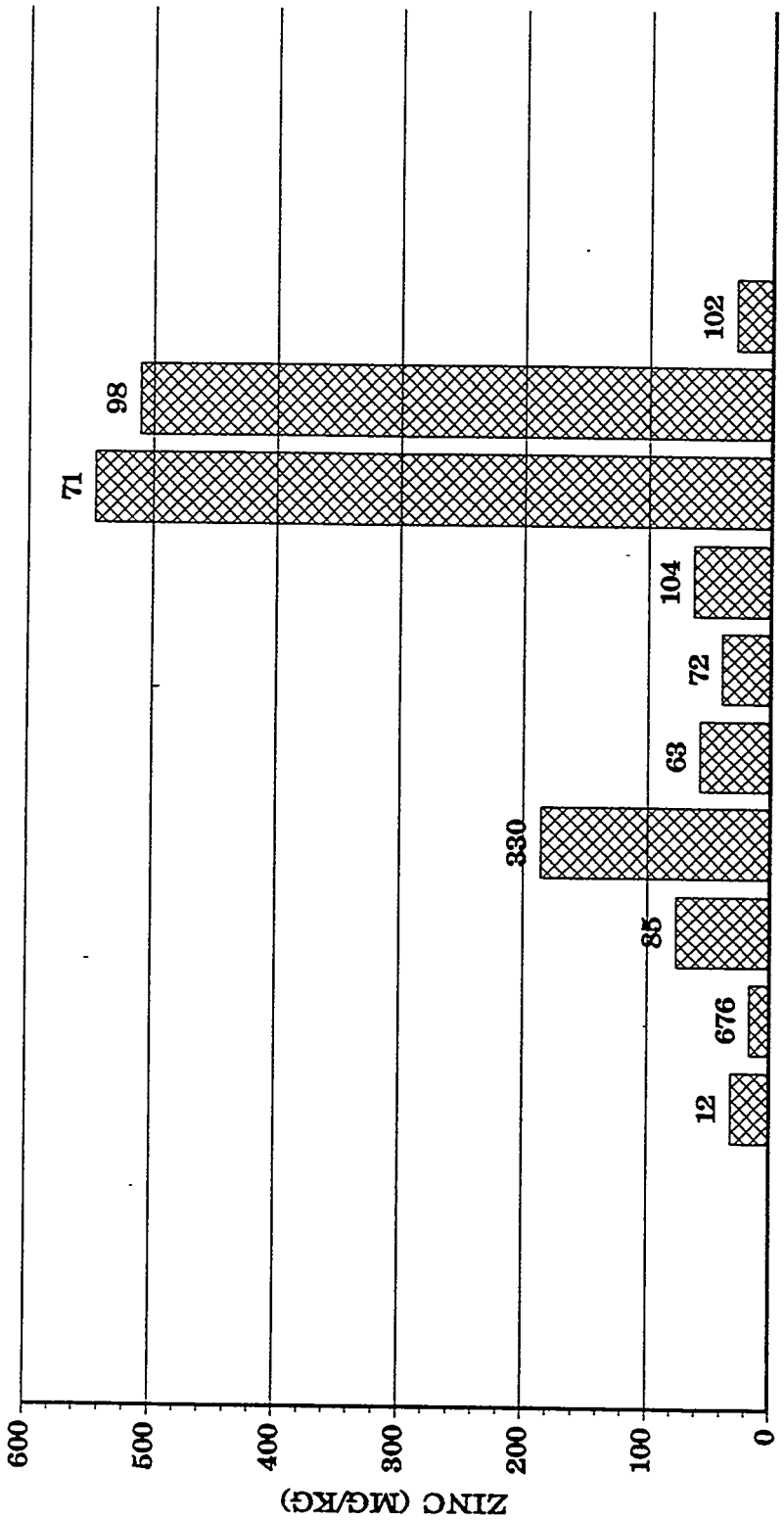


Fig. 3.111. Mean *Zinc* concentrations (mg/kg) in the surface layer of EFPC floodplain soils. Values less than detection were set to zero before averaging. The value above each bar is the number of samples taken. Floodplain segment numbers are plotted going upstream from left to right (see Map 2), and HC refers to the Hinds Creek reference site.

Arsenic was detected at about three times the level in the reference area (HC) in EFPC but was evenly distributed throughout the creek (Fig. 3.93). **Barium** showed levels in the floodplain soils comparable to HC except at Segment 4 (Fig. 3.94). **Beryllium**, like barium, did not exhibit uncharacteristic levels in the soil, except for slight elevation at Segment 1 (Fig. 3.95). **Cadmium** was not detected at HC; therefore, any concentration detected in EFPC was elevated above the reference site levels, and the elevation was especially marked at Segment 4 (Fig. 3.96). **Cesium-137** displayed activity 2 to 3 times HC throughout EFPC and more at Segments 1, 4, and 8 (Fig. 3.97). **Chromium** showed concentrations 3 to 4 times background, with the same overall level throughout the floodplain (Fig. 3.98). **Cobalt-60** was concentrated within all areas of the floodplain compared to HC but increased downstream of Segment 6. As with sediment, this may be the result of the West End Treatment Plant and the influence of Bear Creek (Fig. 3.99). **Copper, Lead,** and **Manganese** were erratically elevated throughout the floodplain (Fig. 3.100 to 3.102). **Mercury**, as would be expected, was concentrated in Segments 1, 4, and 8 (compared to the other segments of the creek) (Fig. 3.103). **Nickel** was slightly increased throughout the soils of EFPC, except for a significant anomaly in Segment 9 (Fig. 3.104). Total **PAHs** showed the influence of an urban environment in Segments 1 to 5, with a coincident decrease in the undeveloped portions of EFPC (Fig. 3.105). Total **PCBs** showed the same distribution as total PAHs, but with a decreasing gradient from the Y-12 Plant (except at Segment 4) (Fig. 3.106). **Silver** was increased over background within Segments 1 to 5 and 8 (Fig. 3.107). **Thorium** was detected in the 6 to 12 pCi/g range but was not analyzed for HC. Presumably, thorium is elevated in the same relative portions as uranium in HC (Fig. 3.108). **Total Uranium** showed the observed high areas noted on Map 8 in Segments 1,4, and 8 (Fig. 3.109). **Vanadium** exhibited only a slight increase over background, with the largest volume at Segment 4 (Fig. 3.110). **Zinc** displayed significant anomalies within Segments 2 and 3. There is no apparent reason for elevated zinc concentrations at these locations (Fig. 3.111).

3.2.6 Soil Geotechnical Data

3.2.6.1 Scope of investigation

The geotechnical investigation was designed and conducted during Phase Ia of the EFPC RI to act as data input into components of the EFPC FS such as contaminant fate and transport modeling, treatability studies, and screening of alternatives. Four types of data were derived: soil morphology and chemistry, hydraulic parameters for the unconsolidated zone aquifer, particle-size distributions, and contaminant relationships.

3.2.6.2 Study sites and methods

Geotechnical samples were collected at each sampling station on the soil transects. Soil profiles were described and samples were collected from the first five horizons. Samples were collected with Shelby tubes where possible. In some cases, Shelby tubes were ineffective in retrieving samples, and bucket augers were used to collect samples. Soil at all transects was typical of floodplains, exhibiting thin horizons or strata indicative of deposition during flood events. In some cases it was necessary to combine two thin, but distinctly different, soil layers to obtain the amount of soil required for analysis.

Six stations were sampled along each transect of the study sites (NO, BR, WA, HC). Unlike the arrangement of the initial study site transects at Hinds Creek Transect HC_{2a}, all of these stations were located on the west bank of the creek because the east bank was a steep bluff. The Hinds Creek HC_{2b} Transect had Stations 01 to 03 on the west bank and Stations 04 to 06 on the east bank. Sample station transects of the EFPC study sites were the same as during the initial study.

Hinds Creek Transects (HC_{2a} and HC_{2b}) The HC_{2a} Transect (Map 4) was located in an area mapped as Newark soil (Moneymaker 1981). The total depth sampled ranged from 53 to 78 cm (21 to 31 in.). Only three horizons were present at Stations 02 and 05 before shale bedrock was encountered. Soil morphology was generally representative of the Newark series. The soil was very wet at the time and showed signs of poor drainage, such as low chroma soil colors, mottling, and oxidized areas along root channels. Water was standing at Stations 02 and 05 at the time of sampling.

At Stations 01 and 06, samples were collected from 0 to 7 cm (0 to 3 in.), 7 to 17 cm (3 to 7 in.), 17 to 35 cm (7 to 14 in.), 10 to 22 cm (4 to 24 in.), and 60 to 78 cm (24 to 31 in.). At Stations 02 and 05, samples were collected from 0 to 10 cm (0 to 4 in.), 10 to 22 cm (4 to 9 in.), and 22 to 53 cm (9 to 21 in.) before encountering bedrock. At Stations 03 and 04, samples were collected from 0 to 5 cm (0 to 2 in.), 5 to 20 cm (2 to 8 in.), 20 to 43 cm (8 to 17 in.), 43 to 54 cm (17 to 21.5 in.), and 54 to 69 cm (21.5 to 27.5 in.).

The HC_{2b} Transect was located in an area mapped as Hamblen soil (Moneymaker 1981). The total depth sampled ranged from 68 to 92 cm (27 to 36.5 in.). Only four horizons were present at Station 02 before encountering shale bedrock. Soil morphology was similar to the range of characteristics for the Hamblen series (Moneymaker 1981). The soils along the HC_{2b} Transect were similar in many ways to the HC_{2a} Transect. One important difference was in the depth of the soil. Soils on the HC_{2b} Transect were much deeper than at the HC_{2a} Transect. Soil

morphology at the HC_{2b} Transect was indicative of better internal drainage, at least near the surface.

At Station 01, samples were collected from 0 to 20 cm (0 to 8 in.), 20 to 39 cm (8 to 15.5 in.), 39 to 49 cm (25.5 to 19.5 in.), 49 to 64 cm (19.5 to 25.5 in.), and 64 to 78 cm (25.5 to 31 in.). At Station 02, samples were collected from 0 to 9 cm (0 to 3.5 in.), 9 to 22 cm (3.5 to 9 in.), 22 to 43 cm (9 to 17 in.), and 43 to 68 cm (17 to 27 in.) before hitting bedrock. At Station 03, samples were collected from 0 to 19 cm (0 to 7.5 in.), 19 to 31 cm (7.5 to 12.5 in.), 31 to 53 cm (12.5 to 21 in.), 53 to 67 cm (21 to 26.5 in.), and 53 to 93 cm (26.5 to 36.5 in.). At Station 04, samples were collected from 0 to 15 cm (0 to 6 in.), 15 to 30 cm (6 to 12 in.), 30 to 50 cm (12 to 20 in.), 50 to 67 cm (20 to 26.5 in.), and 67 to 83 cm (26.5 to 33 in.). At Station 05, samples were collected from 0 to 12 cm (0 to 5 in.), 12 to 30 cm (5 to 12 in.), 30 to 48 cm (12 to 19 in.), 48 to 59 cm (19 to 23.5 in.), and 59 to 74 cm (23.5 to 29.5 in.). At Station 06, samples were collected from 0 to 13 cm (0 to 5.5 in.), 13 to 29 cm (5.5 to 11.5 in.), 29 to 49 cm (11.5 to 19.5 in.), 49 to 62 cm (19.5 to 24.5 in.), and 62 to 76 cm (24.5 to 30 in.).

Sturm Site (WA). The Sturm Transect was located in an area mapped as Hamblen soil (Moneymāker 1981). The total depth of soils sampled ranged from 28.5 to 38.5 in. Soil morphology at the Sturm site was generally representative of Hamblen soil (Moneymaker 1981). Soil was generally deeper and had morphology indicative of better internal drainage than other soil transects sampled in the EFPC floodplain. Soil at Stations 01 to 03 was in a lower topographic position than Stations 04 to 06 on the south side of the creek. Soil at Stations 01 and 02 also showed evidence of disturbance, probably resulting from excavation for the new or old sewer lines. Soil horizons were indistinct at these two stations, and many horizons appeared to be mixed together.

At Station 01, samples were collected from 0 to 17 cm (0 to 7 in.), 17 to 30 cm (7 to 12 in.), 30 to 54 cm (12 to 21.5 in.), 54 to 68 cm (21.5 to 27 in.), and 68 to 91 cm (27 to 36 in.). At Station 02, samples were collected from 0 to 10 cm (0 to 4 in.), 10 to 35 cm (4 to 14 in.), 35 to 53 cm (14 to 21 in.), 53 to 71 cm (21 to 28 in.), and 71 to 97 cm (28 to 38.5 in.). At Station 03, samples were collected from 0 to 6 cm (0 to 2.5 in.), 6 to 27 cm (2.5 to 11 in.), 27 to 40 cm (11 to 16 in.), 40 to 63 cm (16 to 25 in.), and 63 to 87 cm (25 to 34.5 in.). At Station 04, samples were collected from 0 to 12 cm (0 to 5 in.), 12 to 44 cm (5 to 17.5 in.), 44 to 58 cm (17.5 to 23 in.), 58 to 73 cm (23 to 29 in.), and 73 to 93 cm (29 to 37 in.). At Station 05, samples were collected from 0 to 13 cm (0 to 5.5 in.), 13 to 24 cm (5.5 to 9.5 in.), 24 to 50 cm (9.5 to 20 in.), 50 to 66 cm (20 to 26 in.), and 66 to 81 cm (26 to 32 in.). At

Station 06, samples were collected from 0 to 16 cm (0 to 6.5 in.), 16 to 37 cm (6.5 to 14.5 in.), 37 to 47 cm (14.5 to 18.5 in.), 47 to 63 cm (18.5 to 25 in.), and 63 to 72 cm (25 to 28.5 in.).

Bruner's Center Site (BR). The Bruner's Center Transect was located in an area mapped as Newark soil (Moneymaker 1981). Soil morphology at all stations did not correspond well with the description of the Newark series. Soil at Stations 03 to 05 was more like Hamblen soil than Newark. Only at Station 06 did soil morphology match that of the Newark series. The total depth of soil sampled ranged from 63 to 114 cm (25 to 45 in.). Samples were collected only at five of the stations. Station 01 was not sampled because it was apparent from soil morphology that soil at Station 01 was upland soil used as fill material. The presence of large pieces of gravel (>4 in. diam.) made it impossible to advance sampling equipment far enough into the ground to collect samples at that location. Much of the soil at Station 02 also appeared to be fill, but without the large gravel. Only four horizons were sampled at Station 02 before encountering what appeared to be bedrock. Station 05 was located near the sewer lines, and soil morphology at this station suggested that the soil had been disturbed by sewer line excavation. At Stations 03 to 06, a layer of very dark black material that looked like coal dust was present about 6 in. below the surface. This layer was thickest at Stations 03 and 04 near the creek bank, where it was sometimes more than 1 ft thick. In previous studies, this black layer has been correlated with very high levels of mercury.

At Station 02, samples were collected from 0 to 19 cm (0 to 7.5 in.), 19 to 31 cm (7.5 to 12.5 in.), 31 to 44 cm (12.5 to 17.5 in.), and 44 to 63 cm (17.5 to 25 in.) before refusal of sampling equipment. At Station 03, samples were collected from 0 to 19 cm (0 to 7.5 in.), 19 to 43 cm (7.5 to 17 in.), 43 to 68 cm (17 to 27 in.), 68 to 81 cm (27 to 32 in.), and 81 to 96 cm (32 to 38 in.). At Station 04, samples were collected from 0 to 19 cm (0 to 7.5 in.), 19 to 43 cm (7.5 to 17 in.), 43 to 68 cm (17 to 27 in.), 68 to 81 cm (27 to 32 in.), and 81 to 94 cm (32 to 37 in.). At Station 05, samples were collected from 0 to 28 cm (0 to 11 in.), 28 to 41 cm (11 to 16 in.), 41 to 56 cm (16 to 22 in.), 56 to 91 cm (22 to 36 in.), and 91 to 114 cm (36 to 45 in.). At Station 06, samples were collected from 0 to 13 cm (0 to 5 in.), 13 to 25 cm (5 to 10 in.), 25 to 38 cm (10 to 15 in.), 38 to 56 cm (15 to 22 in.), and 56 to 76 cm (22 to 30 in.).

NOAA Site (NO). The NOAA site was located in an area mapped as Newark soil (Moneymaker 1981). Soil at all stations had a morphology consistent with the description of the Newark series. Soil at all stations was poorly drained, with low chroma, glei colors, and oxidized root channels in the upper horizons. At many of the stations, water was standing at the

surface or rose to the surface in the borehole. The black layer observed at the BR site was also evident here. Less evidence of disturbance was found at the NO site than at the other sites. Sampling depths ranged from 71 to 114 cm (28 to 45 in.), and soil profiles were well-developed.

At Station 01, samples were collected from 0 to 18 cm (0 to 7 in.), 18 to 44 cm (7 to 17.5 in.), 44 to 56 cm (17.5 to 22 in.), 56 to 71 cm (22 to 28 in.), and 71 to 83 cm (28 to 33 in.). At Station 02, samples were collected from 0 to 9 cm (0 to 3.5 in.), 9 to 24 cm (3.5 to 9.5 in.), 24 to 38 cm (9.5 to 15 in.), 38 to 58 cm (15 to 23 in.), and 58 to 71 cm (23 to 28 in.). At Station 03, samples were collected from 0 to 12 cm (0 to 5 in.), 12 to 38 cm (5 to 9 in.), 23 to 33 cm (9 to 13 in.), 33 to 63 cm (13 to 25 in.), and 63 to 89 cm (25 to 35 in.). At Station 04, samples were collected from 0 to 10 cm (0 to 4 in.), 10 to 32 cm (4 to 12.5 in.), 32 to 46 cm (12. 5 to 18 in.), 46 to 91 cm (18 to 36 in.), and 91 to 117 cm (36 to 46 in.). At Station 05, samples were collected from 0 to 20 cm (0 to 8 in.), 20 to 30 cm (8 to 12 in.), 30 to 57 cm (12 to 22.5 in.), 57 to 99 cm (22.5 to 39 in.), and 99 to 109 cm (39 to 43 in.). At Station 06, samples were collected from 0 to 11 cm (0 to 4.5 in.), 11 to 22 cm (4.5 to 8.5 in.), 22 to 42 cm (8.5 to 16.5 in.), 42 to 55 cm (16.5 to 21.5 in.), and 55 to 83 cm (21.5 to 32.5 in.).

3.2.6.3 Results

Samples from the three EFPC sites and the two transects at Hinds Creek were submitted for soil chemistry characterization, which included extractable acidity; extractable bases (cadmium, potassium, magnesium, sodium); TOC; and pH. Table 3.33 summarizes the results of the analyses.

For all horizons, extractable acidity is lower at the contaminated sites (ranging from 1.84 to 4.99 meq/100 g) than at the reference site, where values range from 4.08 to 7.52 meq/100 g. In the upper horizons, extractable bases are higher at the contaminated sites than at the reference site, but in the deeper horizons (e.g., Horizons 3, 4, and 5), this relationship is not as apparent.

TOC is higher at the EFPC sites, especially in the top two horizons at BR, where values ranged from 4.64 to 5.19%, and to a lesser degree in the upper horizons at the NO site (3.01 and 2.67%). TOC values at the reference site for the upper two horizons ranged from 0.34 to 1.3%. TOC levels are higher in the Newark soils at HC and also at NO and BR, which were mapped as Newark soil. TOC levels at WA (Hamblen soil) are lower than in Newark soil, although still higher than in Hamblen soil at the reference site.

Table 3.33. EFPC geotechnical soil samples - soil chemistry

HORIZON 1

GEOTECHNICAL PARAMETERS *	SAMPLE LOCATION				
				Hind's Creek	
	NOAA[N]	Bruner's[N]	Sturm's[H]	Hamblen	Newark
Ext. Acidity (MEQ/100G)	4.99	3.52	3.42	5.55	7.52
Extractable CA (PPM)	1542.33	2941.2	2283.83	807	823.83
Extractable K (PPM)	81.33	107.00	93.00	73.50	51.50
Extractable Mg (PPM)	175.67	178.40	156.17	137.17	95.83
Extractable Na (PPM)	10.5	13	19.17	12.33	12.33
TOC	3.01	4.64	2.56	0.74	1.71
pH	6.37	7.18	7.03	5.73	5.50

HORIZON 2

GEOTECHNICAL PARAMETERS *	SAMPLE LOCATION				
				Hind's Creek	
	NOAA[N]	Bruner's[N]	Sturm's[H]	Hamblen	Newark
Ext. Acidity (MEQ/100G)	3.38	3.33	2.5	5.39	5.99
Extractable CA (PPM)	1478	3022.2	1863.5	706.5	891.83
Extractable K (PPM)	65.67	65.60	65.33	51.17	48.67
Extractable Mg (PPM)	144.17	177.40	130.00	126.17	96.00
Extractable Na (PPM)	10	15.4	17.67	12.17	11.83
TOC	2.67	5.19	1.26	0.34	1.3
pH	6.58	7.34	7.02	5.85	5.88

HORIZON 3

GEOTECHNICAL PARAMETERS*	SAMPLE LOCATION				
				Hind's Creek	
	NOAA[N]	Bruner's[N]	Sturm's[H]	Hamblen	Newark
Ext. Acidity (MEQ/100G)	2.75	2.02	2.85	5.23	4.52
Extractable CA (PPM)	1125.5	2680.8	1653.67	1067.17	1042.67
Extractable K (PPM)	45	52.6	48.17	62.5	74.67
Extractable Mg (PPM)	184.50	151.80	106.17	147.17	131.33
Extractable Na (PPM)	10.17	14.00	17.00	14.17	15.67
TOC	0.86	1.51	0.86	0.41	0.87
pH	6.55	7.46	6.98	6.05	6.52

HORIZON 4

GEOTECHNICAL PARAMETERS *	SAMPLE LOCATION				
				Hind's Creek	
	NOAA[N]	Bruner's[N]	Sturm's[H]	Hamblen	Newark
Ext. Acidity (MEQ/100G)	1.97	1.84	3.17	4.63	4.7
Extractable CA (PPM)	707.5	2265.2	1515.33	1590.5	830.75
Extractable K (PPM)	46	47.6	45.67	101.17	63
Extractable Mg (PPM)	239.83	129.20	99.67	168.83	113.00
Extractable Na (PPM)	11.17	15.60	16.33	15.67	14.75
TOC	0.4	3.07	0.85	0.03	0.95
pH	6.85	7.38	6.98	6.30	6.43

HORIZON 5

GEOTECHNICAL PARAMETERS*	SAMPLE LOCATION				
				Hind's Creek	
	NOAA[N]	Bruner's[N]	Sturm's[H]	Hamblen	Newark
Ext. Acidity (MEQ/100G)	2.27	2.7	3.24	4.08	4.75
Extractable CA (PPM)	761.83	1985.5	1533.2	1599.00	1090.25
Extractable K (PPM)	50.67	42.25	46.2	80.25	83.25
Extractable Mg (PPM)	306.00	122.75	94.20	156.00	161.50
Extractable Na (PPM)	12.33	18.25	18.40	15.75	15.25
TOC	0.48	0.63	1.03	0.32	0.96
pH	6.90	7.13	6.78	6.65	6.63

* Represents an average per site

[H]Sample collected from the Hamblen Soil Series

[N]Sample collected from the Newark Soil Series

Measurements for pH are higher at the EFPC sites than at HC, with a range in Horizon 1 from 6.37 at NO to 7.18 at BR, and at HC between 5.5 and 5.73. With increasing depth, the difference in pH between the contaminated sites and the reference site becomes less obvious. BR shows consistently higher pH values than the other sites.

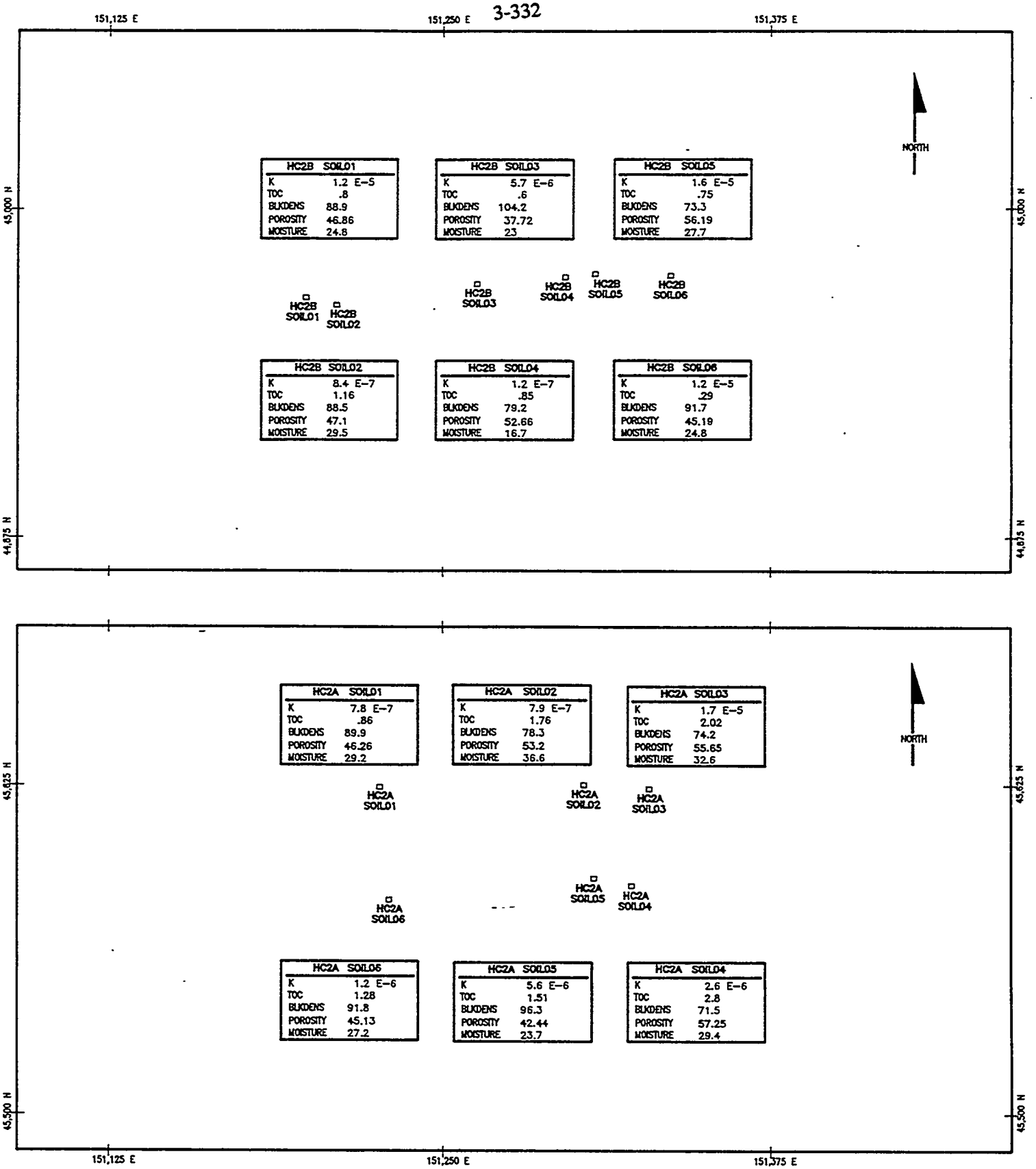
As part of the geotechnical investigation, undisturbed cores were collected for hydraulic conductivity analysis using thin-walled sampling tubes in accordance with EPA-SW846-Method 9100. Stainless steel Shelby tubes (30 in. long and 3 in. in diameter) were driven to a maximum depth of 1.5 m (60 in.). The tubes were capped and delivered to Singleton Laboratories for extrusion of the soil core and analysis of geotechnical parameters including hydraulic conductivity (K), bulk density, porosity (n), and moisture content. Figures 3.112 through 3.131 give a summary of these data for each horizon at the four sites. Values from each of the six stations along the transect at each site were averaged to yield the summary data in Table 3.34.

K ranged from a high of 4.09×10^{-5} cm/sec in Horizon 2 of the BR site to a low of 7.3×10^{-8} cm/sec in Horizon 4, also at the BR site. There is, as expected, a general decrease in hydraulic conductivity with depth, although when the four sites are averaged, Horizon 2 is somewhat more conductive (average conductivity was 1.58×10^{-5}) than the other horizons, which ranged in average conductivity from 1.16×10^{-6} to 8.55×10^{-6}.

Bulk density values ranged from a low of 67.28 lb/ft^3 in Horizon 1 (NO) to a high of 96.40 lb/ft^3 in Horizon 5 (also NO). The BR site had significantly lower bulk density in Horizons 2, 4, and 5 than the other sites. This may be due to the fact that several stations at this site apparently have been disturbed by sewer line construction. As expected, bulk density increases with depth, from a range of 67.28 to 87.63 lb/ft^3 in Horizon 1 to a range of 84.85 to 96.40 lb/ft^3 in Horizon 5.

Average porosity (n) values, likewise, generally decrease with depth. Porosity averaged 54.15% in Horizon 1 and 45.78% in Horizon 5. At the individual sites, only WA data show a continuous decrease in n with depth. At the NO site, the highest n (62.51%) was found in Horizon 3; at BR, Horizon 2 has the highest n (59.79%).

Moisture content also generally decreases from Horizon 1 to 5. At the NO site, the average moisture content at Horizon 1 is 57%, decreasing to 28.21% in Horizon 5. This site had the greatest range in moisture content with depth. It was noted that soil at all NO stations was poorly drained, with water standing at the surface. The BR site data show no pattern of moisture content with depth, ranging from 47.64 to 29.06% overall, and the WA data show Horizons 1 and 5 to



UNITS:
Hg – mg/kg
PCB (Total) – ug/kg
U – pci/g
K – cm/sec

LEGEND
Total Organic Carbon (TOC) – %
BLKDENS – pcf
POROSITY – %
MOISTURE – %

SCALE
1"=50'
0 50' 100'

Fig. 3.112. Geotechnical data for Horizon 1 - Hinds Creek Sites. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

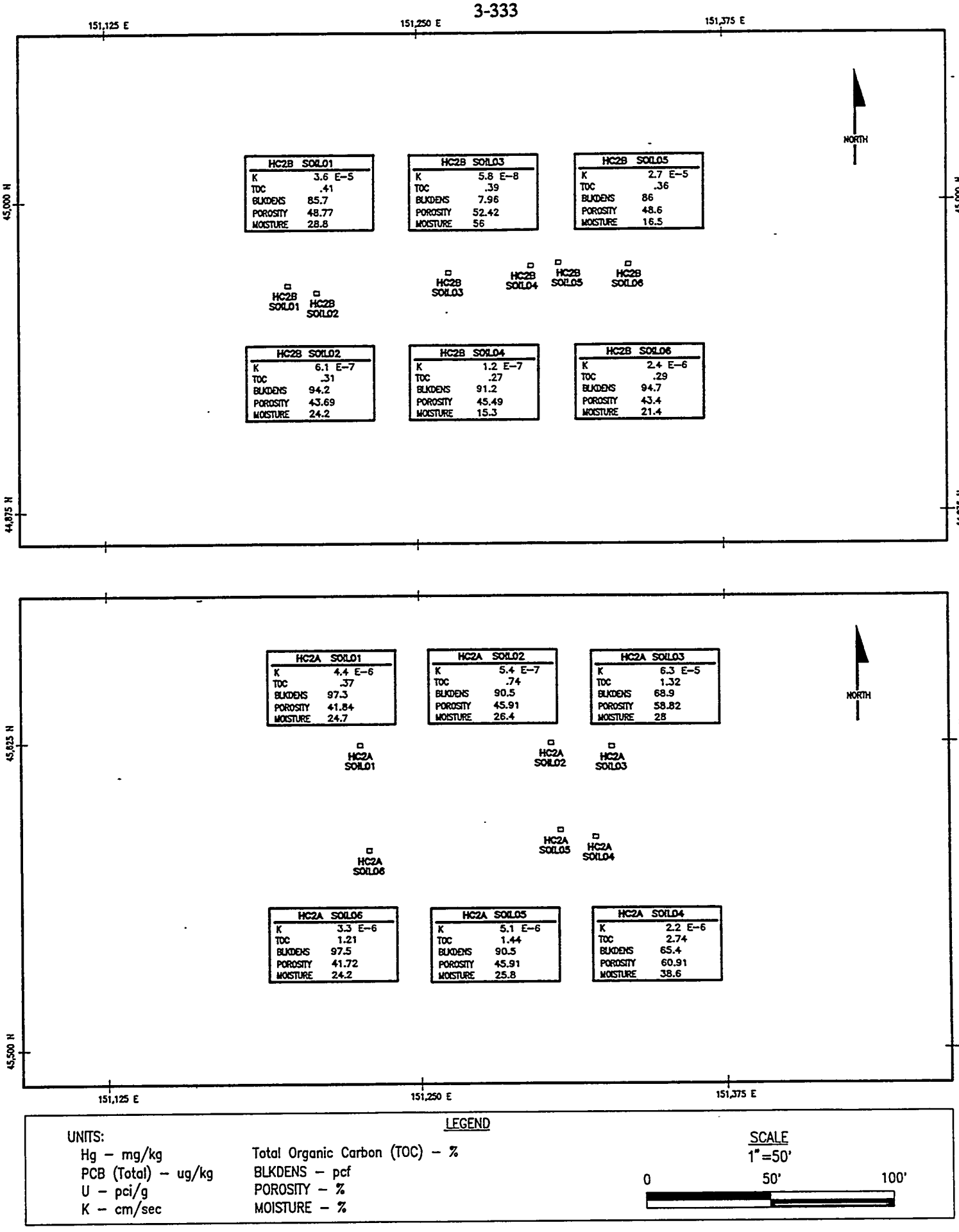


Fig. 3.113. Geotechnical data for Horizon 2 - Hinds Creek Sites. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

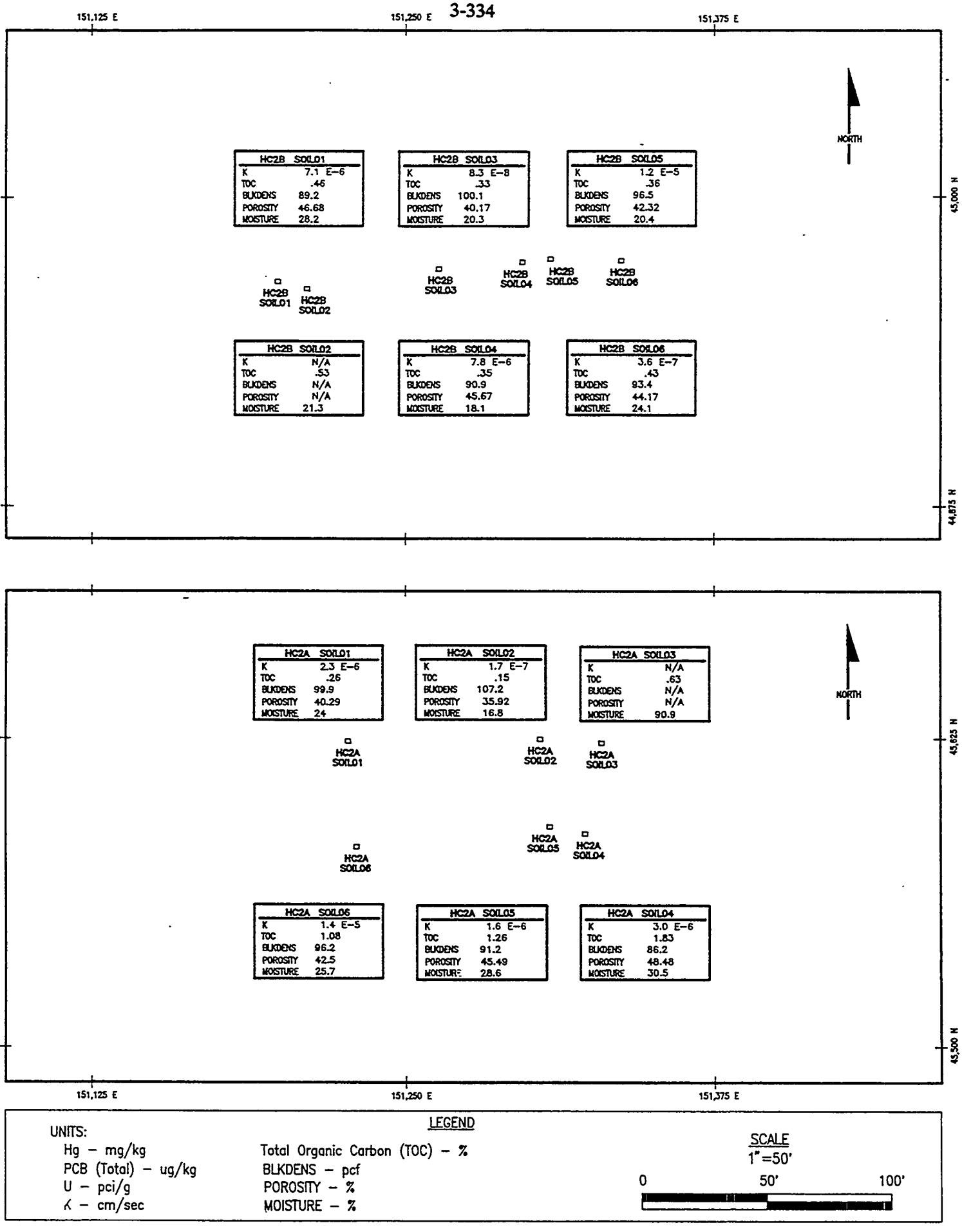


Fig. 3.114. Geotechnical data for Horizon 3 - Hinds Creek Sites. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

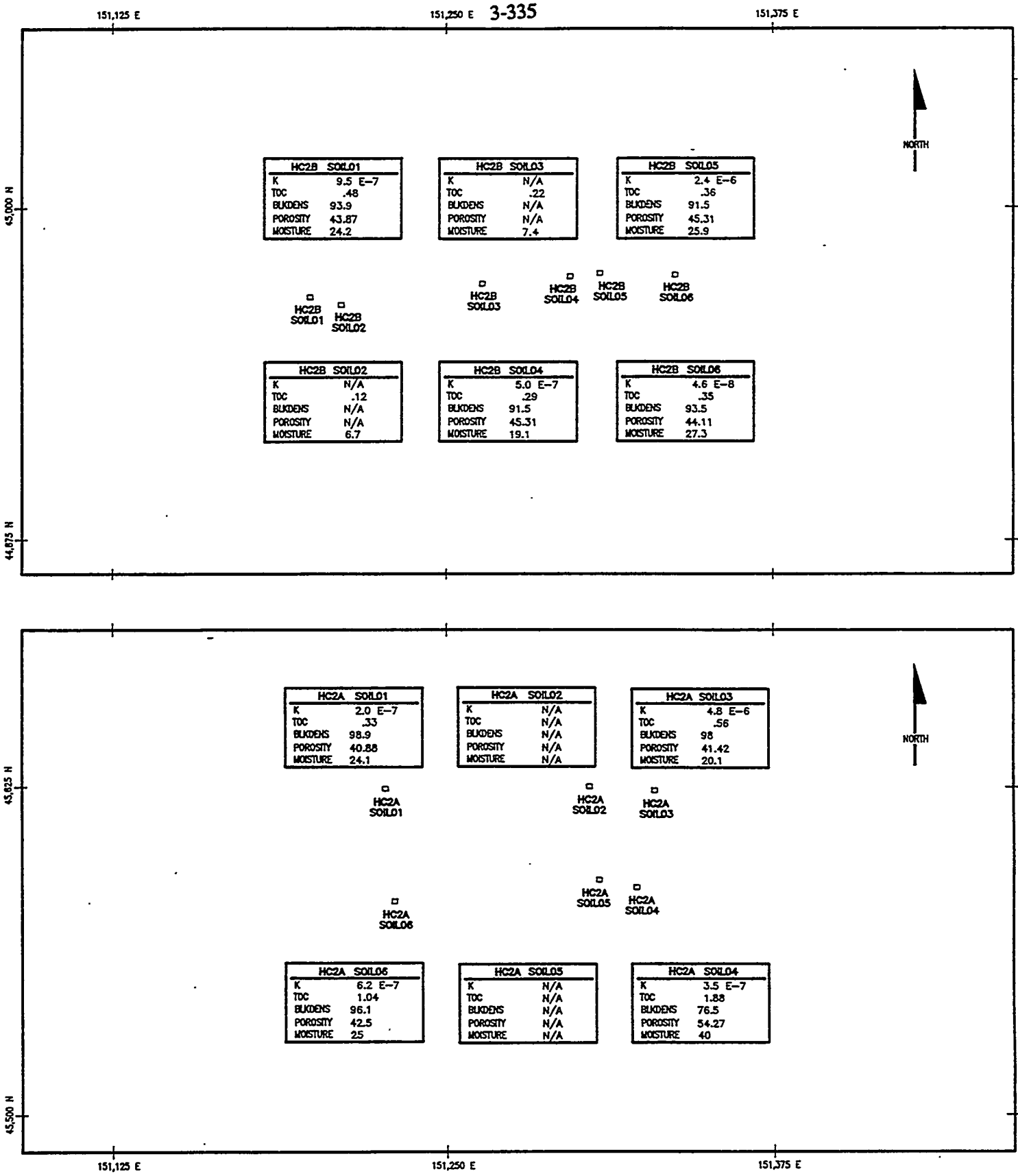


Fig. 3.115. Geotechnical data for Horizon 4 - Hinds Creek Sites. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

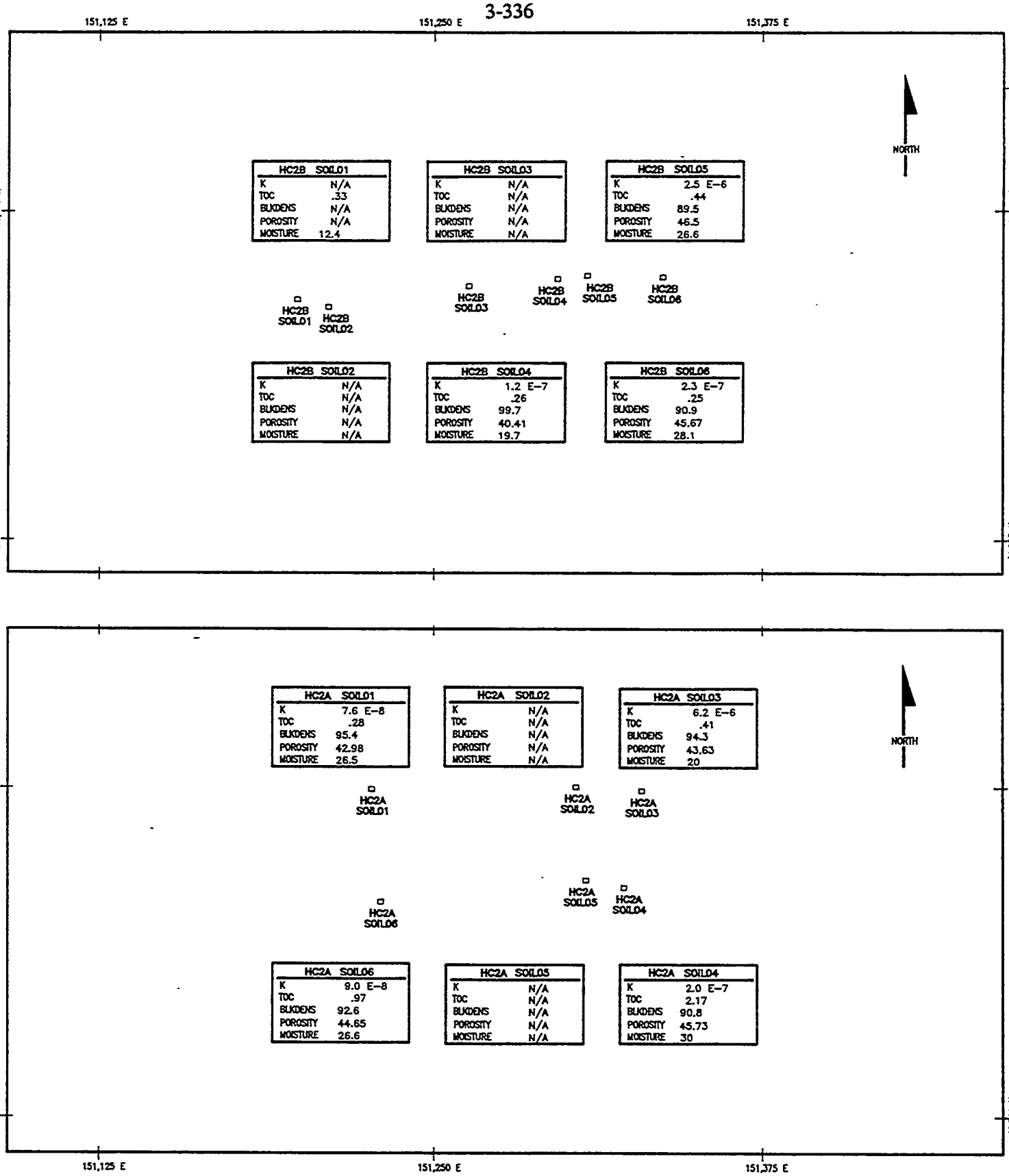


Fig. 3.116. Geotechnical data for Horizon 5 - Hinds Creek Sites. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

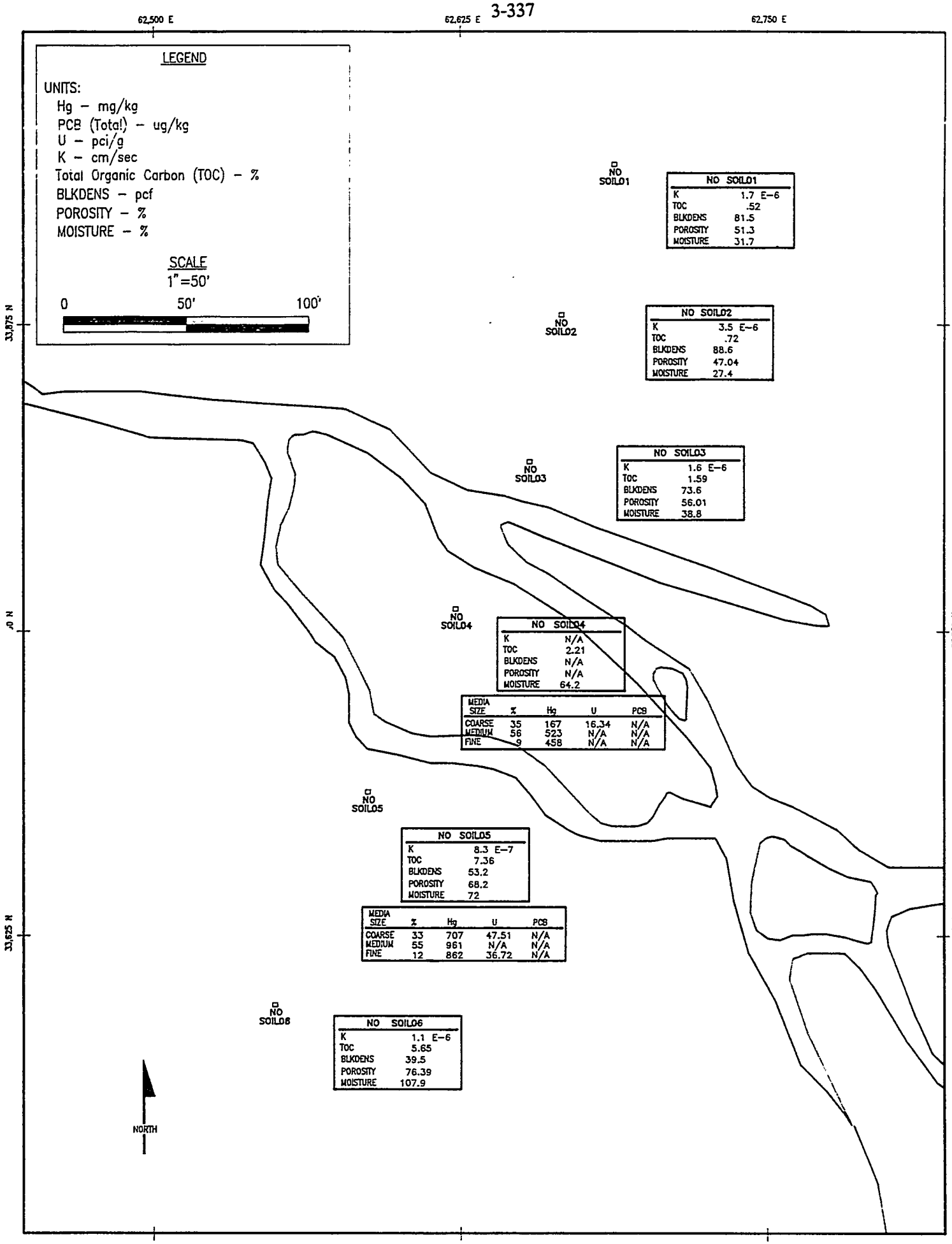


Fig. 3.117. Geotechnical data for Horizon 1 - NOAA Site. Geotechnical data are summarized in Table 3.34, and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

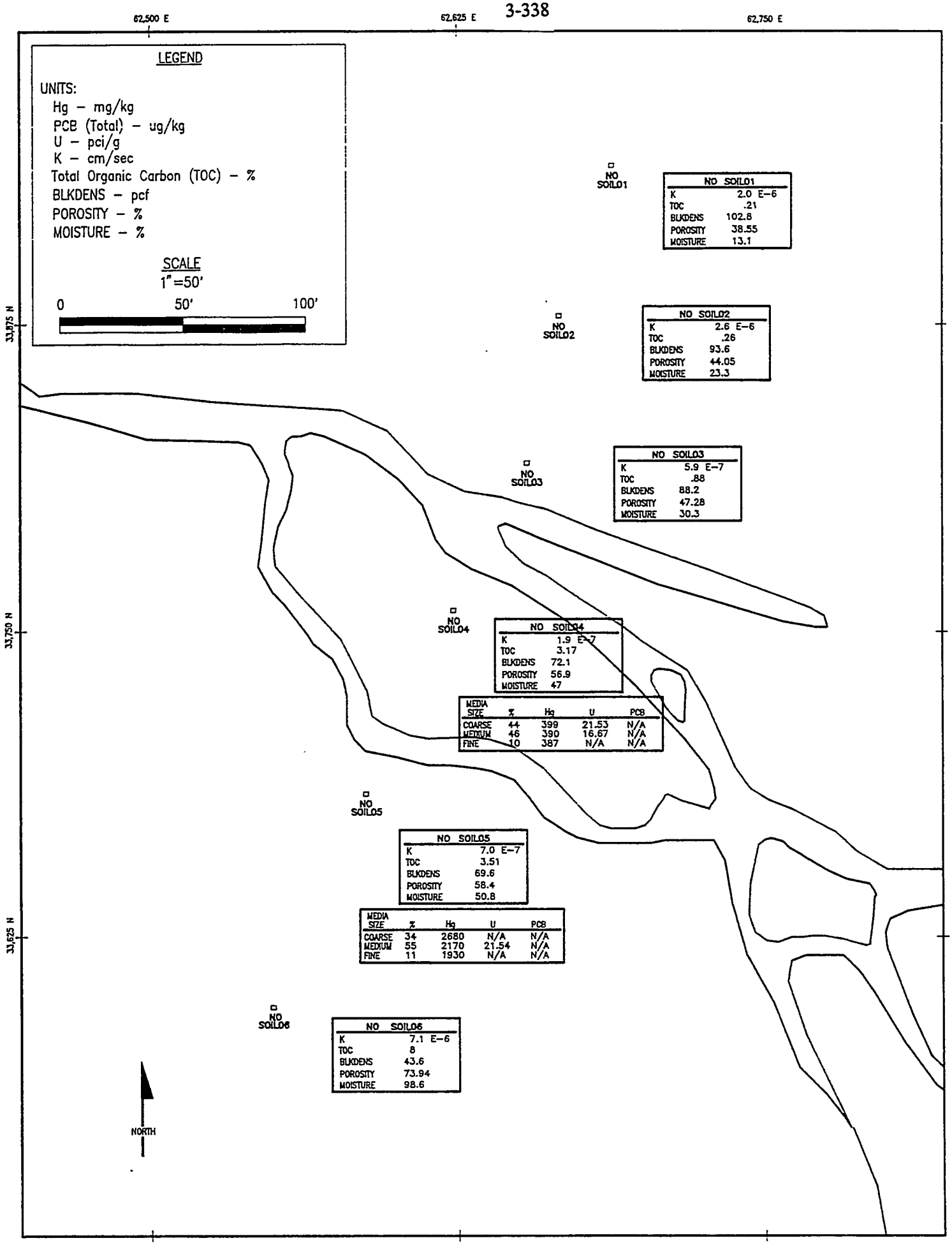


Fig. 3.118. Geotechnical data for Horizon 2 - NOAA Site. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

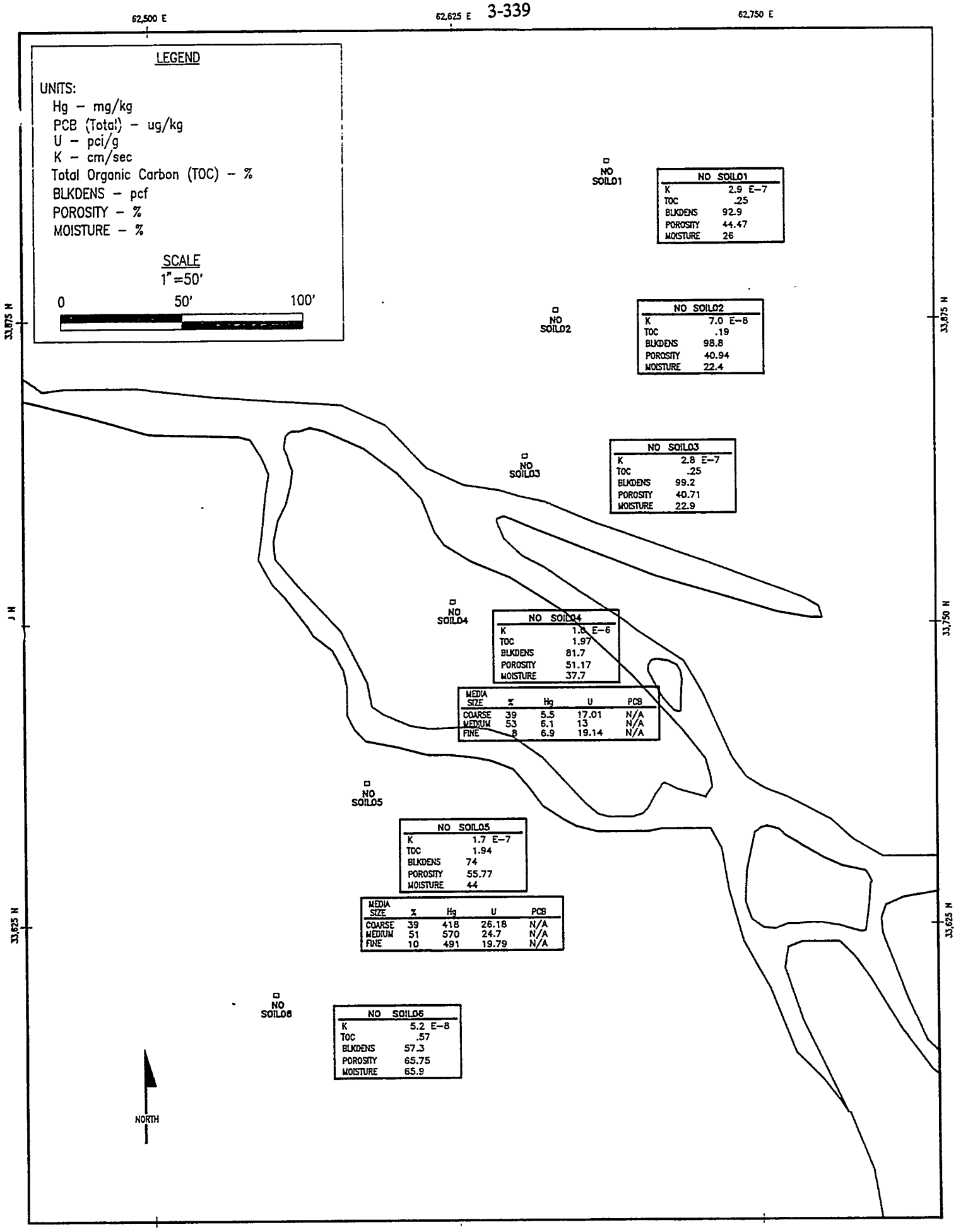


Fig. 3.119. Geotechnical data for Horizon 3 - NOAA Site. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

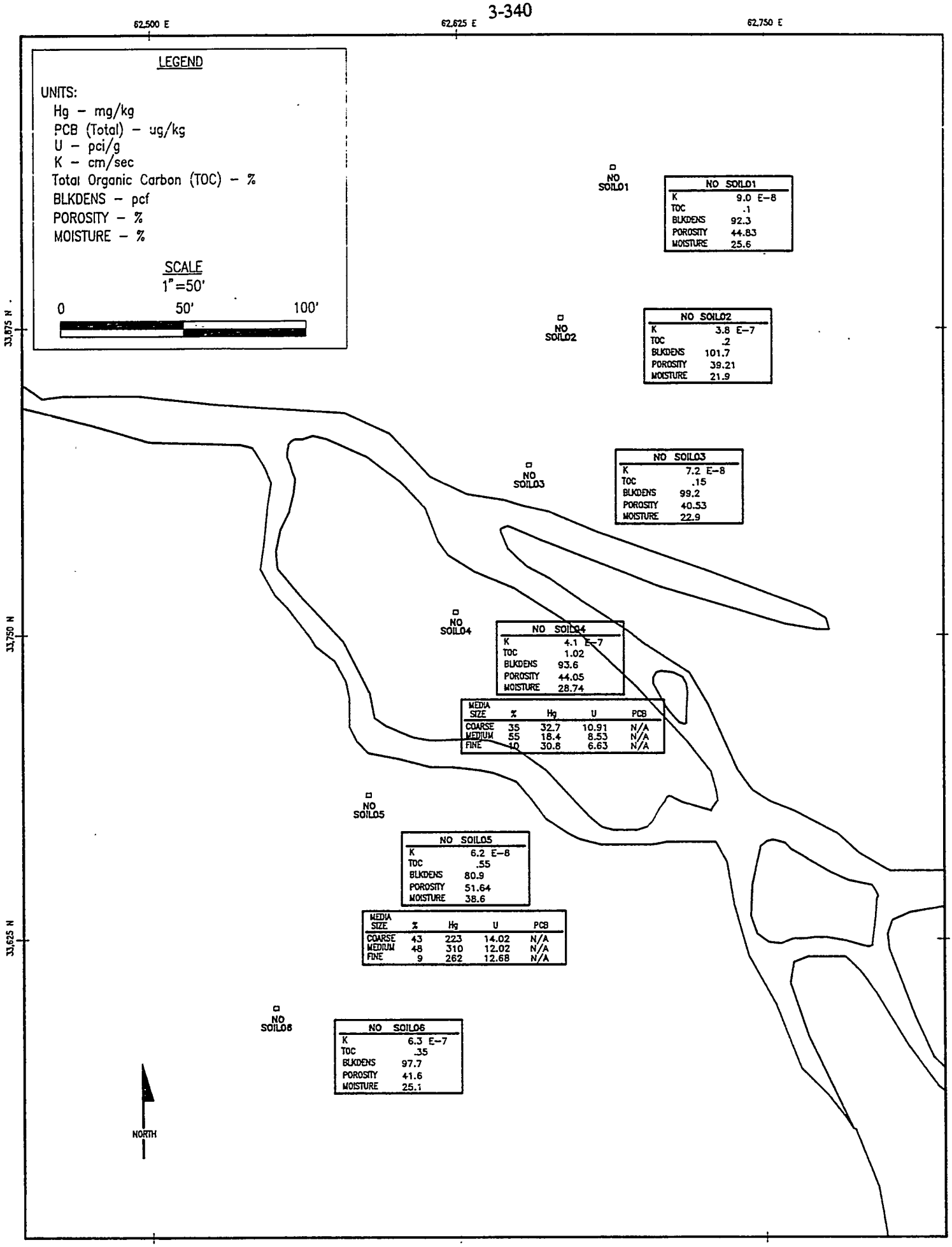


Fig. 3.120. Geotechnical data for Horizon 4 - NOAA Site. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

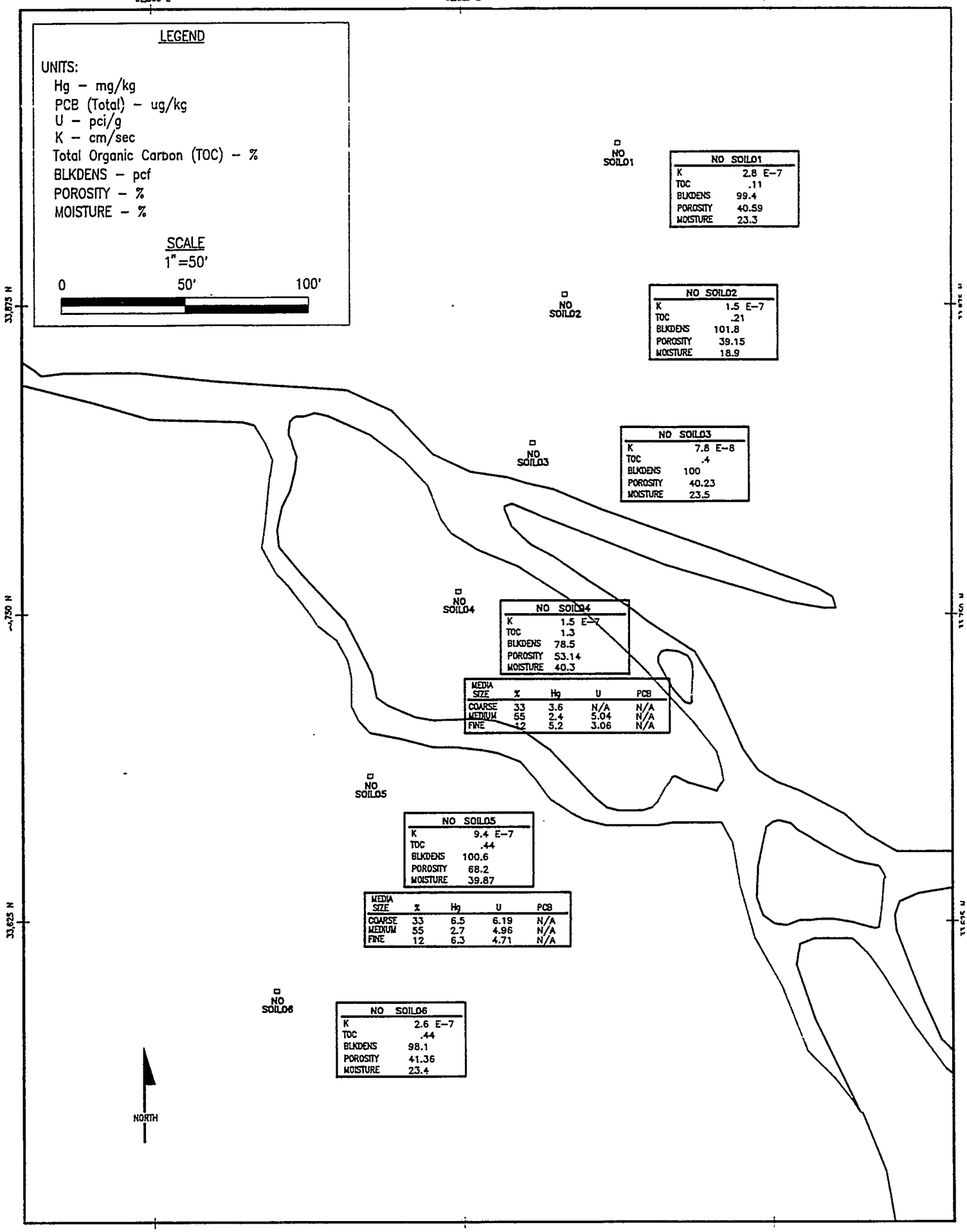


Fig. 3.121. Geotechnical data for Horizon 5 - NOAA Site. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

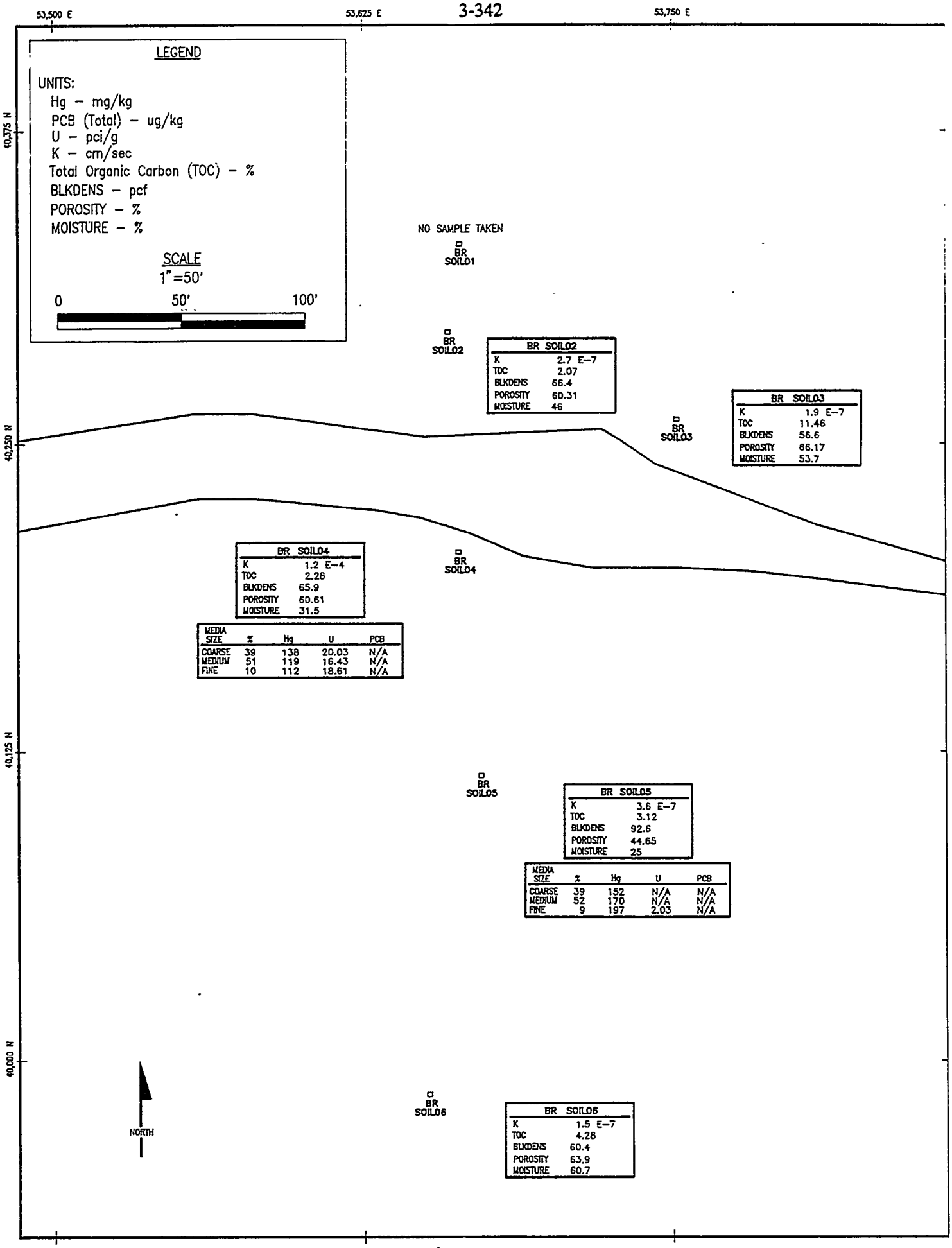


Fig. 3.122. Geotechnical data for Horizon 1 - Bruner's Site. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

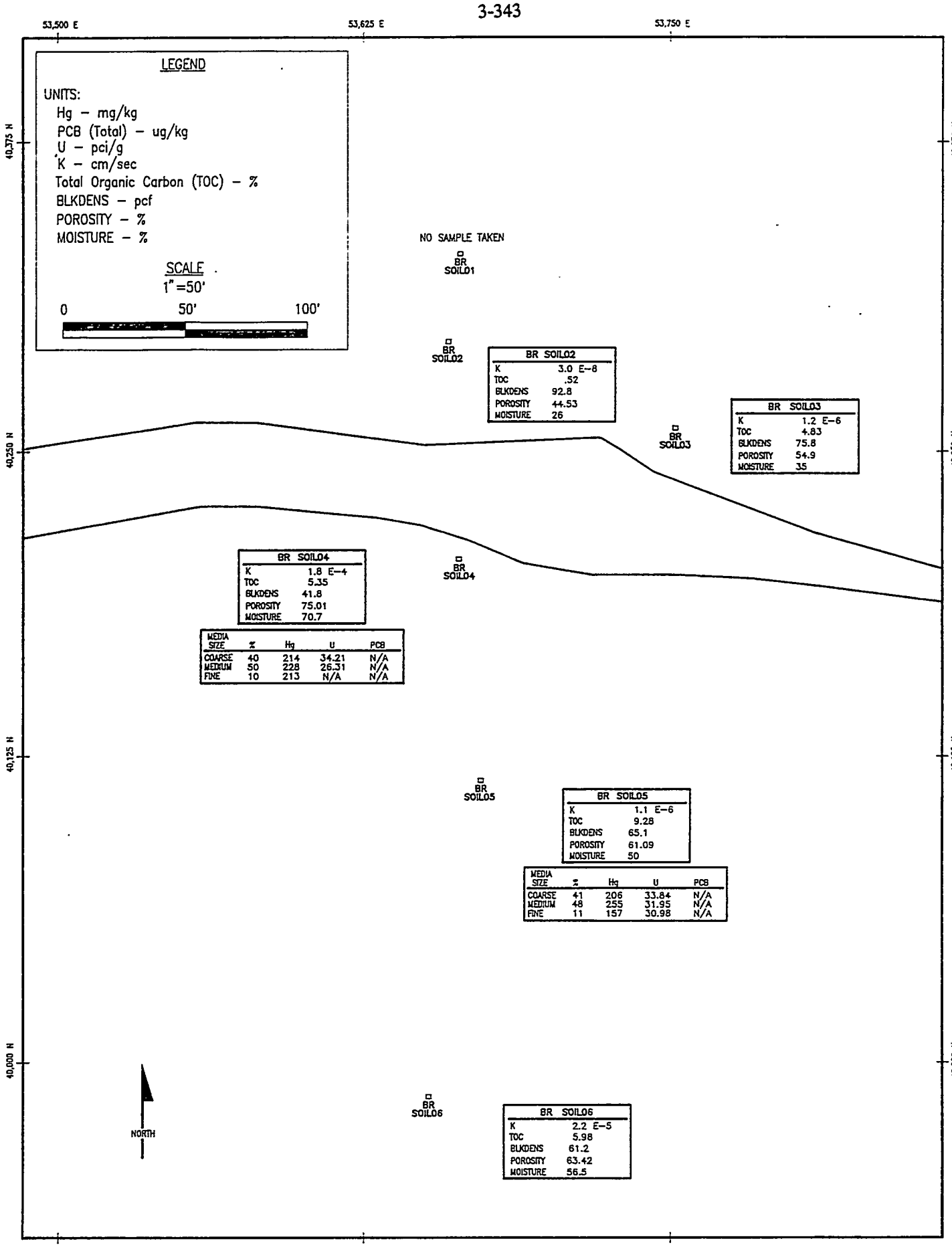


Fig. 3.123. Geotechnical data for Horizon 2 - Bruner's Site. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

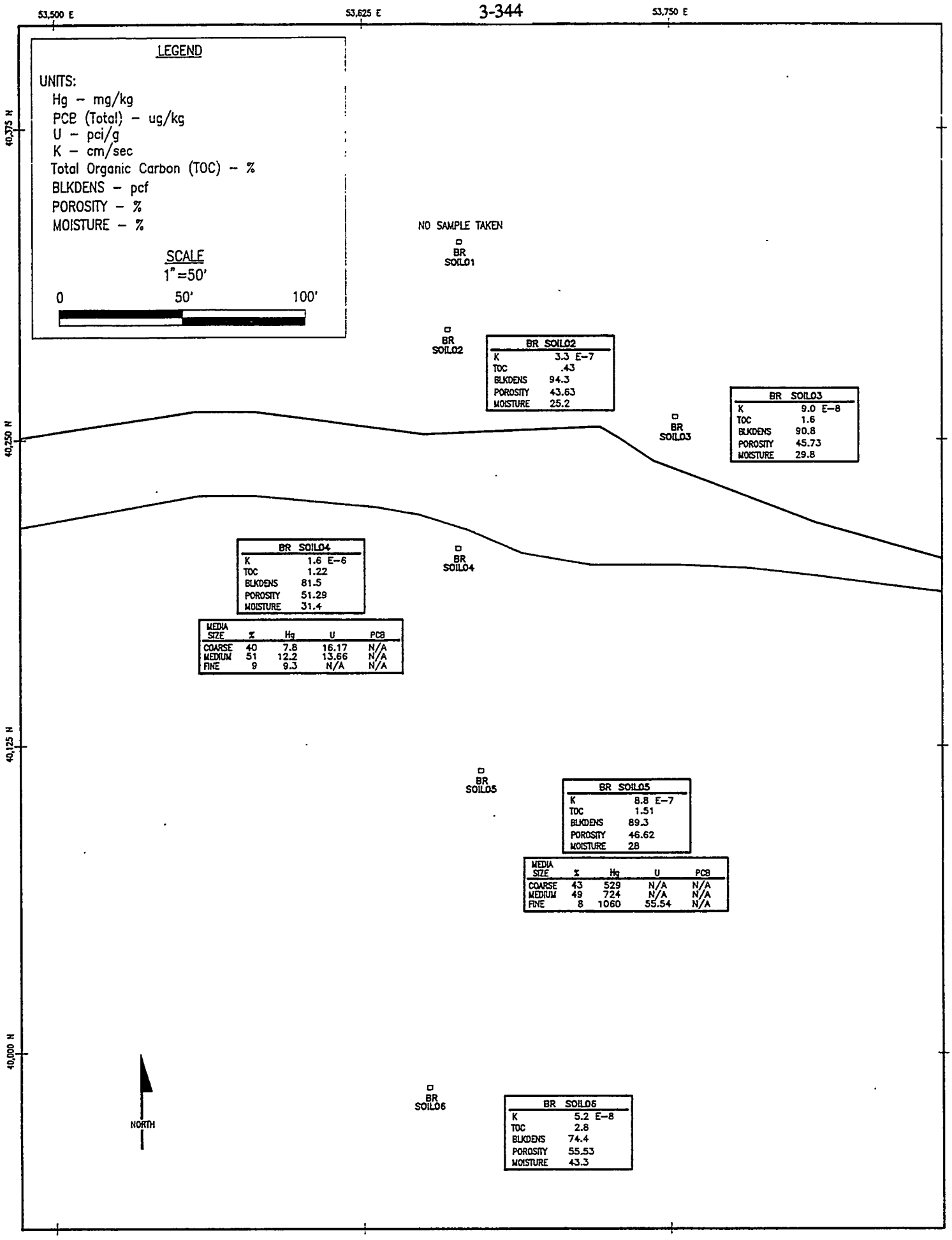


Fig. 3.124. Geotechnical data for Horizon 3 - Bruner's Site. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

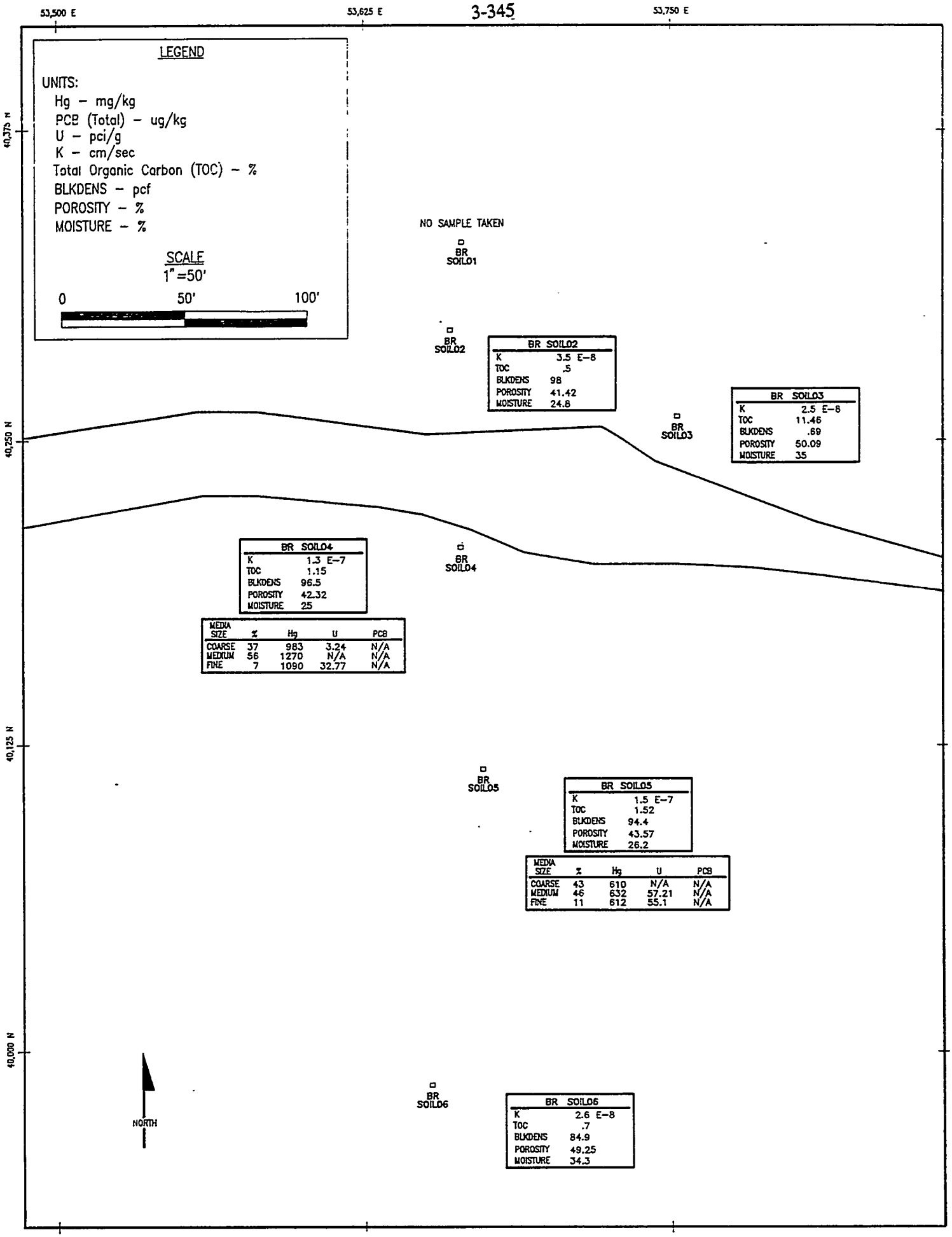


Fig. 3.125. Geotechnical data for Horizon 4 - Bruner's Site. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

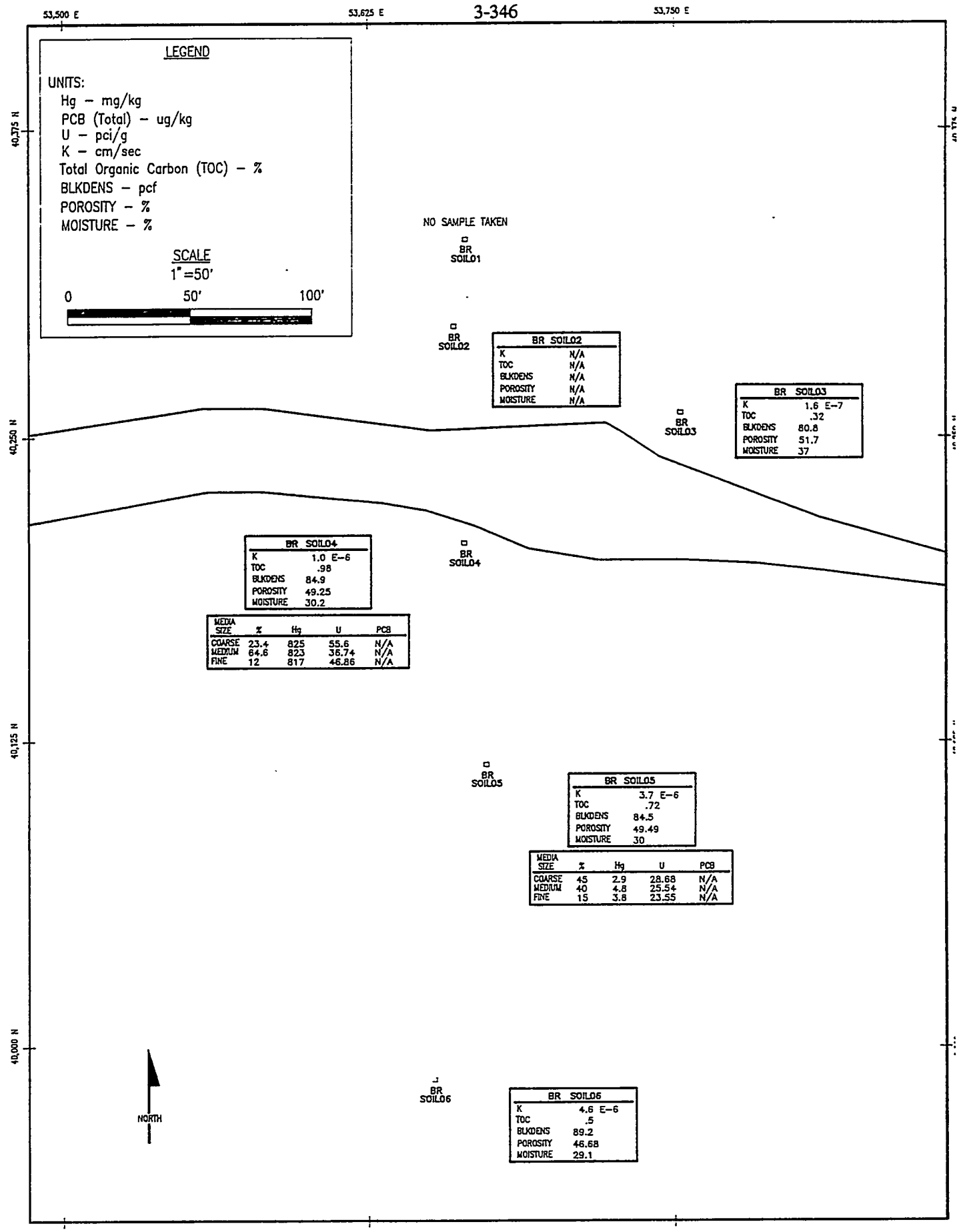


Fig. 3.126. Geotechnical data for Horizon 5 - Bruner's Site. Geotechnical data are summarized in Table 3.34, and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

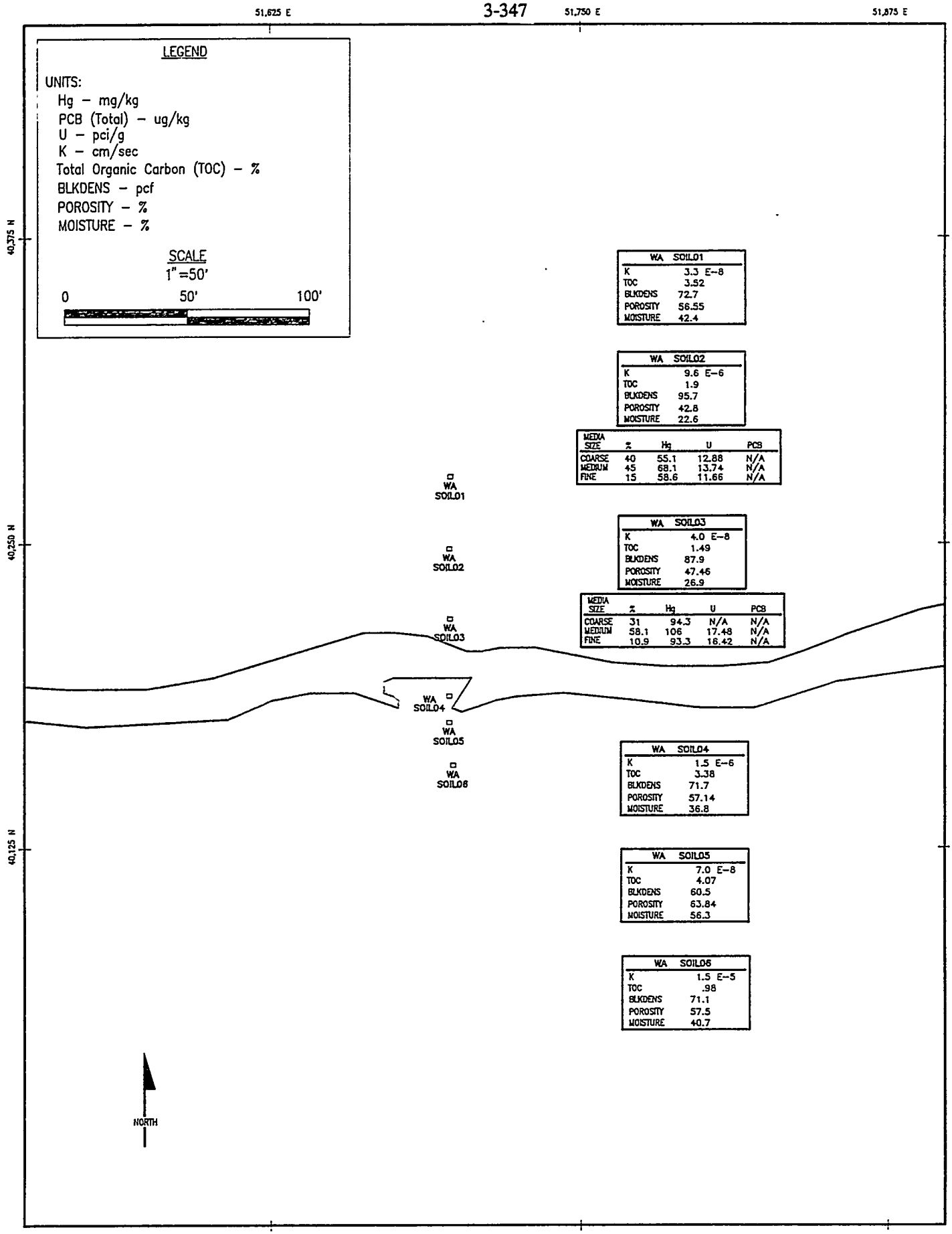


Fig. 3.127. Geotechnical data for Horizon 1 - Sturm Site. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

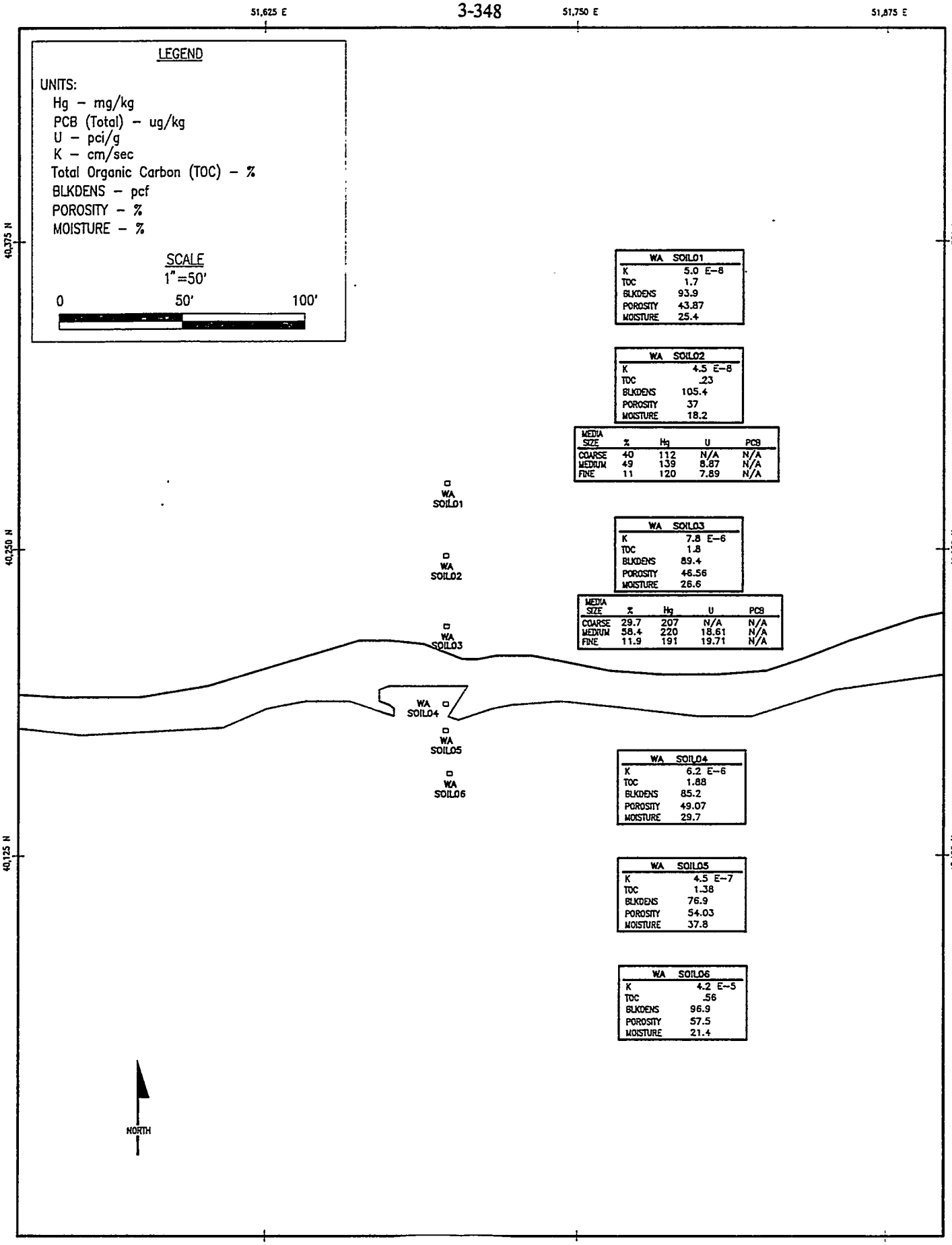


Fig. 3.128. Geotechnical data for Horizon 2 - Sturm Site. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

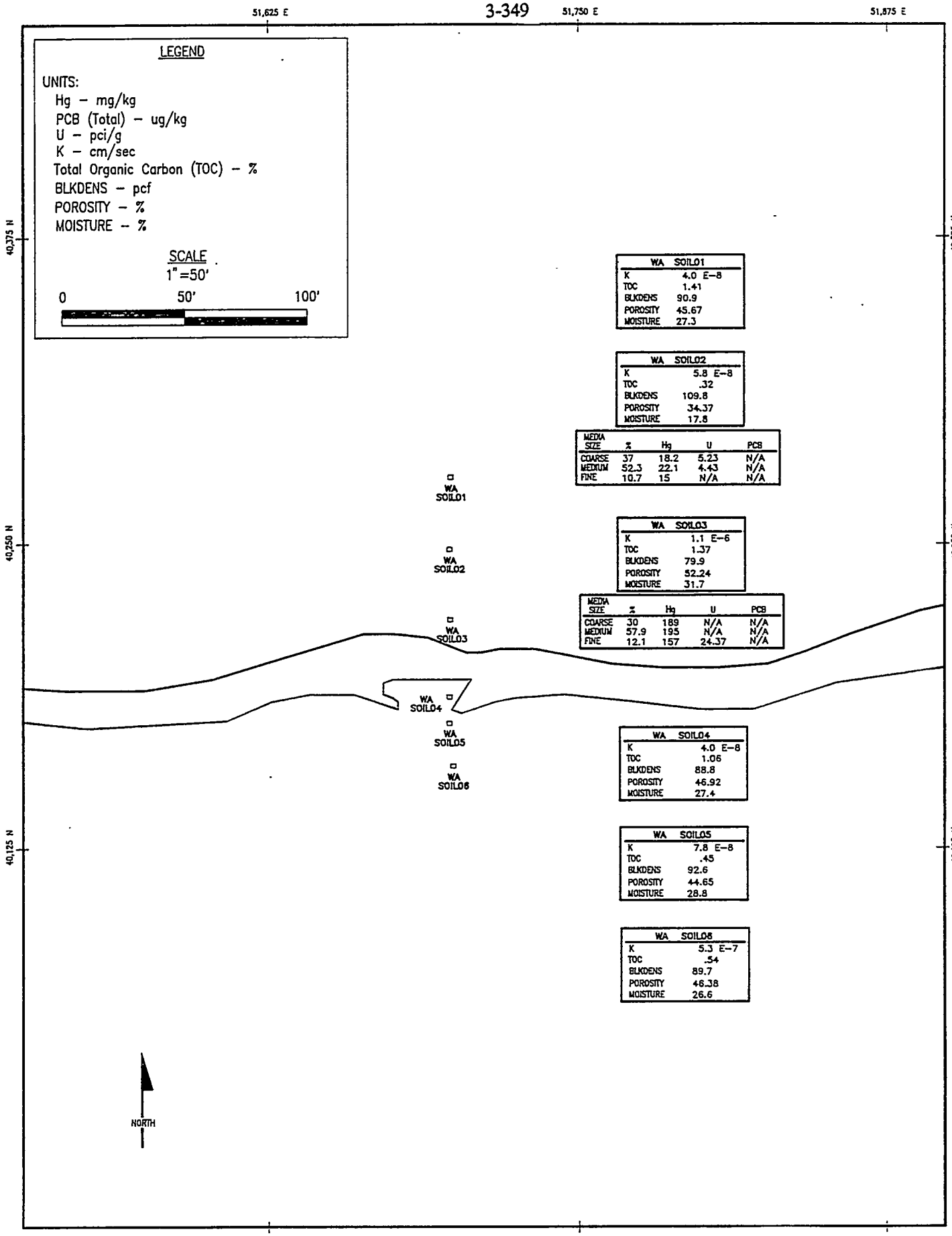


Fig. 3.129. Geotechnical data for Horizon 3 - Sturm Site. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

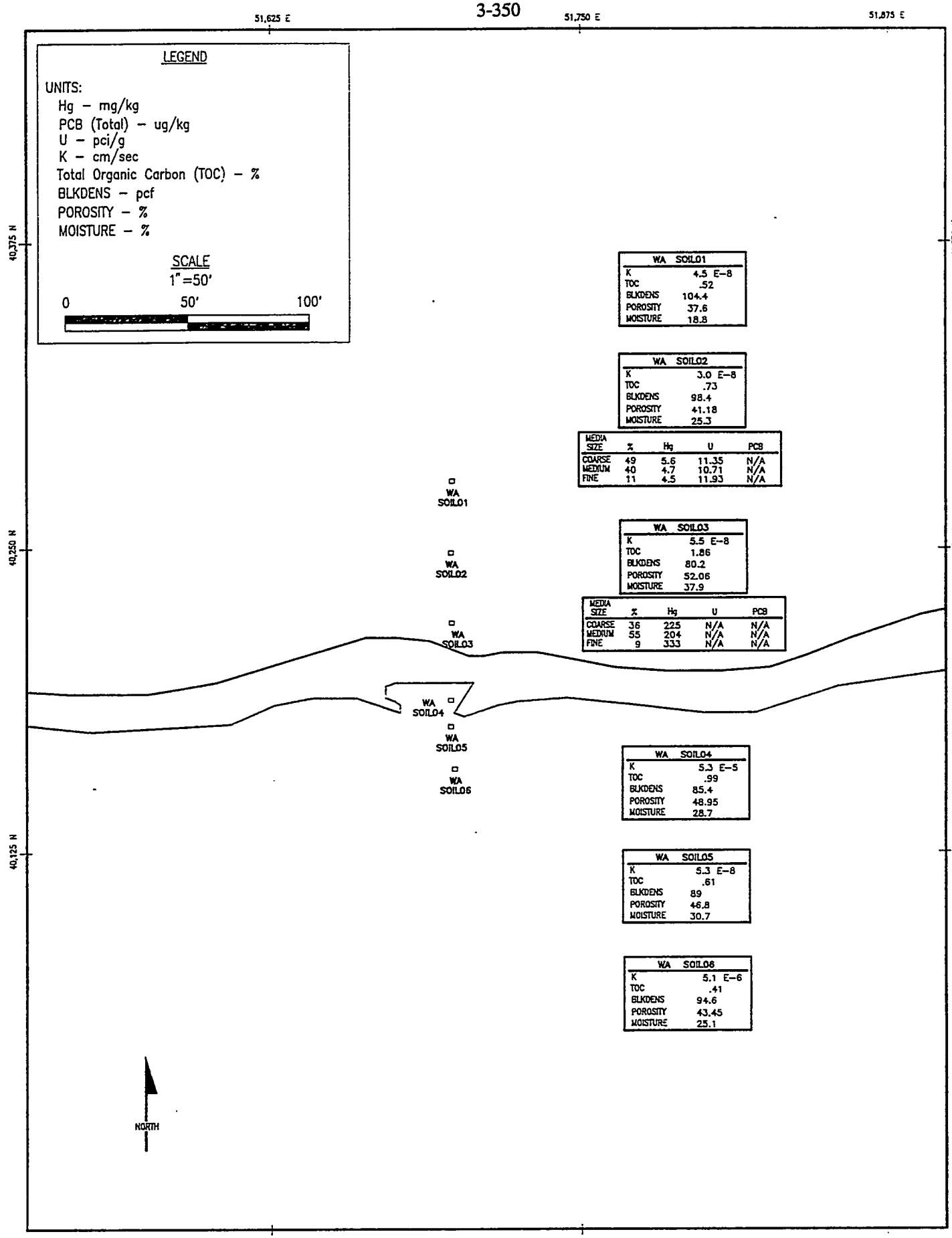


Fig. 3.130. Geotechnical data for Horizon 4 - Sturm Site. Geotechnical data are summarized in Table 3.34, and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

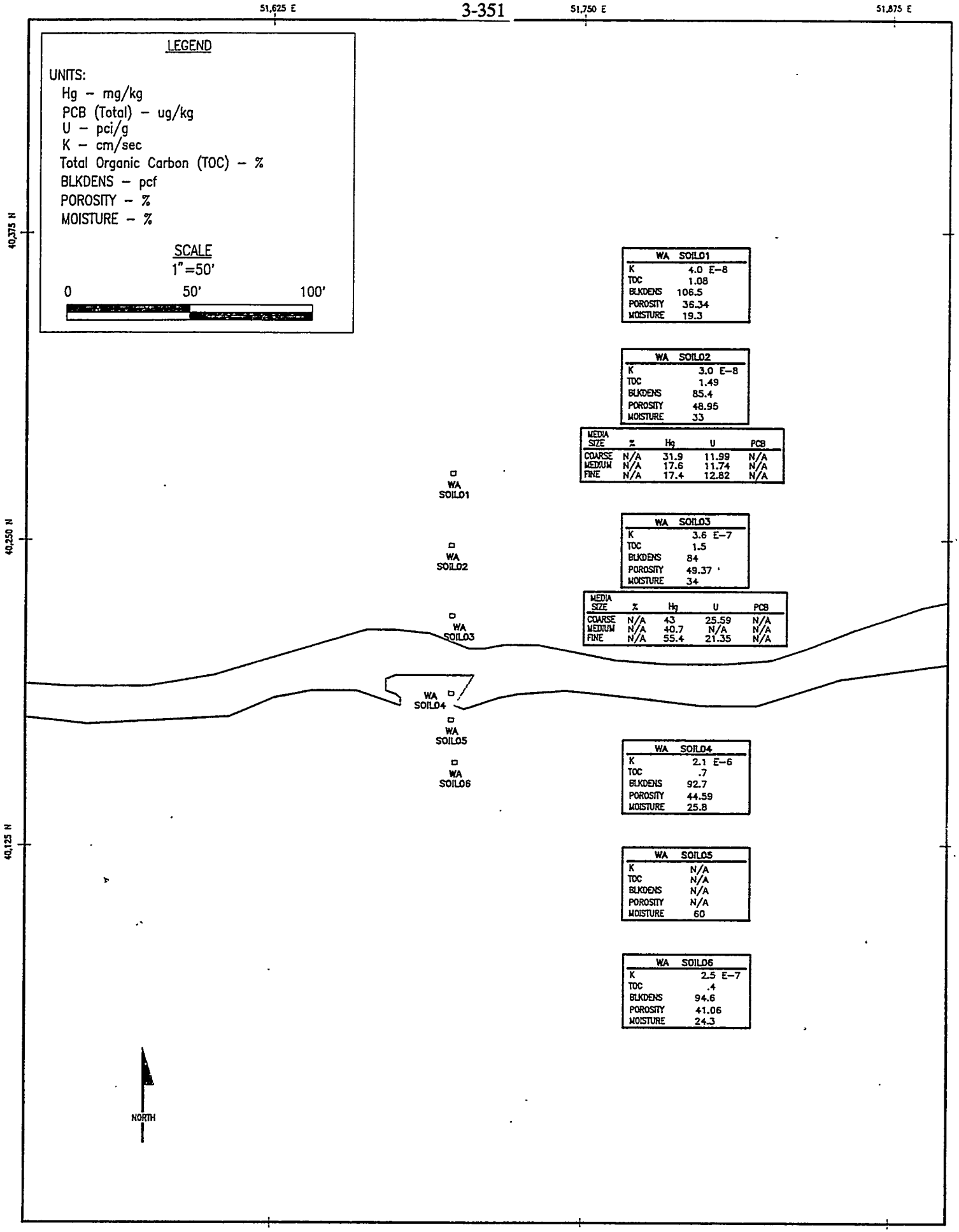


Fig. 3.131. Geotechnical data for Horizon 5 - Sturm Site. Geotechnical data are summarized in Table 3.34 and depths sampled at each horizon are listed in Table 3.35 with grain size distributions.

Table 3.34. EFPC geotechnical soil samples - geotechnical parameters

HORIZON 1

GEOTECHNICAL PARAMETERS *	SAMPLE LOCATION				
				Hind's Creek	
	NOAA[N]	Bruner's[N]	Sturm's[H]	Hamblen	Newark
K (cm/sec)	1.75 E-6	2.42 E-5	4.37 E -6	7.78 E-6	4.66 E-6
BLKDENS (pcf)	67.28	68.38	76.60	87.63	83.67
POROSITY (%)	59.79	59.13	54.22	47.62	49.99
MOISTURE (%)	57.00	43.38	37.62	24.42	29.78

HORIZON 2

GEOTECHNICAL PARAMETERS *	SAMPLE LOCATION				
				Hind's Creek	
	NOAA[N]	Bruner's[N]	Sturm's[H]	Hamblen	Newark
K (cm/sec)	2.20 E-6	4.09 E -5	9.42 E -6	1.10 E-5	1.31 E-5
BLKDENS (pcf)	78.32	67.34	91.28	76.63	85.02
POROSITY (%)	53.19	59.79	48.01	47.06	49.19
MOISTURE (%)	43.85	47.64	26.52	27.03	27.95

HORIZON 3

GEOTECHNICAL PARAMETERS*	SAMPLE LOCATION				
				Hind's Creek	
	NOAA[N]	Bruner's[N]	Sturm's[H]	Hamblen	Newark
K (cm/sec)	3.1 E-7	5.9 E-7	3.08 E -7	5.47 E-6	4.21 E-6
BLKDENS (pcf)	84.00	86.06	91.95	94.02	96.14
POROSITY (%)	62.51	48.56	45.04	43.80	42.54
MOISTURE (%)	36.48	31.54	26.60	22.07	36.08

HORIZON 4

GEOTECHNICAL PARAMETERS *	SAMPLE LOCATION				
				Hind's Creek	
	NOAA[N]	Bruner's[N]	Sturm's[H]	Hamblen	Newark
K (cm/sec)	2.74 E-7	7.3 E-8	9.71 E -6	9.74 E-7	1.49 E-6
BLKDENS (pcf)	94.23	74.90	92.00	92.60	92.38
POROSITY (%)	43.64	45.33	45.01	44.65	44.77
MOISTURE (%)	27.14	29.06	27.75	19.78	27.30

HORIZON 5

GEOTECHNICAL PARAMETERS*	SAMPLE LOCATION				
				Hind's Creek	
	NOAA[N]	Bruner's[N]	Sturm's[H]	Hamblen	Newark
K (cm/sec)	3.1 E -7	2.37 E -6	5.56 E-7	9.5 E-7	1.64 E-6
BLKDENS (pcf)	96.40	84.85	92.64	93.37	93.28
POROSITY (%)	47.11	49.28	44.06	44.19	44.25
MOISTURE (%)	28.21	31.58	32.73	21.70	25.78

* Represents an average per site

[H]Sample collected from the Hamblen Soil Series

[N]Sample collected from the Newark Soil Series

be most saturated (37.62 and 32.73%, respectively), with Horizons 2 to 4 less saturated (26.52 to 27.75%). Soils from the WA site had morphology indicative of better internal drainage than other transects sampled. HC showed low moisture content across both transects for all horizons sampled, ranging from 19.78 to 36.08%.

3.2.6.4 Size fraction analysis and contaminant partitioning

Total size fraction analysis was performed by Singleton Laboratories on soil samples in accordance with ASTM D2217 Rev. 1985. Particle sizes were quantitatively determined by wet-sieve analysis and hydrometer studies to delineate the particle-size distribution (% by weight) for the reference site (HC) Newark and Hamblen soils and contaminated (EFPC) Newark and Hamblen soils. The following classification was used:

Coarse fragments	> 2 mm
Very coarse sand	2 - 1 mm
Coarse sand	1 - 0.5 mm
Medium sand	0.5 - 0.25 mm
Fine sand	0.25 - 0.125 mm
Very fine sand	0.125 - 0.0625 mm
Silt	0.0625 - 0.002 mm
Clay	<0.002 mm

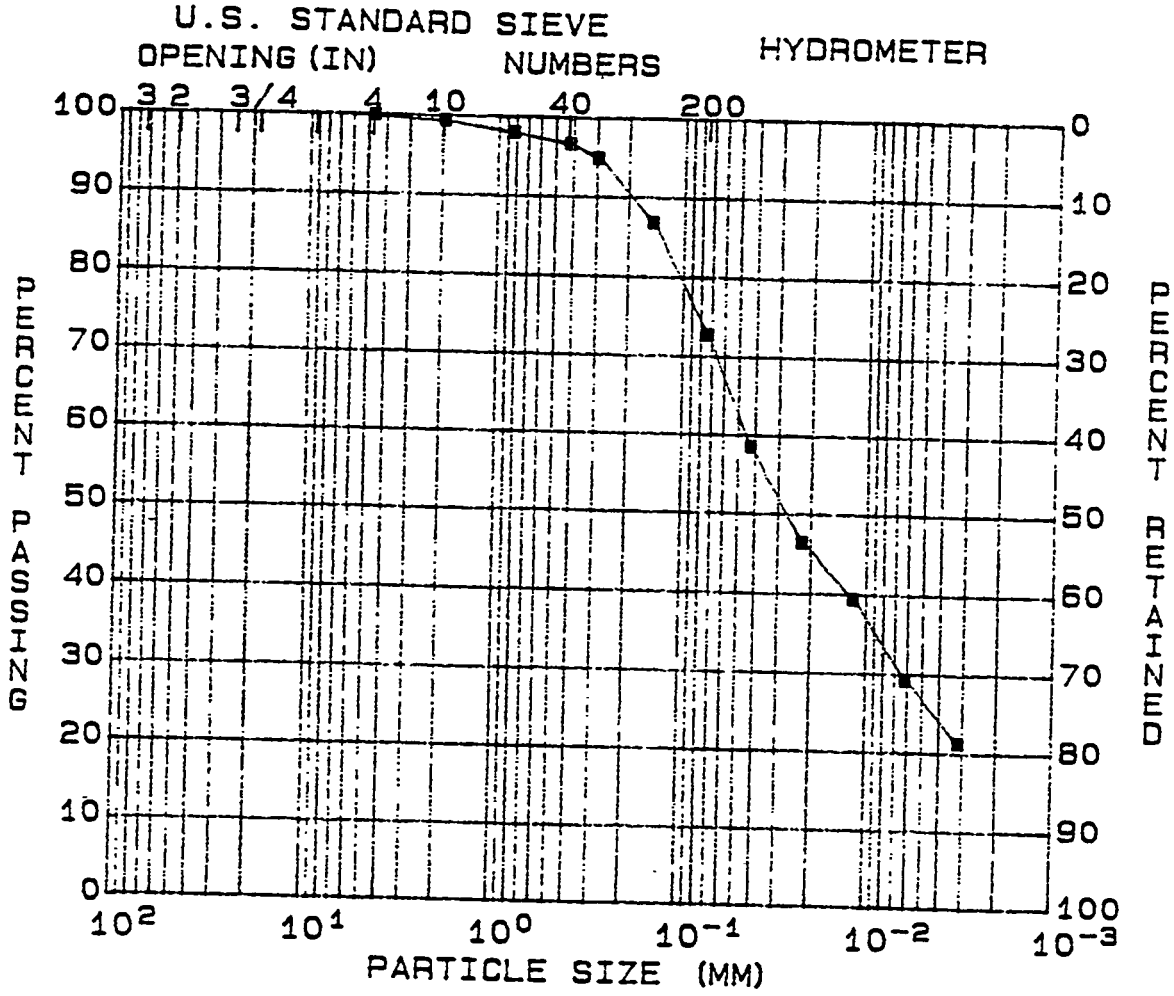
The majority of tests indicate that the soil samples, regardless of the horizon, are composed (80% or more by weight) of silt-sized fractions or smaller (<200 mesh/0.0625 mm). Figure 3.132 is a typical example of an EFPC particle-size analysis.

To confirm the existence of a relationship between contaminant concentrations and particle size, as historical data indicate (TVA 1985), samples from two stations (usually 04 and 05) in each of the five horizons of the EFPC sites were obtained and submitted for particle-size determination by dry sieve analysis. Dry sieves were used to avoid contamination by dispersants, but fine particle aggregates may have remained in the samples. This work was performed by Singleton Laboratories in accordance with ASTM D421 and ASTM 2217 Rev. 1985. Samples were passed through three stainless steel sieves of the following sizes: coarse (> 425 μm, retained on a #40 sieve), medium (425 to 75 μm, retained on a #200 sieve), and fine (<75 μm, passed through a #200 sieve). Contaminant analysis was performed by Compuchem Laboratories for mercury and uranium (where sufficient sample volume existed) for each size fraction.

SINGLETON LABORATORIES
PARTICLE SIZE ANALYSIS

PROJECT: LEE WAN
FEATURE: HORIZON 1
STATION:
RANGE :
PART :

BORING:
EL. : 0-5"
SAMPLE: WA041616
DATE : 05-23-91



GRAVEL (%) = 0
SAND (%) = 27
SILT (%) = 46
CLAY (%) = 27

D10 (MM) = --
D30 (MM) = --
D60 (MM) = --
COEF UNIF = --

SOIL SYMBOL =
MOISTURE (%) = --
SP. GR. = 2.65

L.L. (%) =
P.I. (%) =

DENSITY (pcf) = --
SATURATION (%) = --
VOID RATIO = --

REMARKS:

Fig. 3.132. Example of Singleton Laboratories particle-size analysis (wet sieve).

Table 3.35 shows the contaminant results, by the depth sampled and size fraction for each of the five horizons. There was not sufficient volume for each size fraction to perform analysis for uranium at all locations. The overall vertical distribution of contaminants that was seen in the 1-ft composite samples from the soil transects was reflected in these results. However, more variation was displayed, due to the smaller intervals composited and analyzed. On the average, Horizon 2 was the highest observed in this test due to the bias imposed by the high levels of mercury at Station 05 NO site. Uranium was much more variable.

Figure 3.133 shows average mercury and uranium levels from each horizon for fine, medium, and coarse grain particle-size fractions. The mercury is fairly evenly distributed across all size fractions and shows no concentration in the fine fraction as previous investigations reported (TVA 1985). Mercury levels are highest in Horizon 2 (avg 500 to 636 mg/kg) and decrease in Horizon 1 (avg 297 to 325 mg/kg), which probably reflects the decreased output of mercury into the EFPC system by the Y-12 Plant in recent years. For uranium, it also appears that no consistent relationship between contaminant concentrations and particle size exists. Horizons 1 and 2 have the highest uranium levels and are concentrated in the fine fraction in Horizon 1 and the coarse fraction in Horizon 2. Uranium levels for the deepest three horizons are relatively constant across particle-size fractions.

3.2.6.5 Evaluation

Each site was evaluated for soil morphology as a comparison to SCS mapping, bulk soil geochemistry, hydrologic parameters, and grain size distribution. The soil morphologies identified were in general agreement with the soil types reported by the SCS, with the exception of the Bruner's Center site (BR), which reflected better drainage than previously reported. The bulk soil geochemistry of EFPC generally reflects higher extractable acids and bases; higher TOC (by soil type and particularly in upper horizons); and higher pH, especially in upper horizons, than reference site soils. Hydrologic testing of undisturbed cores produced a range of hydraulic conductivities (4.09×10^{-5} to 7.3×10^{-8} cm/sec), with Horizon 2 demonstrating the highest average conductivity at 1.58×10^{-5} cm/sec. Hydraulic conductivity, bulk density, porosity, and moisture content all generally decreased with depth and reflected a range of values consistent with floodplain deposits. Measurement of grain size distribution indicated that 80% or more, by weight, of the floodplain soil was composed of silt-sized (0.0625 to 0.002 mm) particles or smaller. Contaminants showed no preferential concentration by grain size, but were more common in Horizon 2 than in any other interval. This soil can be generally characterized as poorly drained, moderately acidic, silt-sized, and moderately to poorly sorted floodplain deposits with a moderate to low hydraulic conductivity and a variable degree of soil development.

Table 3.35. EFPC soil geochemistry

HORIZON 1 Mercury (mg/kg)						
PARTICLE SIZE	NO		BR		WA	
	Station 4	Station 5	Station 4	Station 5	Station 1	Station 3
(sample depth)	0"-4"	0"-8"	0"-7.5"	0"-11"	0"-7"	0"-2.5"
Fine	458.0	862.0	112.0	197.0	58.6	93.3
Medium	523.0	961.0	119.0	170.0	68.1	106.0
Coarse	167.0	707.0	138.0	152.0	55.1	94.3
Uranium (pCi/g)						
PARTICLE SIZE	NO		BR		WA	
	Station 4	Station 5	Station 4	Station 5	Station 1	Station 3
(sample depth)	0"-4"	0"-8"	0"-7.5"	0"-11"	0"-7"	0"-2.5"
Fine	NA	36.72	18.61	203.0	11.66	16.42
Medium	NA	NA	16.43	NA	13.74	17.48
Coarse	NA	47.5	20.03	NA	12.88	NA
HORIZON 2 Mercury (mg/kg)						
PARTICLE SIZE	NO		BR		WA	
	Station 4	Station 5	Station 4	Station 5	Station 1	Station 3
(sample depth)	4"-12.5"	8"-12"	7.5"-17"	11"-16"	7"-12"	2.5"-11"
Fine	387.0	1930.0	213.0	157.0	120.0	191.0
Medium	390.0	2170.0	228.0	255.0	139.0	220.0
Coarse	399.0	2680.0	214.0	206.0	112.0	207.0
Uranium (pCi/g)						
PARTICLE SIZE	NO		BR		WA	
	Station 4	Station 5	Station 4	Station 5	Station 1	Station 3
(sample depth)	4"-12.5"	8"-12"	7.5"-17"	11"-16"	7"-12"	2.5"-11"
Fine	NA	NA	NA	30.98	7.89	19.71
Medium	16.67	21.54	26.31	31.95	8.87	18.61
Coarse	21.53	NA	34.21	33.84	NA	NA

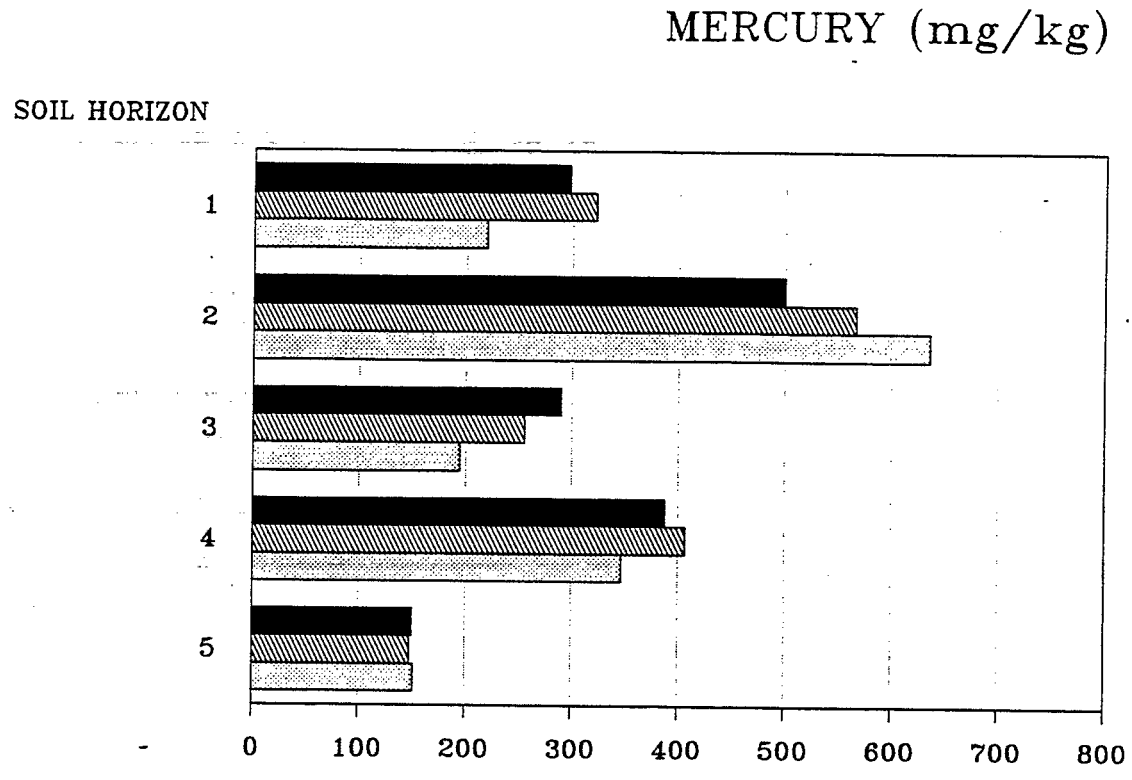
Table 3.35 (continued)

HORIZON 3 Mercury (mg/kg)						
PARTICLE SIZE	NO		BR		WA	
	Station 4	Station 5	Station 4	Station 5	Station 1	Station 3
(sample depth)	12.5"-18"	12"-22.5"	17"-27"	16"-22"	12"-21.5"	11"-16"
Fine	6.9	491.0	9.3	1060.0	15.0	157.0
Medium	6.1	570.0	12.2	724.0	22.1	195.0
Coarse	5.5	418.0	7.8	529.0	18.2	189.0
Uranium (pCi/g)						
PARTICLE SIZE	NO		BR		WA	
	Station 4	Station 5	Station 4	Station 5	Station 1	Station 3
(sample depth)	12.5"-18"	12"-22.5"	17"-27"	16"-22"	12"-21.5"	11"-16"
Fine	19.14	19.79	NA	55.54	NA	24.37
Medium	13.0	24.7	13.66	NA	4.43	NA
Coarse	17.01	26.18	16.17	NA	5.23	NA
HORIZON 4 Mercury (mg/kg)						
PARTICLE SIZE	NO		BR		WA	
	Station 4	Station 5	Station 4	Station 5	Station 1	Station 3
(sample depth)	18"-36"	22.5"-39"	27"-32"	22"-36"	21.5"-27"	16"-25"
Fine	30.8	262.0	1090.0	612.0	4.5	330.0
Medium	18.4	310.0	1270.0	632.0	4.7	204.0
Coarse	32.7	223.0	983.0	610.0	5.6	225.0
Uranium (pCi/g)						
PARTICLE SIZE	NO		BR		WA	
	Station 4	Station 5	Station 4	Station 5	Station 1	Station 3
(sample depth)	18"-36"	22.5"-39"	27"-32"	22"-36"	21.5"-27"	16"-25"
Fine	6.63	12.68	32.77	55.1	11.93	NA
Medium	8.53	12.02	NA	57.21	10.71	NA
Coarse	10.91	14.02	3.24	NA	11.35	NA

Table 3.35 (continued)

HORIZON 5 Mercury (mg/kg)						
PARTICLE SIZE	NO		BR		WA	
	Station 4	Station 5	Station 4	Station 5	Station 1	Station 3
(sample depth)	36"-46"	39"-43"	32"-37"	36"-45"	27"-36"	25"-34.5"
Fine	5.2	6.3	817.0	3.8	17.4	55.4
Medium	2.4	2.7	823.0	4.8	17.6	40.7
Coarse	3.6	6.5	825.0	2.9	31.9	43.0
Uranium (pCi/g)						
PARTICLE SIZE	NO		BR		WA	
	Station 4	Station 5	Station 4	Station 5	Station 1	Station 3
(sample depth)	36"-46"	39"-43"	32"-37"	36"-45"	27"-36"	25"-34.5"
Fine	3.06	4.71	46.86	23.55	12.82	21.35
Medium	5.04	4.96	36.74	25.54	11.74	NA
Coarse	NA	6.19	55.6	28.68	11.99	25.59

3.2.7 Biomonitoring Data



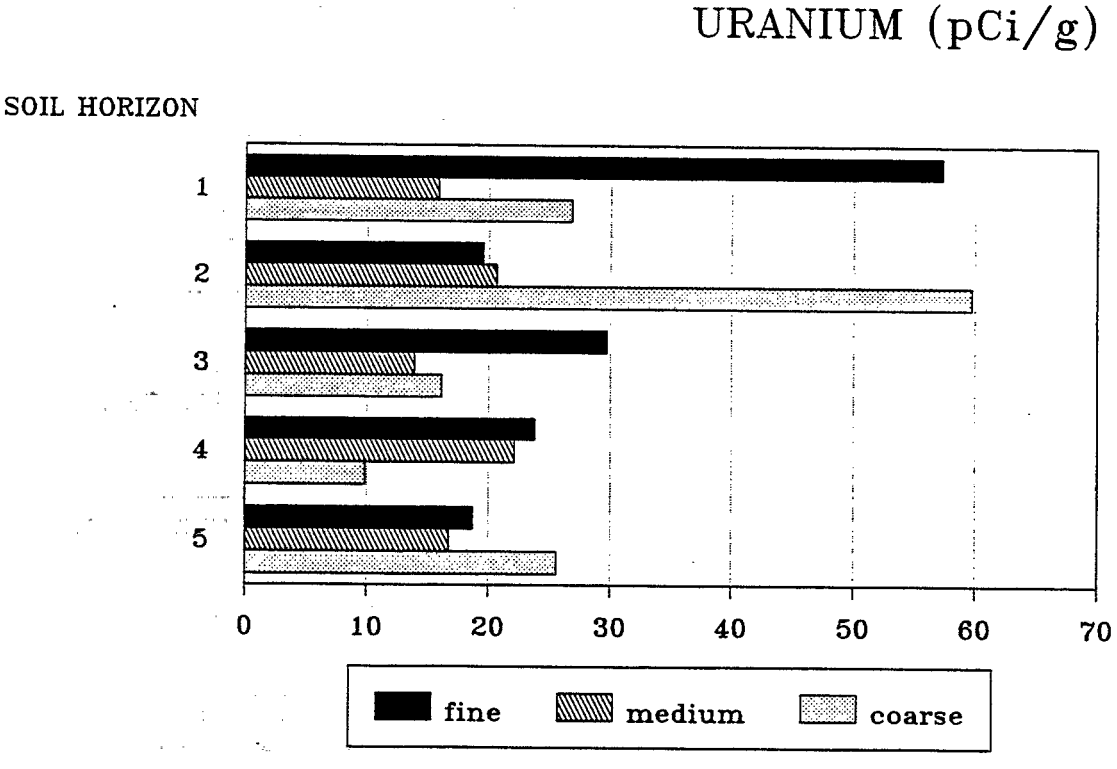


Fig. 3.133. Average uranium activity and mercury concentrations by horizon for all stations.

3.2.7 Biomonitoring Data

The following section presents an overview of biomonitoring data accumulated from EFPC before initiation of the EFPC RI and ERA. Further discussion of previous investigations is supplied in the ERA (Sect. 6.2.3.1). Contaminants (metals, pesticides/PCBs, organics, and radionuclides) in fish and other aquatic animals were measured in 1984 during the TVA Instream Contaminant Study (Task 4) and have been measured every year since 1985 as part of the ongoing Y-12 BMAP (mercury, PCBs, ^{137}Cs). These studies have found elevated levels of mercury and PCBs in fish, with the highest concentrations found in the upper reaches of EFPC near the Y-12 Plant. Other metals were not found at levels above background. PAHs were bioaccumulated by freshwater clams placed in EFPC but have not been found at elevated levels in indigenous species of fish. Cesium-137 has been detected in fish but does not decrease with distance downstream from Y-12.

3.2.7.1 Historical data

Van Winkle et al. (1984) collected fish samples (bluegill, rock bass, largemouth bass, and white bass) from EFPC by electrofishing at four locations below NHP and at one location in Bear Creek. The fish were weighed, measured, and processed. Moss and liverwort samples were also collected at four stations along EFPC and Bear Creek. Pasture grass was collected from clip plots located at two different sites. All of these samples were analyzed for total mercury by digesting them using a reflux technique. The liberated mercury was reduced to the elemental state and measured by the cold vapor atomic absorption method.

The data for the fish demonstrated a correlation between mercury concentration and fish weight. Although there was a decrease in concentration with distance downstream, the mercury concentration in 87% of the bluegill exceeded the U.S. Food and Drug Administration (FDA) action level of 10 $\mu g/g$ in the edible portion of the fish. The total mercury concentration in moss also indicated a decrease in mercury downstream. Total mercury concentrations averaged 3.5 and 0.2 $\mu g/g$ fresh weight for dead and live foliage, respectively, for pasture grass in the floodplain of EFPC. Calculations show that mercury concentrations in milk from cows grazing along EFPC present no health hazard, but that mercury concentrations in beef may exceed 1.0 $\mu g/g$ fresh weight. Results for Bear Creek reveal that mercury concentrations are considerably less for all media sampled than those of EFPC.

In the TVA study, fish, frogs, turtles, and crayfish were collected from three sites (mi 13.8, mi 8.8, and mi 4.0) along EFPC from mid-May through June 1984. Fauna from all three sites

were analyzed for the presence of selected metals (cadmium, chromium, silver, arsenic, mercury, and nickel). Fauna from at least one site were analyzed for priority pollutants (metals, PCBs, pesticides, and semivolatile and volatile organic compounds) and radionuclides (^{89}Sr and ^{90}Sr, gross alpha and beta emitters, and gamma emitters). Supplemental fish samples were also collected from two additional EFPC sites (mi 13.8, mi 1.7) from mid- to late May 1984 and analyzed for 12 priority pollutant metals (antimony, arsenic, beryllium, cadmium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc), and one radionuclide (^{99}Tc).

Thirteen aquatic biota species from EFPC had total mercury concentrations exceeding the 0.3 mg/kg background level. The FDA action level for methylmercury in fish is 1.0 mg/kg. Mean total mercury (almost 100% of which is methylmercury in fish) concentrations were at or above 1.0 mg/kg in flesh from three fish species and in frogs from EFPC. Individual samples of snapping turtles, crayfish, and three additional fish species had maximum mercury concentrations exceeding 1.0 mg/kg.

Other priority pollutant metals found at elevated concentrations in EFPC were arsenic (crayfish), beryllium (fish), cadmium (fish, crayfish, frogs), chromium (fish, frogs, crayfish, turtles), copper (fish), selenium (fish), silver (fish, crayfish, turtles), and thallium (fish).

Analyses of 110 priority pollutant organic compounds (including PCBs, pesticides, and semivolatile and volatile organics) identified seven compounds exceeding analytical detection limits. PCBs were most significant, with levels exceeding the FDA action level of 2.0 mg/kg for PCBs in fish flesh. Radiological analyses of fish flesh found ^{137}Cs to be the most elevated radionuclide. In EFPC, ^{137}Cs levels in fish were substantially above background levels, but no samples exceeded the U.S. Nuclear Regulatory Commission (NRC) limit.

ORAU analyses have found background levels of mercury in garden plots planted in Oak Ridge. Plot studies indicated that garden vegetables did not concentrate mercury, with the exception of collard greens, which had a mercury concentration 25% higher than the soil in which they were grown.

Revis et al. (1989) fed mercury-contaminated soil from EFPC to laboratory mice. Mercury was absorbed through the intestinal tract and bioaccumulated in the kidney. This bioaccumulation was not correlated with increased mortality or other deleterious physiological changes in the mice.

Relative-abundance-estimates of fish collected in EFPC indicated greater population densities in upper reaches of the stream. Normally, fish densities are greatest near the mouth of the stream, decreasing in the upstream direction. It has been suggested by Van Winkle et al. that

the Oak Ridge Sewage Treatment Plant at EFPC mi 8.3 could be affecting the distribution and abundance of fish in EFPC. The sites with the highest densities of "edible" fish (based on size and species) were those above the sewage treatment plant. This is the section of the creek most accessible to the public; it is also the section in which the greatest concentrations of contaminants in fish were observed.

3.2.8 Air Data

Background information on air quality is provided with the intent to show that the Y-12 Plant has not affected the air quality of the EFPC floodplain. Air monitoring has been performed on the ORR and around the Y-12 Plant for some time. A source of information on airborne emissions from the Y-12 Plant is the ORR Environmental Report for 1990 (Energy Systems 1991). This report summarizes the results of air monitoring on the ORR and provides a basis for estimating source and background values relative to EFPC. Air has been eliminated from consideration as a migration pathway for contaminants from the EFPC floodplain soil as a result of these studies. This section presents a summary of the results of historical air monitoring activities on ORR and at EFPC (Sect. 3.2.8.1) and the findings of a recent study along EFPC (Sect. 3.2.8.2).

3.2.8.1 Historical data

According to the ORR Environmental Report for 1990 (Energy Systems 1991), 102,000 Ci of radionuclides were released to the atmosphere from Oak Ridge installations during 1990. The variations in release amounts from year to year can be accounted for almost totally by two inert gases, xenon and krypton. These gases have little or no interaction with the terrestrial biosphere, including humans.

Uranium is the primary radioactive element released from the Y-12 Plant. Uranium emissions have shown a gradual decrease in recent years at the plant. During 1990, the lowest discharge from the Y-12 Plant in the past 5 years was recorded, in part due to improved uranium emissions monitoring in 1987 and the installation of new exhaust-gas filtration systems at the plant.

Atmospheric radionuclide concentrations occurring in the environment around the ORR and the surrounding region are monitored or sampled continuously by an air-monitoring network. Air concentration measurements are taken for 15 radioactivity parameters: gross alpha, gross beta, ^{137}Cs, ^{237}Np, ^{234}Pa, ^{238}Pu, ^{239}Pu, ^{99}Tc, ^{228}Th, ^{230}Th, ^{232}Th, ^{234}Th, ^{234}U, ^{235}U, and ^{238}U. Analysis of the ORR perimeter air-sampling data shows that operations on the ORR are very

slightly increasing local concentrations of radionuclides. These range from < 0.01 to 0.057% of the derived concentration guides for the network averages. Therefore, ORR operations have slight impact on local air quality and do not measurably impact the regional air quality (Energy Systems 1991).

Also monitored were ambient fluoride concentration, sulphur dioxide (SO_2) concentrations, total suspended particles, and mercury concentrations. Ambient air concentrations of fluorides measured during 1990 at each of the Y-12 Plant perimeter air-monitoring fluoride stations were well below TDEC standards. Measured SO_2 concentrations were also well below state standards throughout 1990. Total suspended particle samples collected at the Y-12 Plant were not in excess of state primary or secondary standards in 1990 (Energy Systems 1991).

Data for mercury in ambient air at five monitoring stations at the Y-12 Plant suggest that the environment and human health are not impacted by releases of mercury to the atmosphere. The highest observed 7-day concentrations have, with one exception, been less than 50% of the National Emission Standards for Hazardous Air Pollutants criterion (1.0 $\mu g/m^3$) and < 1% of the workplace standard of 50 $\mu g/m^3$. The data do show that ambient air mercury concentrations in the Y-12 Plant area are, in general, slightly elevated above natural background and may reach significantly elevated concentrations for short periods in localized areas. Disturbances, such as excavation of soil in contaminated areas, appear to elevate ambient air concentrations of mercury. Ambient air concentrations exhibited a seasonal pattern, with the highest values typically occurring in the warmer months.

In another study (Turner et al. 1992), mercury concentrations over Lake Reality were measured between December 1989 and February 1990, and July to September 1990. Samples were taken at elevations from 0 to 2 m (0 to 78 in.) above the water using iodated, activated charcoal filters. A strong seasonal dependence was seen for mercury concentrations, but upstream, where one might expect mercury to be higher in the air over the creek, the observed concentrations were low (3 to 23 ng/m^3) and much less than the threshold of human health concern.

3.2.8.2 Current data

In a recent unpublished study (Turner et al. 1992), ambient air concentrations of mercury were measured at several locations in the EFPC floodplain during late summer and early fall of 1991, and spring of 1992 (see Appendix H). The monitoring sites were selected in proximity to areas of known elevated mercury soil contamination (up to 3000 $\mu g/g$). Two independent methods of trapping and analyzing mercury in ambient air were utilized. The more sensitive

method involves amalgamating mercury in ambient air on a gold-coated quartz medium. Mercury is desorbed (released) by heating and passed through an atomic fluorescence spectrophotometer. These absorbers are used for short-term monitoring (minutes to hours) and are sufficiently sensitive that only small volumes of ambient air need to be passed over the absorber prior to analysis. The second method employs iodated, activated charcoal as the mercury trapping medium. It is more difficult to analyze, but can trap enormous quantities of mercury without significant breakthrough, and is used for long-term monitoring (days to weeks). The charcoal is digested in acid, then analyzed by atomic absorption spectrophotometry.

Air samples were collected on August 23, 1991, using the gold absorbers at three floodplain sites and at one control site atop Chestnut Ridge (Walker Branch watershed). In addition, two floodplain sites were monitored over a 10-week period (August 23 to November 12) using the charcoal absorbers, which were exchanged on a weekly cycle. Finally, one floodplain site was resampled on March 17, 1992 using the gold absorber at two elevations above the soil (Appendix H).

All concentrations (range: 3.1 to 12.4 ng/m^3) were similar to levels expected in air at uncontaminated sites and far below the threshold level ($\geq$ 1000 ng/m^3) of human health concern (Table 3.36). The time trends of weekly average concentration showed no difference between monitoring sites, but revealed a strong dependence on average weekly air temperature (Fig. 3.134). Extended monitoring data for the control site (Walker Branch watershed) shows a strong seasonal pattern in ambient air mercury concentrations, with mercury vapor concentrations between 3 and 8 ng/m^3 throughout most of the year, peaking in the summer months with values approaching 15 ng/m^3. This reflects the dependence of mercury volatilization on temperature.

Table 3.36. Results of EFPC air monitoring using gold-coated quartz absorbers

Location	Date	Time	Height (m)	Air temperature	Soil temperature	Mercury (ng/m^3)
NOAA	8/23/91	1100-1600	0.5	25°C	-	10.9
Lysimeter	8/23/91	1100-1600	0.5	25°C	-	5.9
Minit Chek	8/23/91	1100-1600	0.5	25°C	-	5.9
Walker Branch Watershed	8/23/91	1100-1600	0.5	25°C	-	5.1
NOAA	3/17/92	1500-1600	0.17	25°C	12°C	8.1±0.4
NOAA	3/17/92	1500-1600	1.7	25°C	12°C	8.0±0.5

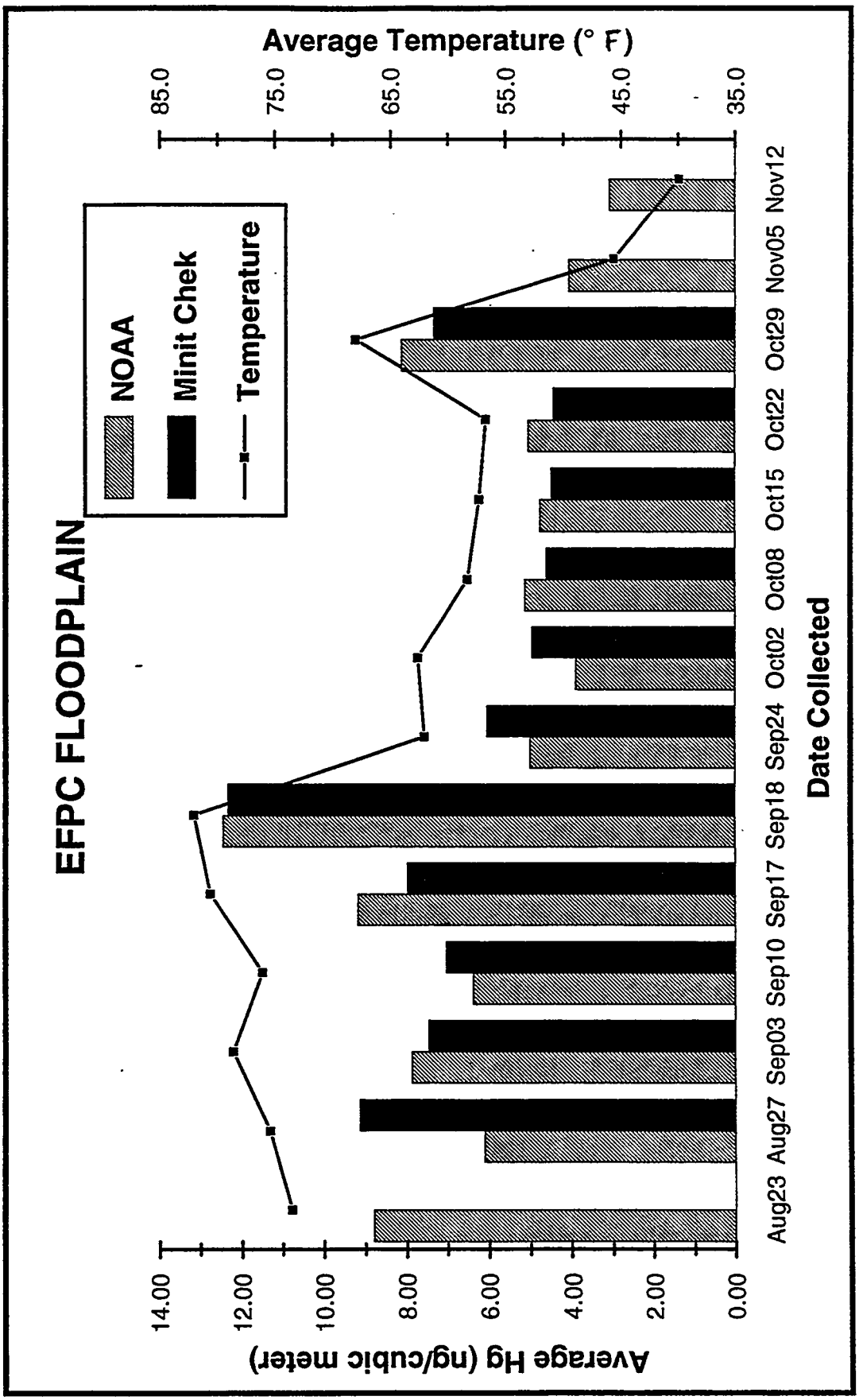


Fig. 3.134. Average mercury concentrations (ng/m^3) and temperatures (°F), showing relationship to each other.

Radiation Survey Data

The distribution of radiological contamination over the ORR and surrounding area has been assessed by airborne radiation surveys. These surveys have been flown since 1959, and a review of the aerial monitoring program is presented in Sect. 3.2.9.1. The results of a recent survey that encompasses EFPC are presented in Sect. 3.2.9.2.

3.2.8.3 Historical data

Historically, most of the radiation survey information on the ORR and surrounding area has been provided by the Aerial Measuring System, an aerial radiological surveillance capability maintained by DOE. The Aerial Measuring System is presently operated and maintained by EG&G Energy Measurements Inc. (EG&G/EM) under contract to DOE.

The first aerial radiological survey of the ORR and surrounding area was conducted during the spring of 1959 by the USGS using a fixed-wing aircraft flying at a 152-m (500-ft) altitude and 1.6-km (1-mi) line spacing. Its primary purpose was to characterize the radiogeology of the area. In 1973, EG&G/EM conducted a survey using a fixed-wing aircraft flying at an altitude of 152 m (500 ft) and speed of 170 knots. Sites identified as having anomalous radiation levels were re-surveyed with a helicopter-mounted Aerial Measuring System (AMS) flying at an altitude of 76 m (250 ft) and speed of 70 knots. The increased sensitivity provided detailed coverage of radiological activity at the anomalous radiation sites.

In 1980, an aerial radiological survey of the entire ORR and nearby surrounding area, encompassing 440 km^2 (170 m^2), was conducted. The survey consisted of parallel flight lines 152 m (500 ft) apart at an altitude of 91 m (300 ft). During September 12-29, 1989, an aerial radiological survey of the ORR, city of Oak Ridge, and the surrounding area was conducted using parameters identical to those used during the 1980 survey (Maurer 1992a).

3.2.8.4 Current data

Most recently, an aerial radiological survey of the ORR and surrounding area in Oak Ridge, which encompasses EFPC, was conducted during the period March 30 to April 14, 1992 (Maurer, draft 1992b). Several sites on the ORR were surveyed, including the EFPC 100-year floodplain from the Y-12 Plant to the K-25 Site. The survey consisted of a series of parallel flight lines 76 m (250 ft) apart at an altitude of 46 m (150 ft). The survey was conducted by a helicopter flying at a speed of 70 knots. In support of aerial measurements, ground-based exposure rates and soil samples were obtained from seven "benchmark" sites located within the

survey area. The ground-based measurements were used to verify the integrity of the aerial measurements. Radionuclide assays of representative soil samples were also performed to determine corresponding radioisotopic concentrations. In addition, high-altitude aerial photographs were obtained for use as base maps for the aerial contour data, and oblique aerial photographs were obtained for site documentation.

Two methods were used to analyze the aerial radiation data. The first was the gross count rate method, used to determine the ground level exposure rates. The second was the spectral window method, used to determine the man-made radioactivity and the photopeak count rates for specific man-made radionuclides (Maurer draft 1992). Typical background exposure rates varied from 7 to 11 μR/h (including the estimated cosmic ray contribution of 3.8 μR/h). The results of the aerial and ground-based measurements were found to vary as much as $\pm$30%.

Terrestrial exposure rates at 1 m above ground level were deduced from aerial measurements, integrated with the corresponding aircraft position coordinates, and compiled to produce a contour map (Fig. 3.135). These contours were superimposed on the high-altitude aerial photographs. The data for the EFPC floodplain are presented in the 1992 draft report by Maurer. Total terrestrial gamma exposure rates at 1 m for the EFPC floodplain range from < 8 to 20 μR/h, with the overwhelming majority of readings being < 13 μR/h. One site was identified with rates between 13 to 20 μR/h within the EFPC floodplain. This site corresponds to the Bruner's Center site, which was known from historical data to contain high contaminant concentrations within the creek. Even these readings are not statistically significant, as exposure rates < 10 μR/h above background rates (7 to 11 μR/h within the Oak Ridge area) are considered of no concern, and the correlations between aerial and ground-based measurements vary as much as $\pm$30%.

The man-made gross count rate for the EFPC sites is shown in Maurer (draft 1992, Fig. 13). There is no evidence for radioactivity produced by man-made radionuclides within the 100-year floodplain of the EFPC. The results of this survey are presented in Fig. 3.135.

3.3 DATA QUALITY REPORT

3.3.1 Overview

Purpose. The purpose of this section is to provide an assessment of the QA/QC results from the EFPC RI to confirm that the data used in this report meet the DQOs established for this investigation. Both quantitative measures and qualitative assessments will be presented to

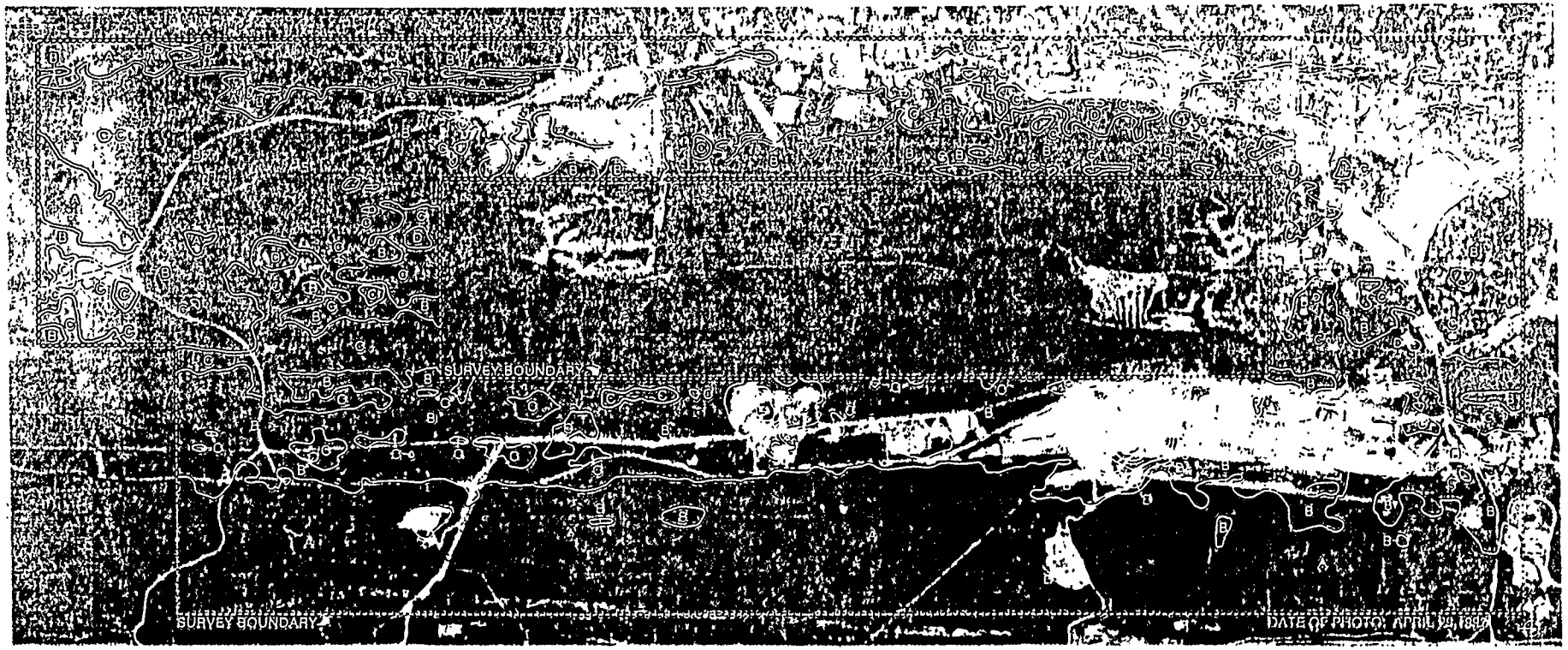


Fig. 3.135. Terrestrial gamma exposure rate contour map for the Y-12 and EFPC sites (Maurer draft 1992).

characterize these data as having sufficient quality to satisfy these objectives. The primary intent of this assessment is to illustrate that data originating from the EFPC RI can withstand scientific scrutiny (for its intended purposes), are technically defensible, and are of a known and acceptable precision and accuracy.

To gain an appreciation of the magnitude of the RI, some summary statistics may be appropriate. The EFPC OU (including the SLB) extends over 25 km in length and covers more than 650 acres. The investigation required 2 years of field work to complete the sampling tasks, and a total of 4723 samples (4014 field and 709 QC) were taken exclusive of the ecological investigation (discussed in Sect. 6). Approximately 93,000 discrete analyses (i.e., analytes) were obtained, reviewed, and integrated in the assessment (not including field measurements or descriptions).

Several steps must be performed to achieve the desired level of data quality in a project of this size. As discussed in Sect. 3.2, decisions were made during the initial scoping of the EFPC RI to define the level and quantity of data. DQOs were established to guide the implementation of the field sampling and laboratory analysis. A QA program was established to standardize procedures and to document activities (see Section 3.2 for DQOs and QA). The program provided a means to detect and correct any deficiencies in the process. Upon receipt by the EFPC team, data underwent a verification and validation review to identify and qualify any problems related to the analysis. This final step confirms that data used in the investigation meet certain minimum criteria.

QA Program. A primary goal of the EFPC QA program is to ensure that the results of analysis of all environmental samples are fit for their intended use. To this end, a QAPP, a QAPjP, and field procedures were compiled to guide the investigation (see Sect. 3.2). Audits and surveillances were conducted to determine the adequacy of field and laboratory performance as evaluated against the QA plan and procedures. For the project as a whole, there have been 85 surveillances performed covering field activities as well as procedural activities such as training and document review. In total, 564 nonconformance reports (NCRs) were written (as of April 7, 1993) concerning quality deficiencies. While some of the NCRs noted multiple problems, a general breakdown of the causes is as follows:

289 - chain of custody, holding times, sample documentation
129 - data validation and electronic data formats
53 - field activities and task

13 - procedural deficiencies such as training records, logbooks, and document reviews
86 - other

Of the 564 NCRs, 534 have been resolved and closed. The remaining NCRs are of the type that does not impact usability of the data.

As of early 1993, there have been seven audits of record performed on the EFPC program. These audits include the SAIC/Radian team audits of subcontractors, DOE Oak Ridge ER audits of the EFPC RI, and a DOE HQ audit of the DOE Oak Ridge ER Program. The chronology of audits was as follows:

- November 1990: SAIC/Radian audit of EFPC;
- December 1990: SAIC/Radian audit of CompuChem Laboratory;
- July 1991: DOE audit of CompuChem Laboratory;
- August 1992: DOE audit of EFPC Sampling and Analysis Program;
- January 1992: DOE audit of Radian Laboratories/Texas;
- January 1992: DOE audit of CompuChem Laboratory; and
- DOE HQ audit of EFPC Data Quality (as part of the off-site ER Program for DOE Oak Ridge).

These audits produced 67 findings. The findings were directed mainly at the Document Control process, i.e., document reviews, records, and the central records facility. However, other findings include QA-related management activities, sample collection practices, and laboratory activities. Most of the findings (31) were recorded early in the program and were closed under the QA program controls. The most recent audit by DOE HQ was, in general, complimentary of the EFPC program.

Data assessment and review. Analytical data generated under this project have been subjected to a rigorous process of data verification, validation, and review. The following describes this systematic process and the evaluation activities performed. Several criteria have been established against which the data are compared and from which a judgment is rendered regarding the acceptance and qualification of the data. Because it is beyond the scope of this report to cite those criteria, the reader is directed to the following documents for specific detail:

- Technical Support Contractor QA Technical Procedure (TP-DM-300-7) Data Verification and Validation;

- Region I EPA - Laboratory Data Validation, Functional Guidelines for Evaluating Inorganic Analyses;
- Region I EPA - Laboratory Data Validation, Functional Guidelines for Evaluating Organic Analyses; and
- ES/ER/TM-16 Requirements for Quality Control of Analytical Data for the Environmental Restoration Program, Martin Marietta Energy Systems.

Data verification. Upon receipt of data reports from the laboratory, the data verification staff performed a systematic examination of the reports, following standardized data checklists to ensure the content, presentation, and administrative validity of the data. Discrepancies identified during this process were recorded and documented utilizing the QA Program NCR system.

In conjunction with the data verification, standardized laboratory electronic data disks were subjected to comprehensive review utilizing EPA Contract Compliance Screening (CCS) software. This software performed both a structural and technical assessment of the laboratory-delivered reports. The structural evaluation ensured that all required data had been reported and that they had been reported accurately. The technical evaluation ensured that all contract-specified requirement had been followed and that analytical requirements had been conformed with.

In addition, standardized data disks for CLP organic and inorganic analyses were processed by the Computer Assisted Validation and Evaluation Assessment Tool (CAVEAT) software. Reports from this software application were used to support the data validation phase of the process.

CLP inorganic and organic data validation. During this phase of the review and evaluation process, data were subjected to a systematic technical review by examining all analytical QC results and laboratory documentation, following the appropriate functional guidelines for laboratory data validation. These EPA data validation guidelines define the technical review criteria, methods for evaluation of the criteria, and actions resulting from the review of these criteria. The primary objective of this phase was to assess and summarize the quality and reliability of the data for the intended use and to document factors that may affect the usability of the data. It is important to note that there are areas of overlap between data validation and contract compliance screening; however, contract compliance is not the goal of data validation. As stated in the data verification section, both CCS and CAVEAT reports were utilized in the data validation phase to assist in the technical review of data. Technical criteria

examined during the data validation phase included but were not limited to:

Inorganic	Organic
Data completeness	Data completeness
Holding times	Holding times
Calibration	Calibration
- Initial	- Initial
- Continuing	- Continuing
Blanks	Blanks
ICP interference check sample	Surrogate recovery
MS sample analysis	MS sample analysis
Laboratory duplicate sample analysis	MS duplicate analysis
Field duplicate sample analysis	Field duplicates
Laboratory control sample analysis	Internal standards performance
Furnace atomic absorption	GC/MS tuning
ICP serial dilution analysis	Target compound list (TCL) compound identification
Detection limits	Compound quantitation and
Sample results verification	reported detection limits
	Tentatively identified compounds
	System performance

As an end result of this phase of the review, data were qualified based on the technical assessment of the evaluation criteria. Qualifiers were generated for each analytical result to indicate the usability of the data for intended purposes. For the overall purposes of this investigation, however, data were either accepted or rejected as meeting Level IV quality requirements. With certain exceptions (such as defining the extent of contamination), data from this RI have been designed to meet the highest qualification for their intended use in the human health risk assessment. For other intended uses, the data user must examine the DQOs for broader application of data.

Radiological data validation. To date, procedures for radiological analyses and procedures for radiological data validation have not been established to the level of inorganic/organic analyses under CLP. The EFPC RI undertook a conservative approach to radiological data

validation. For that reason, criteria and the methods for radiological data assessment have been described in more detail. EFPC radiochemical analytical data were validated using "Laboratory Data Validation Guidelines For Evaluating Radionuclide Analyses" (SAIC, Rev 4 1992) and "Laboratory Data Validation Guidelines For Evaluating Neutron Activation Analyses" (SAIC, Rev 2 1992). These documents were developed with the intent to provide data validation guidelines for radioanalytical data equivalent to those provided by EPA under its CLP guidance. These documents provide a systematic process for reviewing the data against the defined criteria to provide assurance that the data are adequate for their intended use. The data validation criteria are summarized below:

Holding Times - The objective is to ascertain the validity of results based on the holding time of the sample from time of collection to time of analysis. Note: The holding time is based on the date of collection (rather than verified time of sample receipt) and date of digestion/distillation. It is a technical evaluation rather than a contractual requirement.

The following holding times for water were based on those found for inorganics in *Laboratory Data Validation Functional Guidelines for Evaluating Inorganics Analyses*, July 1, 1988 Draft, and *Manual for the Certification of Laboratories Analyzing Drinking Water*, EPA-570/9-82-002.

- tritium and iodine solutions: 5 days, with no preservative;
- cesium: 6 months, when preserved to pH <2 in HCl;
- plutonium: 6 months, when preserved in 2M HNO^3; and
- other radionuclides: 6 months, when preserved to pH <2 in HNO^3 or HCl.

Calibration - Compliance requirements for satisfactory instrument calibration are established to ensure that the instrument is capable of producing acceptable quantitative data. Initial and continuing calibrations demonstrate that the instrument is capable of acceptable performance at the beginning of the calibration period, and routine calibration verification and system checks document that the initial calibration is still valid.

Initial calibrations must be performed at regularly frequencies and verified daily. There are several parameters that are determined and verified as part of the calibration process. The daily energy, efficiency, and resolution factors are compared to the initial calibration factors, which are used in the final calculation of the result or identification of the analyte.

Background determinations are also key to obtaining a correct result. If the background is determined incorrectly, it will give a bias to the final results. A negative bias (too much background subtracted out) is more readily determined.

The following limits were used in the validation of calibration verification data:

- efficiency: ± 10% from initial calibration;
- resolution: ± 3 standard deviations;
- energy: ± 1 FWHM;
- self-absorption curves: ± 3 standard deviations;
- HV plateau curve: ± 3 standard deviations;
- efficiency quench curves: ± 10% from initial calibration;
- background: ± 3 standard deviations; and
- background quench curves: ± 3 standard deviations.

Analytical results were qualified as estimated when analyses were performed under calibrations that did not meet these criteria or when calibration frequency criteria were not met.

Blanks - Blank analysis results are assessed to determine the existence and magnitude of contamination problems. The criteria for evaluation of blanks applies to any blank associated with the samples. If problems with any blank exist, all data associated with the case are carefully evaluated to determine whether there is an inherent variability in the data for the case, or if the problem is an isolated occurrence not affecting other data.

Blank data are evaluated according to the following criteria or limits:

- Gross blanks: ± 3 standard deviations and
- Net blanks: net blank result must be less than associated uncertainty.

A blank is analyzed with each batch of samples or for every 20 samples (5% of samples), whichever is more frequent. If the blank QC results fall outside the appropriate tolerance limits or if the net blank results are not less than the associated uncertainty, results for all associated samples that are less than 10 times the blank value were qualified as estimated.

Sample-specific Chemical Recovery - Laboratory performance on individual samples subject to chemical process and separation is established by means of spiking with tracer quantities of other radioisotopes of the same element or carrier quantities of the inactive isotope of the same or a chemically similar element. All samples are spiked prior to sample preparation.

Generally, recoveries of 50-100% are considered acceptable. However, lower recoveries may be typical for some matrices, and the acceptable lower limit may be lowered in such instances. Sample analyses were qualified for use according to the following limits for this project:

Aqueous Matrices:

- 50-100%: Acceptable
- 20-<50% or >100-150%: Estimated
- <20% or >150%: Unusable

Solid Matrices:

- 40-100%: Acceptable
- 10-<40% or >100-150%: Estimated
- <10% or >150%: Unusable

Laboratory Control Sample - The LCS serves as a monitor of the overall accuracy and performance of all steps in the analysis, including the sample preparation. An LCS is analyzed with each batch of samples or for every 20 samples (5% of samples), whichever is more frequent. If the LCS recovery is outside of the acceptable limits, all associated results in the batch are qualified as follows:

Aqueous Matrices:

- 80-120%: Acceptable
- 50-<80% or >120-150%: Estimated
- <50% or >150%: Unusable

Solid Matrices:

- 70-130%: Acceptable
- 40-<70% or >130-160%: Estimated
- <40% or >160%: Unusable

For these limits to apply, the LCS must contain greater than 10 times the radionuclide's detection limit activity.

MS Samples - The matrix spike sample (MSS) analysis provides information about the affect of each sample matrix on the digestion and measurement methodology. MSSs are required with each batch or for every 20 samples (5% of samples), whichever is more frequent, when sample-specific chemical recovery mechanisms are not available. If the MSS recovery is outside of the acceptable limits, all associated results in the batch are qualified as follows:

Aqueous Matrices:

- 80-120%: Acceptable
- 50-<80% or >120-150%: Estimated
- <50% or >150%: Unusable

Solid Matrices:

- 70-130%: Acceptable
- 40-<70% or >130-160%: Estimated
- <40% or >160%: Unusable

Duplicate Samples - Duplicate analyses are indicators of laboratory precision based on each sample matrix. At least one duplicate is analyzed per batch of samples or for every 20 samples (5% of samples), whichever is more frequent.

The duplicate analyses results are in agreement when the two standard deviations (95% confidence limit) uncertainties overlap. The DER, which is the ratio of the difference between the duplicate results to the sum of the two standard deviations uncertainties for duplicate results, must be ≤ 1. When this criterion is not met, all associated samples in the batch are qualified as estimated.

Radionuclide Quantitation and Implied Detection Limits - The objective is to ensure that the reported quantitation results are accurate and that the required detection limits have been met. When detection limit requirements are not met, the results are qualified stating so. All results are evaluated relative to the uncertainty associated with the analysis. The following criterion is evaluated in the quantitation evaluation:

Result Calculation Errors:

- ≤ 10% acceptable
- >10-20% estimated
- >20% unusable

When the following criteria are not met, all associated samples in the batch are qualified as estimated:

- analytical uncertainties must be reported;
- aliquot sizes must ≥ 1 g for solids and ≥ 100 mL for aqueous samples; and
- dry mounted samples for counting:
  - ≤ 5 mg/cm^2 for alpha analyses
  - ≤ 10 mg/cm^2 for beta analyses.

Chemical Separation Specificity (Alpha Spectroscopy) - Chemical separation specificity is the ability to separate various radionuclides by chemical separation techniques so that interferences do not exist. The chemical separation specificity can be verified for alpha spectroscopy measurements by observation of the alpha energy spectrum. The proper qualitative identification of spectral peaks can be verified by matching the peak energy with library energies. The following criteria are used to verify chemical separation specificity and proper identification of alpha peaks:

- no radionuclides interfere with the quantitation of the radionuclide of interest once the chemical separation process has been completed and
- energy of the radionuclide of interest must be within 40 keV of the observed peak energy.

When these criteria are not met, all associated samples in the batch are qualified as unusable.

Target Radionuclide List Identification (Gamma Spectroscopy) - The target radionuclide list (TRL) contains those radionuclides for which a quantitative analysis is required. Therefore, net quantitation with uncertainties must be provided for all TRL radionuclides (whether or not the radionuclide is identified in the peak search and identification). This is accomplished by determining the net area in the region associated with the radionuclide when the radionuclide is not detected by the computerized peak search routine. When a peak is detected for the radionuclide, positive identification is achieved through the use of the following criterion:

- the target radionuclide energy must be within 2 keV of the observed peak.

When this criterion is not met, the results are qualified as "uncertain identification."

The spectrum is also reviewed to determine whether there are any spectral interferences that could cause errors in quantitation. If there are any radionuclide gamma peaks that interfere with the quantitation of the radionuclide of interest, the results are qualified as unusable.

Systems Performance - During the period following instrument performance QC checks (e.g., blanks, tuning, calibration, etc.), changes may occur in the system that degrade the quality of the data. While this degradation would not be directly shown by QC checks until the next required series of analytical QC runs, a thorough review of the ongoing data acquisition may yield indicators of instrument performance. Some examples of instrument performance indicators for various factors are shown below:

- abrupt, discrete shifts in background or detector response may indicate contamination and/or gain or threshold changes;
- poor spectroscopy performance affects both qualitative and quantitative results. Indications of substandard performance include:
  - high background levels or shifts in energy calibration;
  - extraneous peaks;
  - loss of resolution; and
  - peak-tailing or peak splitting that may result in inaccurate quantitation.

Continued analytical activity with degraded performance suggests lack of attention or professional experience. Based on the instrument performance indicators, the data reviewer must decide whether the system has degraded to the point of affecting data quality or validity. If data quality may have been affected, data are qualified using the reviewer's best professional judgment.

Data evaluation. The final phase in data assessment and review is the process of data examination in terms of temporal or spatial data comparisons. During this phase, data from similar or related sites and locations or data collected over time were compared to examine the distribution of data points. Additionally, newly collected sampling data were compared with historical data to determine comparability of data and trends exhibited by different data sets.

Extensive use of graphical and spatial mapping data-display tools were also used to allow visual examination of very large data sets.

3.3.2 CLP/NAA Data Assessment

Assessment of usable data will be grouped into three types of analyses for the purposes of this report. Inorganic/organic analyses under the CLP, radiological analyses, and NAA (in both sections) will be discussed. Data obtained in connection with the ERA are examined in Sect. 6.

Usable data. Usable data are defined as those data that passed individual scrutiny of the verification and validation process and have been accepted for unrestricted application to the human health risk assessment or equivalent applications of Level IV data. Certain data may be qualified as estimated; however, a determination has been made that these data are also acceptable for Level IV use. Other data have been rejected from Level IV use but have less rigorous applications such as defining overall extent of contamination within the floodplain.

For the EFPC project, 96% of the data generated from field activities (radiological data are discussed later) were determined to be usable (Table 3.37). Of the major analytical groupings, only TCLP and NAA have overall rejection rates exceeding 10%. NAA provided acceptable data for 89% of the analyses, while TCLP provided 82%. Table 3.38 furnishes a further breakdown of the major analytical groups by analyte. (Note: if a specific analyte is not listed individually, none of the analyses for that analyte has been rejected, and the analyte has been included in the "other" chemical category.) Specific analytes that were below the 90% level included:

Anions	- Sulfide (68%)
NAA	- Antimony (87%)
	- Arsenic (69%)
Semivolatiles	- 2,4-Dinitrophenol (89%)
TCLP	- phenols (25%)
	- other organics (66-75%)
	- silver (85%)

None of the above analytes was considered critical to the investigation or identified as a potential COC. Sulfide was part of the water analyses and not a COC. Abundant data (including results of CLP analyses) are available for antimony and arsenic in soils, even with an 87% and 69% acceptance rate with NAA. The single semivolatile organic compound listed above is only one

Table 3.37. EFPC rejection rates for analytical groups (ecological-specific data not included)

Chemical class	Reason for rejection	Phase Ia			Phase Ib			Combined		
		Not rejected	Rejected	% OK	Not rejected	Rejected	% OK	Not rejected	Rejected	% OK
Anions		619		89	16		100	635		90
	Holding time exceeded		22	3					22	3
	Quantitation problem		52	8					52	7
	Class Total		74						74	
Herbicides		33		92				33		92
	Holding time exceeded		3	8					3	8
	Class Total		3						3	
Inorganics		13,451		99	2,712		98	16,163		98
	Holding time exceeded		7	<1					7	<1
	Calibration problem					36	1		36	<1
	Blank problem		18	<1					18	<1
	Matrix spike recovery		141	1		27	1		168	1
	Quantitation problem		32	<1					32	<1
	Class Total		198			63			261	
Inorganics by NAA		34		100	22,470		89	22,504		89
	Laboratory control sample					17	<1		17	<1
	Matrix spike recovery					2,004	8		2,004	8
	MS recovery; Quant. problem					93	<1		93	<1
	Quantitation problem					546	2		546	2
	Class Total					2,660			2,660	
Pesticides/PCBs		7,794		100	3,101		97	10,895		99
	Analysis not requested					63	2		63	1
	Quantitation problem					42	1		42	<1
	Class Total					105			105	

Table 3.37 (continued)

Chemical class	Reason for rejection	Phase Ia			Phase Ib			Combined		
		Not rejected	Rejected	% OK	Not rejected	Rejected	% OK	Not rejected	Rejected	% OK
Semivolatile organics		19,041		99	10,484		100	29,525		99
	Calibration problem		1	<1		33	<1		34	<1
	Surrogate recovery		120	1					120	<1
	Matrix spike recovery		6	<1					6	<1
	Class Total		127			33			160	
TCLP		194		80	90		85	284		82
	Calibration problem					14	13		14	4
	Surrogate recovery		47	20					47	14
	Matrix spike recovery					2	2		2	1
	Class Total		47			16			63	
Volatile organics		8,469		100				8,469		100
	Calibration problem		3	<1					3	<1
	Class Total		3						3	
Other		13		100	16		100	29		100
	Class Total									
All classes	Total	49,648	452	99	38,889	2,877	93	88,537	3,329	96

Table 3.38. EFPC rejection rates by analyte for major analytical groups (ecological-specific data not included)

Chemical class	Chemical	Reason for rejection	Not rejected	Rejected	% of Chemical	% of Class
Anions	Ammonia		89		97.80	12.55
		Quantitation problem		2	2.20	0.28
		Total	89	2		
	Chloride		116		87.88	16.36
		Quantitation problem		16	12.12	2.26
		Total	116	16		
	Nitrate/Nitrite		97		98.98	13.68
		Quantitation problem		1	1.02	0.14
		Total	97	1		
	Sulfate		116		87.88	16.36
		Quantitation problem		16	12.12	2.26
		Total	116	16		
	Sulfide		85		68.55	11.99
		Holding time exceeded		22	17.74	3.10
		Quantitation problem		17	13.71	2.40
		Total	85	39		
	All other non-rejected compounds		132		100.00	18.62
		Total	132			
	Total anions		635	74		
Herbicides	2,4,5-T		11		91.67	30.56
		Holding time exceeded		1	8.33	2.78
		Total	11	1		
	2,4,5-TP		11		91.67	30.56
		Holding time exceeded		1	8.33	2.78
		Total	11	1		
	2,4-D		11		91.67	30.56
		Holding time exceeded		1	8.33	2.78
		Total	11	1		
	Total herbicides		33	3		
Inorganics	Aluminum		677		99.85	4.12
		Matrix spike recovery		1	0.15	0.01
		Total	677	1		
	Antimony		605		89.23	3.68
		Matrix spike recovery		73	10.77	0.44
		Total	605	73		

Table 3.38 (continued)

Chemical class	Chemical	Reason for rejection	Not rejected	Rejected	% of Chemical	% of Class
Inorganics (cont'd)	Arsenic		641		94.54	3.90
		Matrix spike recovery		21	3.10	0.13
		Quantitation problem		16	2.36	0.10
		Total	641	37		
	Iron		677		99.85	4.12
		Matrix spike recovery		1	0.15	0.01
		Total	677	1		
	Lead		659		97.20	4.01
		Holding time exceeded		2	0.29	0.01
		Matrix spike recovery		11	1.62	0.07
		Quantitation problem		6	0.88	0.04
		Total	659	19		
	Mercury		1,206		94.81	7.34
		Holding time exceeded		2	0.16	0.01
		Calibration problem		36	2.83	0.22
		Matrix spike recovery		28	2.20	0.17
		Total	1,206	66		
	Selenium		632		93.22	3.85
		Holding time exceeded		3	0.44	0.02
		Matrix spike recovery		33	4.87	0.20
		Quantitation problem		10	1.47	0.06
		Total	632	46		
	Thallium		660		97.35	4.02
		Blank problem		18	2.65	0.11
		Total	660	18		
	All other non-rejected compounds		10,406		100.00	63.36
		Total	10,406			
	Total inorganics		16,163	261		
Inorganics by NAA	Antimony		2,730		87.00	10.85
		Matrix spike recovery		192	6.12	0.76
		MS recovery; Quant.		56	1.78	0.22
		Quantitation problem		160	5.10	0.64
		Total	2,730	408		

Table 3.38 (continued)

Chemical class	Chemical	Reason for rejection	Not rejected	Rejected	% of Chemical	% of Class
Inorganics by NAA (cont'd)	Arsenic		2,160		68.83	8.59
		Matrix spike recovery		781	24.89	3.10
		MS recovery; Quant.		37	1.18	0.15
		Quantitation problem		160	5.10	0.64
		Total	2,160	978		
	Chromium		2,901		92.45	11.53
		Matrix spike recovery		191	6.09	0.76
		Quantitation problem		46	1.47	0.18
		Total	2,901	237		
	Mercury		2,901		91.46	11.53
		Laboratory control		20	0.63	0.08
		Matrix spike recovery		197	6.21	0.78
		Quantitation problem		54	1.70	0.21
		Total	2,901	271		
	Selenium		2,981		95.00	11.85
		Laboratory control		17	0.54	0.07
		Matrix spike recovery		94	3.00	0.37
		Quantitation problem		46	1.47	0.18
		Total	2,981	157		
	U235		3,089		97.85	12.28
		Matrix spike recovery		38	1.20	0.15
		Quantitation problem		30	0.95	0.12
		Total	3,089	68		
	U238		2,822		89.93	11.22
		Matrix spike recovery		292	9.31	1.16
		Quantitation problem		24	0.76	0.10
		Total	2,822	316		
	Zinc		2,920		93.05	11.61
		Matrix spike recovery		192	6.12	0.76
		Quantitation problem		26	0.83	0.10
		Total	2,920	218		
	Total Inorganics by NAA		22,504	2,653		

Table 3.38 (continued)

Chemical class	Chemical	Reason for rejection	Not rejected	Rejected	% of Chemical	% of Class
Pesticides/PCBs	4,4'-DDD		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	4,4'-DDE		369		98.66	3.35
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	369	5		
	4,4'-DDT		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	Aldrin		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	Dieldrin		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	Endosulfan I		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	Endosulfan II		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	Endosulfan sulfate		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		

Table 3.38 (continued)

Chemical class	Chemical	Reason for rejection	Not rejected	Rejected	% of Chemical	% of Class
Pesticides/PCBs (cont'd)	Endrin		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	Endrin aldehyde		157		96.91	1.43
		Analysis not requested		3	1.85	0.03
		Quantitation problem		2	1.23	0.02
		Total	157	5		
	Endrin ketone		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	Heptachlor		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	Heptachlor epoxide		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	Toxaphene		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	All other non-rejected compounds		3,339		100.00	30.35
		Total	3,339			
	alpha-BHC		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	alpha-Chlordane		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		

Table 3.38 (continued)

Chemical class	Chemical	Reason for rejection	Not rejected	Rejected	% of Chemical	% of Class
Pesticides/PCBs (cont'd)	beta-BHC		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	delta-BHC		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	gamma-BHC (Lindane)		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	gamma-Chlordane		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	p,p'-Methoxychlor		370		98.67	3.36
		Analysis not requested		3	0.80	0.03
		Quantitation problem		2	0.53	0.02
		Total	370	5		
	Total pesticides/PCBs		10,895	105		
Semivolatile organics	2,4,5-Trichlorophenol		378		97.93	1.27
		Surrogate recovery		8	2.07	0.03
		Total	378	8		
	2,4,6-Trichlorophenol		378		97.93	1.27
		Surrogate recovery		8	2.07	0.03
		Total	378	8		
	2,4-Dichlorophenol		379		98.19	1.28
		Surrogate recovery		7	1.81	0.02
		Total	379	7		
	2,4-Dimethylphenol		378		97.93	1.27
		Surrogate recovery		8	2.07	0.03
		Total	378	8		

Table 3.38 (continued)

Chemical class	Chemical	Reason for rejection	Not rejected	Rejected	% of Chemical	% of Class
Semivolatile organics (cont'd)	2,4-Dinitrophenol		343		88.86	1.16
		Calibration problem		34	8.81	0.11
		Surrogate recovery		9	2.33	0.03
		Total	343	43		
	2-Chlorophenol		378		97.93	1.27
		Surrogate recovery		8	2.07	0.03
		Total	378	8		
	2-Methylphenol		378		97.93	1.27
		Surrogate recovery		8	2.07	0.03
		Total	378	8		
	2-Nitrophenol		378		97.93	1.27
		Surrogate recovery		8	2.07	0.03
		Total	378	8		
	4,6-Dinitro-2-methylphenol		377		97.67	1.27
		Surrogate recovery		9	2.33	0.03
		Total	377	9		
	4-Chloro-3-methylphenol		378		97.93	1.27
		Surrogate recovery		8	2.07	0.03
		Total	378	8		
	4-Methylphenol		378		97.93	1.27
		Surrogate recovery		8	2.07	0.03
		Total	378	8		
	4-Nitrophenol		376		97.41	1.27
		Surrogate recovery		9	2.33	0.03
		Matrix spike recovery		1	0.26	0.00
		Total	376	10		
	Benzo(b)fluoranthene		385		99.74	1.30
		Matrix spike recovery		1	0.26	0.00
		Total	385	1		
	Benzo(k)fluoranthene		385		99.74	1.30
		Matrix spike recovery		1	0.26	0.00
		Total	385	1		
	Benzoic acid		194		97.49	0.65
		Surrogate recovery		5	2.51	0.02
		Total	194	5		

Table 3.38 (continued)

Chemical class	Chemical	Reason for rejection	Not rejected	Rejected	% of Chemical	% of Class
Semivolatile organics (cont'd)	Di-n-butylphthalate		385		99.74	1.30
		Matrix spike recovery		1	0.26	0.00
		Total	385	1		
	Pentachlorophenol		376		97.41	1.27
		Surrogate recovery		9	2.33	0.03
		Matrix spike recovery		1	0.26	0.00
		Total	376	10		
	Phenol		378		97.93	1.27
		Surrogate recovery		8	2.07	0.03
		Total	378	8		
	Pyrene		385		99.74	1.30
		Matrix spike recovery		1	0.26	0.00
		Total	385	1		
	All other non-rejected compounds		22,538		100.00	75.92
		Total	22,538			
	Total Semivolatile organics		29,525	160		
TCLP	2,4,5-Trichlorophenol		2		25.00	0.60
		Surrogate recovery		6	75.00	1.81
		Total	2	6		
	2,4,6-Trichlorophenol		2		25.00	0.6
		Surrogate recovery		6	75.00	1.81
		Total	2	6		
	2-Methylphenol		2		25.00	0.60
		Surrogate recovery		6	75.00	1.81
		Total	2	6		
	3-Methylphenol		2		25.00	0.60
		Surrogate recovery		6	75.00	1.81
		Total	2	6		
	4-Methylphenol		2		25.00	0.60
		Surrogate recovery		6	75.00	1.81
		Total	2	6		
	Chlordane		6		75.00	1.81
		Calibration problem		2	25.00	0.60
		Total	6	2		

Table 3.38 (continued)

Chemical class	Chemical	Reason for rejection	Not rejected	Rejected	% of Chemical	% of Class
TCLP (cont'd)	Endrin		6		75.00	1.81
		Calibration problem		2	25.00	0.60
		Total	6	2		
	Heptachlor		6		75.00	1.81
		Calibration problem		2	25.00	0.60
		Total	6	2		
	Heptachlor epoxide		6		75.00	1.81
		Calibration problem		2	25.00	0.60
		Total	6	2		
	Silver		12		85.71	3.63
		Matrix spike recovery		2	14.29	0.60
		Total	12	2		
	Total cresols		2		66.67	0.60
		Surrogate recovery		1	33.33	0.30
		Total	2	1		
	Toxaphene		6		75.00	1.81
		Calibration problem		2	25.00	0.60
		Total	6	2		
	All other non-rejected compounds		218		100.00	65.86
		Total	218			
	gamma-BHC (Lindane)		6		75.00	1.81
		Calibration problem		2	25.00	0.60
		Total	6	2		
	p,p'-Methoxychlor		6		75.00	1.81
		Calibration problem		2	25.00	0.60
		Total	6	2		
	Total TCLP		284	47		
Volatile organics	2-Butanone		242		99.18	2.80
		Calibration problem		2	0.82	0.02
		Total	242	2		
	Acetone		242		99.18	2.0
		Calibration problem		1	0.41	0.01
		Blank problem		1	0.41	0.01
		Total	242	2		

Table 3.38 (continued)

Chemical class	Chemical	Reason for rejection	Not rejected	Rejected	% of Chemical	% of Class
Volatile organics (cont'd)	Methylene chloride		243		99.59	2.81
		Blank problem		1	0.41	0.01
		Total	243	1		
	All other non-rejected compounds		7,907		100.00	91.53
		Total	7,907			
	Total Volatile Organics		8,634	5		
Other	All other non-rejected compounds		29		100.00	100.00
	Total other		29			

of several phenols and was not a COC. The organics detected in the TCLP samples were not compounds of particular interest, and acceptable TCLP results for silver at 85% did not prohibit an assessment. In summary, only a very limited number of analyses did not meet data evaluation criteria, and no assessments for the investigation were restricted due to lack of data.

Project precision. Precision is the measure of the degree of repetitiveness of a determination of an analytical result. It can be evaluated by measuring the agreement between independent measurements made under identical conditions. The RPD between two laboratory duplicate analysis results has traditionally been used to evaluate duplicate results. However, the usefulness of the RPD is limited to samples that contain contaminants significantly above the method detection limit so that the random background and signal fluctuations are a small percentage of the signal and, therefore, do not contribute significantly to the measured precision. In addition, samples in a solid matrix with a high degree of inhomogeneity can exhibit lack of precision in the duplicate analyses (as seen in the pilot study, Sect. 3.2.5.2)

For a measure of project precision, Table 3.39 contains the average RPD for duplicate pairs from all analytical batches (CLP soil, NAA soil, and CLP water) by various analytes. Appendix J contains the control charts displaying RPD by sequentially numbered batches and by sample location. When the RPD approaches zero, complete agreement is achieved between duplicate sample pairs, indicating a high degree of precision. The acceptable upper limits applied to each analytical batch (i.e., sample delivery group) for inorganic soil analysis is 35%. On a project-wide basis, only mercury does not meet (on the average) this batch-specific criterion. However, examination of the control charts (Fig. 3.136 and Fig. 3.137; reproduced from Appendix J) demonstrate that the majority of CLP and NAA soil mercury duplicate pairs fall within the control limit. Furthermore, the means for CLP and NAA methods are not significantly different (CLP soil mean = 37, standard deviation = 53; NAA soil mean = 43, standard deviation = 35). For comparison, EPA (1987a) references an ASTM study that shows historic precision of mercury analysis (cold vapor atomic absorption) to have an RPD of 35.4% (reported as relative standard deviation = 25%). Outliers in the EFPC data set account for the higher average soil RPDs and are thought to be a function of mercury heterogeneity in soil. Overall, precision for soils analysis has been determined to be adequate for the EFPC project.

None of the average RPDs for CLP water analysis falls within the batch control limit of 20%. CLP water analyses for mercury (Fig. 3.138) are representative of other analytes in that RPDs either are well below the 20% limit or are near the 200% value. This is attributable to a number of mercury concentrations being near the contract required detection limit (CRDL). At

Table 3.39. Mean laboratory duplicate sample analysis relative percent difference

Sample media	Analytical method	Parameter	Lower control limit	Upper control limit	Number of observations	Average relative % difference	Minimum relative % difference	Maximum relative % recovery	Standard deviation
Soil	EPA CLP	Arsenic		35	25	27.5	0.1	200.0	40.4
		Beryllium		35	24	8.1	0.1	22.3	5.9
		Cadmium		35	12	25.5	0.1	200.0	55.9
		Chromium		35	24	8.5	0.4	33.7	9.1
		Copper		35	24	11.7	0.6	33.3	10.7
		Lead		35	46	20.0	0.1	159.6	32.0
		Manganese		35	24	18.1	0.5	70.2	16.4
		Mercury		35	29	37.0	0.1	200.0	53.5
		Silver		35	9	9.2	1.2	29.5	9.8
		Vanadium		35	24	9.8	0.5	30.3	9.3
		Zinc		35	23	7.3	0.5	28.3	7.1
Soil	NAA	Arsenic		35	130	24.3	1.2	154.2	25.2
		Chromium		35	145	15.2	0.0	161.1	18.4
		Mercury		35	31	42.6	3.0	156.3	35.5
		Uranium-235		35	125	13.5	0.0	122.7	16.0
		Uranium-238		35	109	22.8	1.3	116.1	20.4
		Zinc		35	23	26.2	3.8	71.7	19.9
Water	EPA CLP	Arsenic		20	9	121.3	0.3	200.0	94.7
		Beryllium		20	3	68.7	2.6	200.0	113.7
		Chromium		20	10	31.4	2.3	200.0	60.6

Table 3.39 (continued)

Sample media	Analytical method	Parameter	Lower control limit	Upper control limit	Number of observations	Average relative % difference	Minimum relative % difference	Maximum relative % recovery	Standard deviation
Water (cont'd)	EPA CLP (cont'd)	Copper		20	14	43.3	2.9	200.0	67.8
		Lead		20	18	81.4	0.3	200.0	92.1
		Manganese		20	31	10.1	0.1	200.0	35.9
		Mercury		20	9	92.6	1.4	200.0	101.4
		Silver		20	3	137.0	11.0	200.0	109.1
		Vanadium		20	9	38.9	4.6	200.0	61.1
		Zinc		20	32	36.6	0.4	200.0	49.2

Source: EFPC Phase Ia and Ib QA/QC data on 04/01/93.

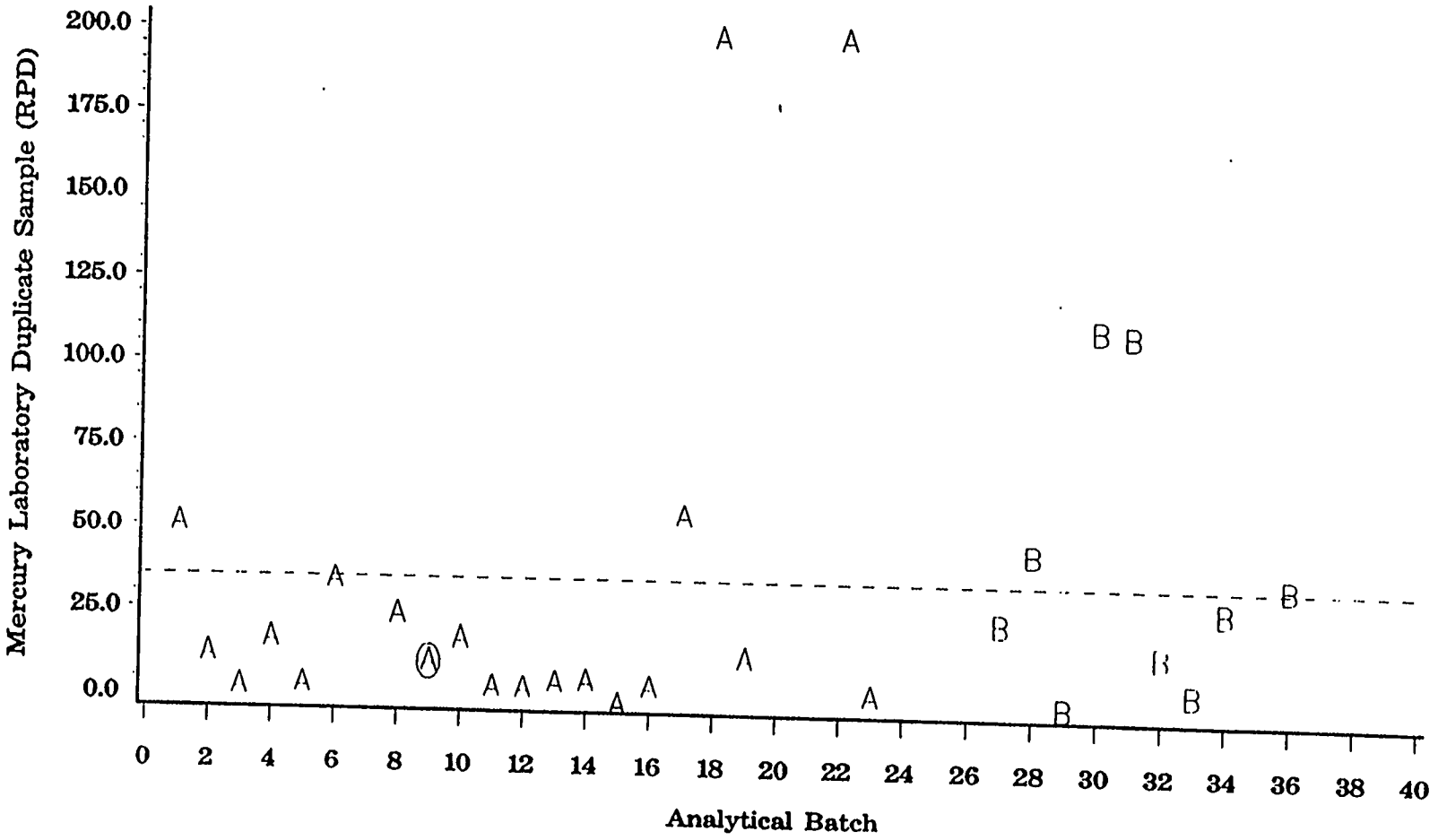


Fig. 3.136. EPA CLP soil laboratory duplicate sample recoveries for mercury sample analyses. Data points for which CLP criteria provide exceptions for data qualification have been excluded from this presentation. Control limits represent CLP duplicate RPD guidance. Circled points indicate rejected data from the data validation process.

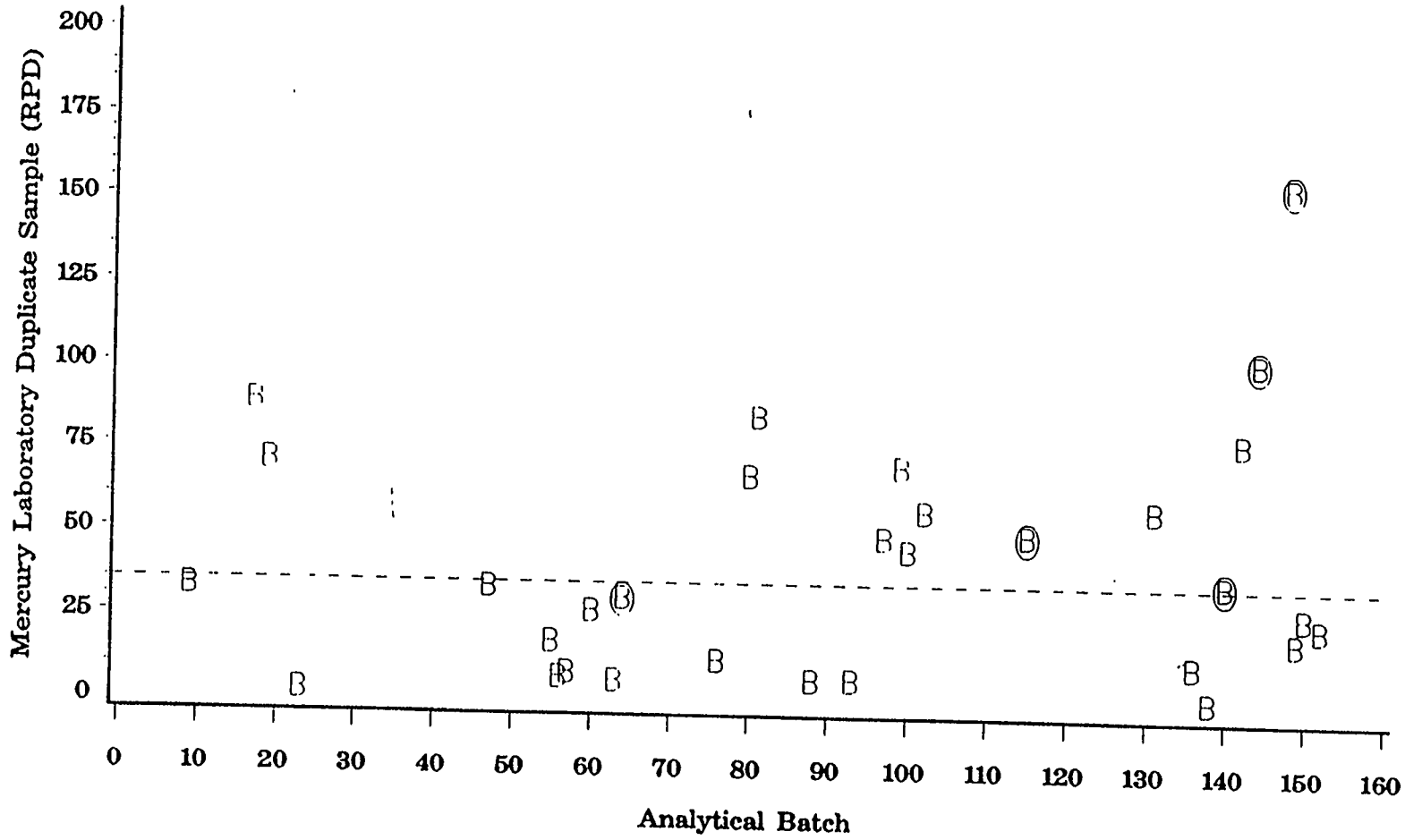


Fig. 3.137. NAA soil laboratory duplicate sample RPDs for mercury sample analyses. Data points for which CLP criteria provide exceptions for data qualification have been excluded from this presentation. Control limits represent CLP duplicate RPD guidance. Circled points indicate rejected data from the data validation process.

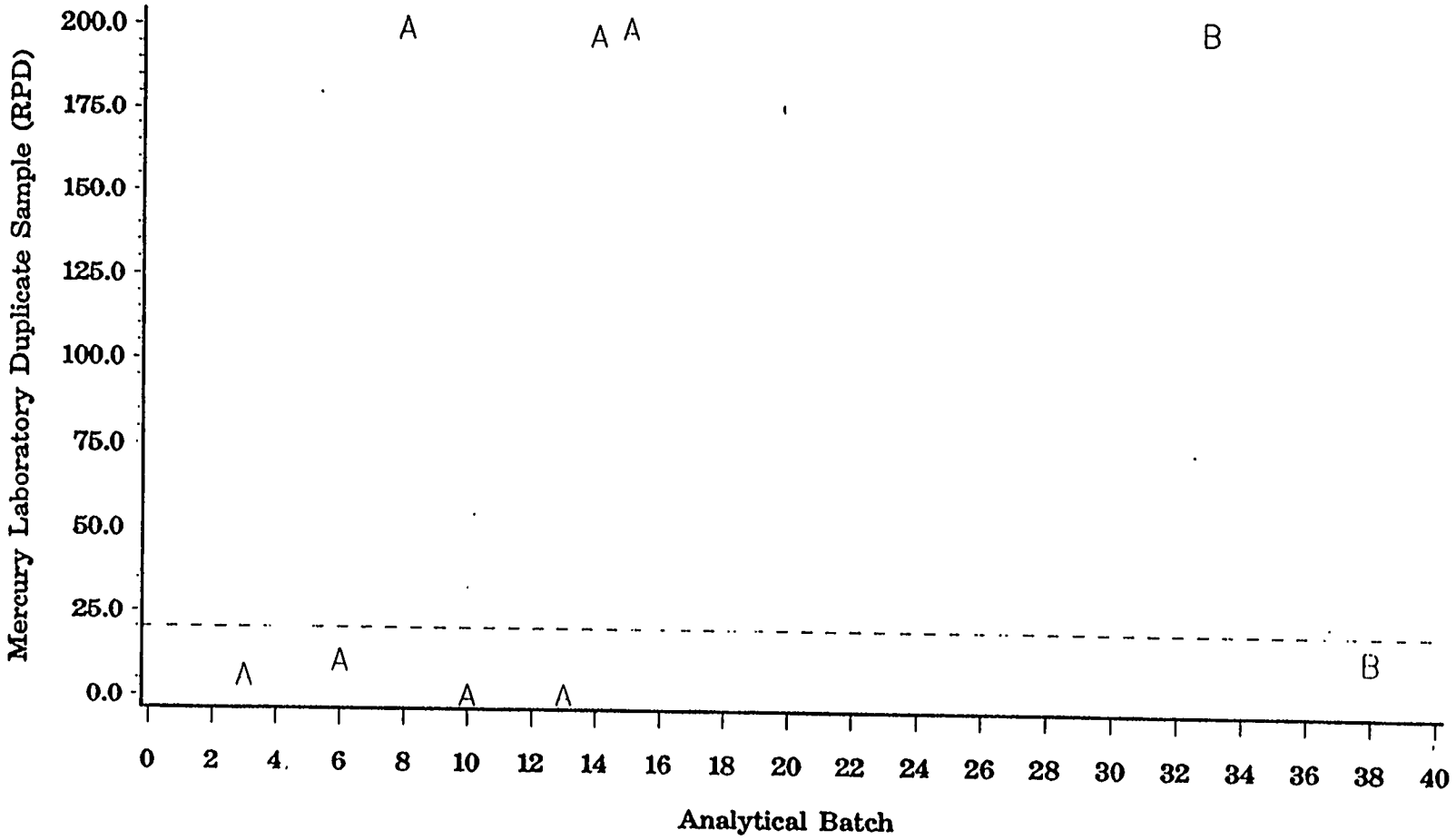


Fig. 3.138. EPA CLP water laboratory duplicate sample recoveries for mercury sample analyses. Data points for which CLP criteria provide exceptions for data qualification have been excluded from this presentation. Control limits represent CLP duplicate RPD guidance. Circled points indicate rejected data from the data validation process.

this level (<5 times the CRDL), the control limit is ±CRDL, which may represent an RPD of 200%. Nonetheless, project precision is judged to be adequate for the uses of the water analytical data (which were to identify the COCs in the surface and groundwater and provide an assessment of the population distribution of each analyte for risk assessment purposes).

Project accuracy. Accuracy is the closeness of agreement between an observed result and the true value for a sample analysis. Accuracy can be evaluated for a particular laboratory method by measuring the agreement between an observed result from analysis of a reference standard analyzed with a batch and its certified value. The difference between the observed analytical result and the known value will be a combination of a random component (measured by precision evaluation) and systematic error component (bias). The bias alone can be evaluated from the average difference when a large number of standards are analyzed. Accuracy is measured through the use of LCSs and MSSs. LCSs measure the accuracy of the methods independent of the sample matrix (i.e., the LCS matrix is not the same as the environmental sample), while accuracy determined by the MSS is a function of both matrix and method. Batch control limits for LCSs are analyte-specific for soil and ±20% for water. MSS limits are 25% for soil and water. NAA validation guidelines have adopted the same batch control limits as CLP.

Table 3.40 details the results of the LCS analyses for CLP soil, NAA soil, and CLP water. The results demonstrate a low degree of bias for all the soil analytes (except arsenic by NAA) and a moderately negative (<10%) bias for water. Compared with the historical bias for mercury analysis of soils (-9.1%, from the aforementioned study), the EFPC RI results exhibit an average of +3.9% for CLP (see Fig. 3.139) and -5.5% for NAA (see Fig. 3.140). (Note: mercury LCS is not required for CLP water analyses under the CLP SOW).

Average MSS recoveries for CLP soil, NAA soil, and CLP water all fall within the group control limits of 75-125% recovery (Table 3.41). From an inspection of the control chart (Fig. 3.141), mercury by NAA appears to have an acceptable but negative bias.

MSS provided for the largest proportion of rejected analyses for NAA. The following is a discussion of the rejected analytical batches for NAA:

Most of the rejected NAA mercury results were qualified for reasons of technical defensibility that may not actually result in problems with accuracy. There appear to have been several reasons for rejection. Several batches [HG1157, HG1125, and HG1084

Table 3.40. Mean laboratory control sample analysis percent recovery

Sample media	Analytical method	Parameter	Lower control limit	Upper control limit	Number of observations	Average percentage recovery	Minimum percent recovery	Maximum percent recovery	Standard deviation
Soil	EPA CLP	Arsenic	70	130	26	102.8	74.5	125.8	15.3
		Beryllium	85	115	25	97.1	88.7	109.3	5.4
		Cadmium	80	120	25	97.5	92.1	108.4	4.6
		Chromium	80	120	25	95.3	86.2	109.4	6.6
		Copper	85	115	25	96.4	88.0	104.8	4.6
		Lead	80	120	48	94.1	81.8	114.7	7.9
		Manganese	85	115	25	97.9	90.1	110.3	5.6
		Mercury	70	130	44	103.9	67.7	383.3	44.6
		Silver	70	130	25	91.0	74.3	106.3	6.7
		Vanadium	80	120	25	100.5	92.2	113.1	6.0
		Zinc	75	125	25	93.3	80.0	109.4	7.9
Soil	NAA	Arsenic	80	120	156	91.2	0.2	142.1	17.3
		Chromium	80	120	154	103.1	0.9	166.0	12.3
		Mercury	80	120	157	94.5	6.3	144.0	15.6
		Uranium-235	80	120	155	98.4	80.6	127.8	5.7
		Uranium-238	80	120	154	99.3	8.0	360.0	25.3
		Zinc	80	120	154	101.0	9.4	137.6	11.6
Water	EPA CLP	Arsenic	80	120	38	102.4	90.6	119.2	8.2
		Beryllium	80	120	35	91.4	81.9	110.0	6.6
		Cadmium	80	120	35	94.5	85.4	102.2	3.6

Table 3.40 (continued)

Sample media	Analytical method	Parameter	Lower control limit	Upper control limit	Number of observations	Average percentage recovery	Minimum percent recovery	Maximum percent recovery	Standard deviation
Water (cont'd)	EPA CLP (cont'd)	Chromium	80	120	35	90.7	81.0	106.0	5.5
		Copper	80	120	35	94.5	85.5	103.6	3.7
		Lead	80	120	37	99.8	81.9	112.7	7.6
		Manganese	80	120	35	91.3	83.5	105.1	4.5
		Silver	80	120	35	93.1	31.8	149.0	14.6
		Vanadium	80	120	35	92.6	84.7	105.0	4.2
		Zinc	80	120	35	94.2	85.6	104.9	3.7

Source: EFPC Phase Ia and Ib QA/QC data on 04/01/93.

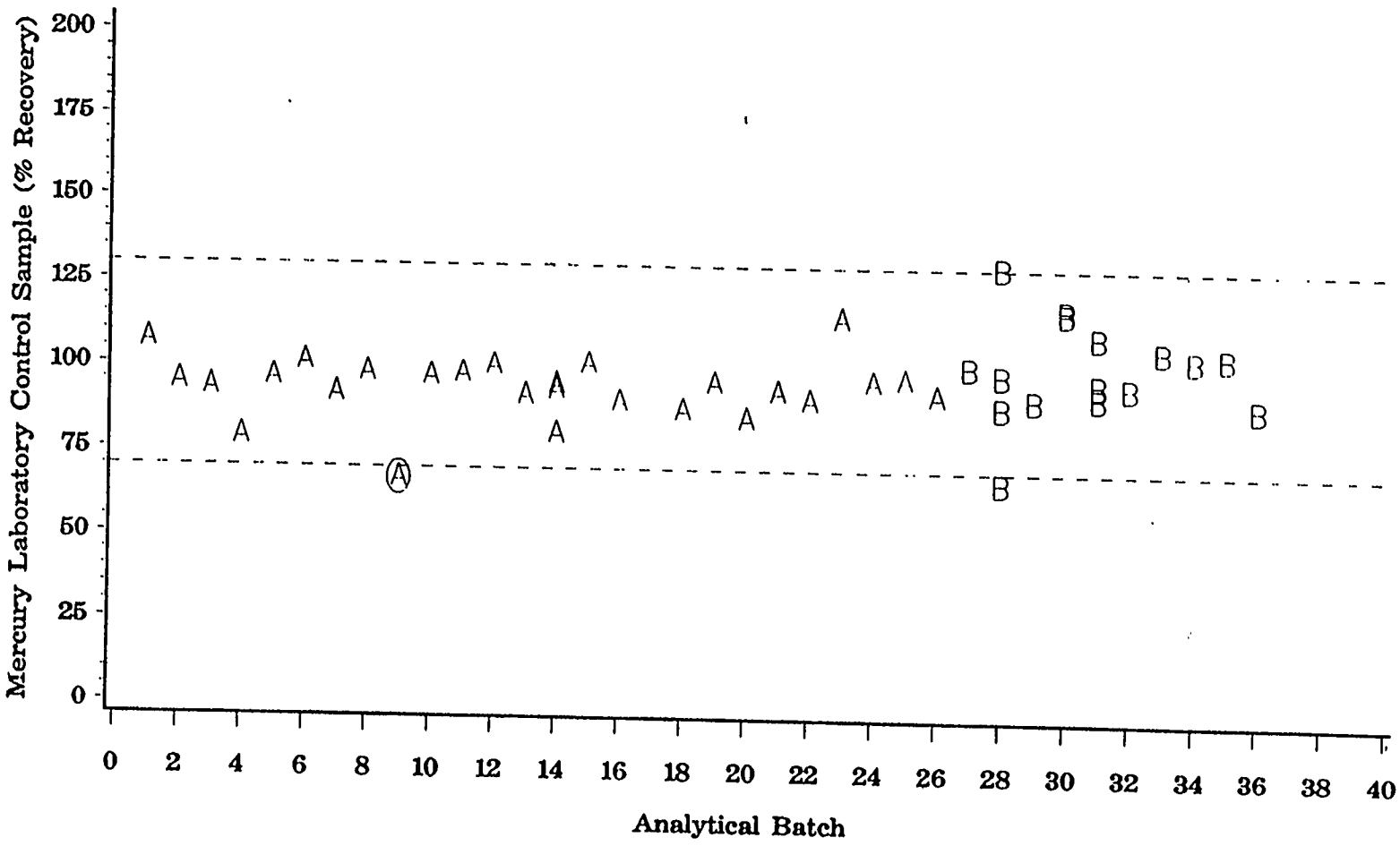


Fig. 3.139. EPA CLP Soil laboratory control sample recoveries for mercury sample analyses. Circled points indicate rejected data from the data validation process.

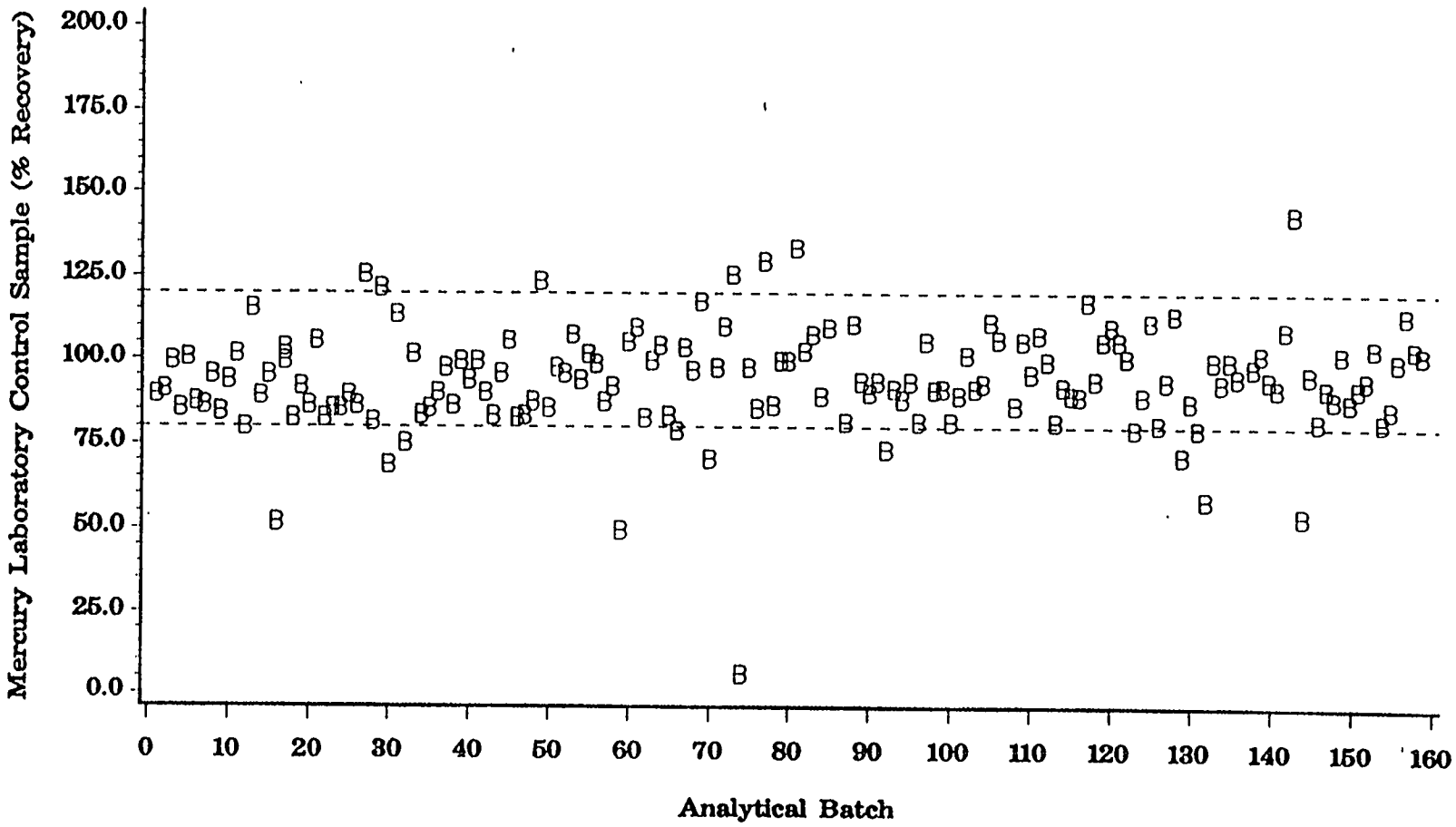


Fig. 3.140. NAA soil laboratory control sample recoveries for mercury sample analyses.

Table 3.41. Mean MSS analysis percent recovery

Sample media	Analytical method	Parameter	Lower control limit	Upper control limit	Number of observations	Average percentage recovery	Minimum percent recovery	Maximum percent recovery	Standard deviation
Soil	EPA CLP	Arsenic	75	125	25	80.9	0.9	127.1	30.4
		Beryllium	75	125	24	95.2	85.7	106.0	4.9
		Cadmium	75	125	24	96.1	67.2	117.6	10.5
		Chromium	75	125	24	89.3	65.2	102.7	9.7
		Copper	75	125	24	94.7	38.6	162.2	20.5
		Lead	75	125	31	105.0	-76.9	311.6	63.4
		Manganese	75	125	9	98.9	-12.6	249.8	69.1
		Mercury	75	125	10	106.2	79.8	144.9	21.3
		Silver	75	125	24	84.8	41.4	111.5	17.3
		Vanadium	75	125	24	93.2	80.9	106.1	5.5
		Zinc	75	125	24	88.4	59.2	108.4	11.6
Soil	NAA	Arsenic	75	125	147	82.8	-15.3	357.4	55.2
		Chromium	75	125	148	84.6	-2.1	170.1	24.7
		Mercury	75	125	147	83.5	-78.3	156.2	26.2
		Uranium-235	75	125	153	94.1	8.6	110.9	12.3
		Uranium-238	75	125	149	80.1	-29.4	131.7	24.3
		Zinc	75	125	146	98.1	-11.7	170.3	26.9
Water	EPA CLP	Arsenic	75	125	37	95.1	26.3	178.5	24.9
		Beryllium	75	125	35	100.1	83.3	110.1	5.5

Table 3.41 (continued)

Sample media	Analytical method	Parameter	Lower control limit	Upper control limit	Number of observations	Average percentage recovery	Minimum percent recovery	Maximum percent recovery	Standard deviation
Water (cont'd)	EPA CLP (cont'd)	Cadmium	75	125	35	101.3	79.3	129.6	11.4
		Chromium	75	125	35	98.5	76.4	108.5	6.3
		Copper	75	125	35	98.9	79.2	108.7	5.9
		Lead	75	125	36	91.3	-220	662.0	113.7
		Manganese	75	125	31	97.7	79.2	119.5	7.9
		Mercury	75	125	33	85.9	0.0	130.7	32.2
		Silver	75	125	35	93.9	74.5	104.5	6.6
		Vanadium	75	125	35	98.2	78.9	110.0	5.8
		Zinc	75	125	35	98.4	80.3	110.4	6.5

Source: EFPC Phase Ia and Ib QA/QC data on 04/01/93.

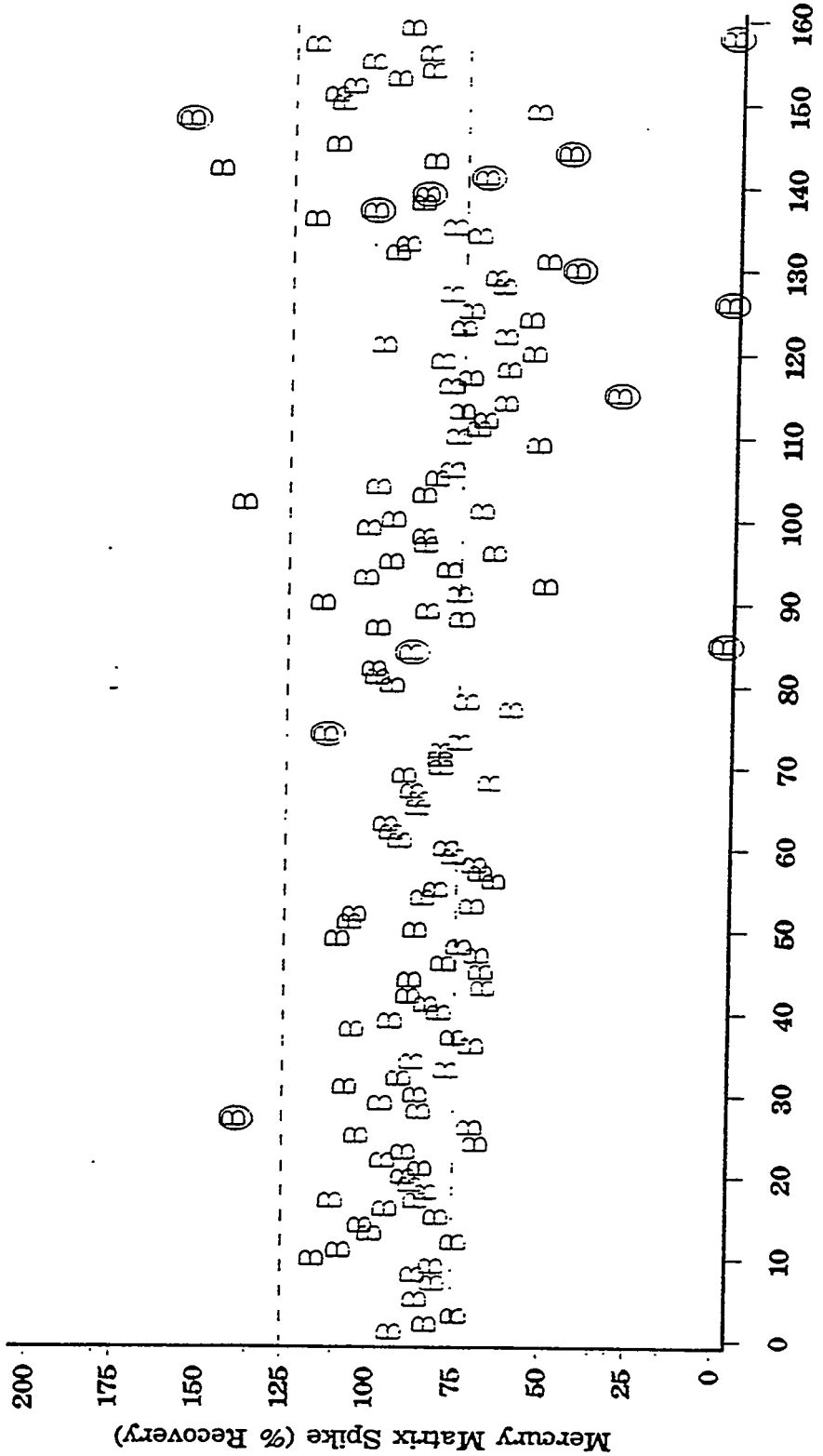


Fig. 3.141. NAA soil MS recoveries for mercury sample analyses. Note that data points for which CLP criteria provide exceptions for data qualification have been excluded from this presentation. Control limits represent CLP spike recovery guidance. Circled points indicate rejected data from the validation process.

(numbers 157, 125, and 84 on the control charts)] were rejected because the MS recovery was zero and appeared simply to have not been spiked. All analytes for these batches (except ^{235}U) have essentially zero recovery of the spike, yet LCS recovery for mercury was within acceptable criteria.

Another group of batches, rejected because the MS recovery was either too high or too low, had detectable mercury concentrations in the samples that were spiked (HG1063, HG1082, HG1085, HG1114, and HG1147). Because mercury distribution within a sample is very heterogeneous, samples split for a spike may not have identical concentrations. The MS recoveries of this group ranged from -137% to 156%. The fact that both high and low recoveries were observed supports the idea that the deviations in the recoveries were the result of heterogeneity rather than matrix interferences. The LCSs for batches in this group were within acceptable criteria.

One batch, HG1129, had a MSS recovery of 44% and no detectable mercury in the unspiked sample. Other QC sample criteria were acceptable for this batch. The reason for this type of result is unknown. It could represent a problem in spiking only and no problem with the other analyses, or it may indicate an analysis problem.

A large group of batches (HG1140, 1139, 1138, and 1136) had quantitation problems with specific samples. Lab records indicated that two samples had the same irradiation time, a physical impossibility with the system setup. Because this meant that the decay times and raw data were not absolutely correct, the affected samples were rejected. This mainly affects the legal defensibility of the data but not the final results. Another quantitation problem involved hand calculations from raw data that did not match the computer-generated reported values from the laboratory. Generally these indicated overestimates in the reported calculations. This involved batches HG1026, HG1078, and HG1083.

Batch HG1073 had a bad LCS but an acceptable MSS. This makes the cause uncertain, but it may simply mean that the wrong LCS was used. Another batch, HG1143, has definite problems. Both the LCS and MSS were low enough to result in rejected results.

Accuracy on a project-wide basis has been determined to be acceptable for both CLP analysis and NAA. While some of the data were qualified as usable but estimated, or unusable due to poor MS recoveries, the accepted data are sufficient for use by all phases of the project.

However, data rejected based on level IV criteria will support lower level (i.e., level II and III) data uses such as extent and distribution of contamination.

3.3.3 Radiological/NAA Data Assessment

The following is a description of the analysis techniques, a summary of the results of the validation process for each of the target radionuclides and an evaluation of the data quality provided by each analytical method. The TRL for Phase Ia included ^{60}Co, $^{89, 90}Sr$, ^{137}Cs, $^{234,235,238}U$, ^{237}Np, and ^{241}Am; analysis was performed by CompuChem Laboratories (Raleigh, North Carolina). The TRL for Phase Ib included ^{60}Co, ^{137}Cs, ^{233}Pa, $^{234,235,238}U$, $^{228,230,232}Th$, and ^{237}Np, analyzed by ORAU (Oak Ridge, Tennessee).

3.3.3.1 Description and evaluation of methods

Gamma Spectroscopy Analyses. Analyses for ^{60}Co, ^{137}Cs, ^{237}Np, and ^{241}Am were performed in both Phases Ia and Ib by gamma spectroscopy. Because the gamma energies for ^{237}Np have natural interferences, it was quantified by the measurement of its daughter, ^{233}Pa, assuming equilibrium (approximately 9 months since separation). Quantitation for ^{60}Co and ^{237}Np was not performed for some of the Phase Ia samples. Quantitation for ^{237}Np in Phase Ib was performed by both gamma spectroscopy and alpha spectroscopy. Alpha spectroscopy normally has greater sensitivity and lower detection limits. However, due to low recoveries for chemical separations, many of the samples showed higher sensitivity and greater reliability with gamma spectroscopy.

Gamma spectroscopy is normally a reliable method of measurement for these radionuclides because no chemical separation or processing of the sample is necessary. Accordingly, most of these measurements were acceptable. However, all of the ^{241}Am results for Phase Ia were qualified as usable but estimated due to calibration uncertainty resulting from an error in the preparation of the calibration americium standard. Figure 3.142 summarizes the percentages of the Phase Ia gamma spectroscopy results that were qualified as either usable but estimated or unusable (due to quantitation errors, laboratory controls being outside of control limits, blank contamination, and disagreement of duplicate results). Except for a few analyses that had reported values more negative than the uncertainty, all of the gamma results from Phase Ib were acceptable.

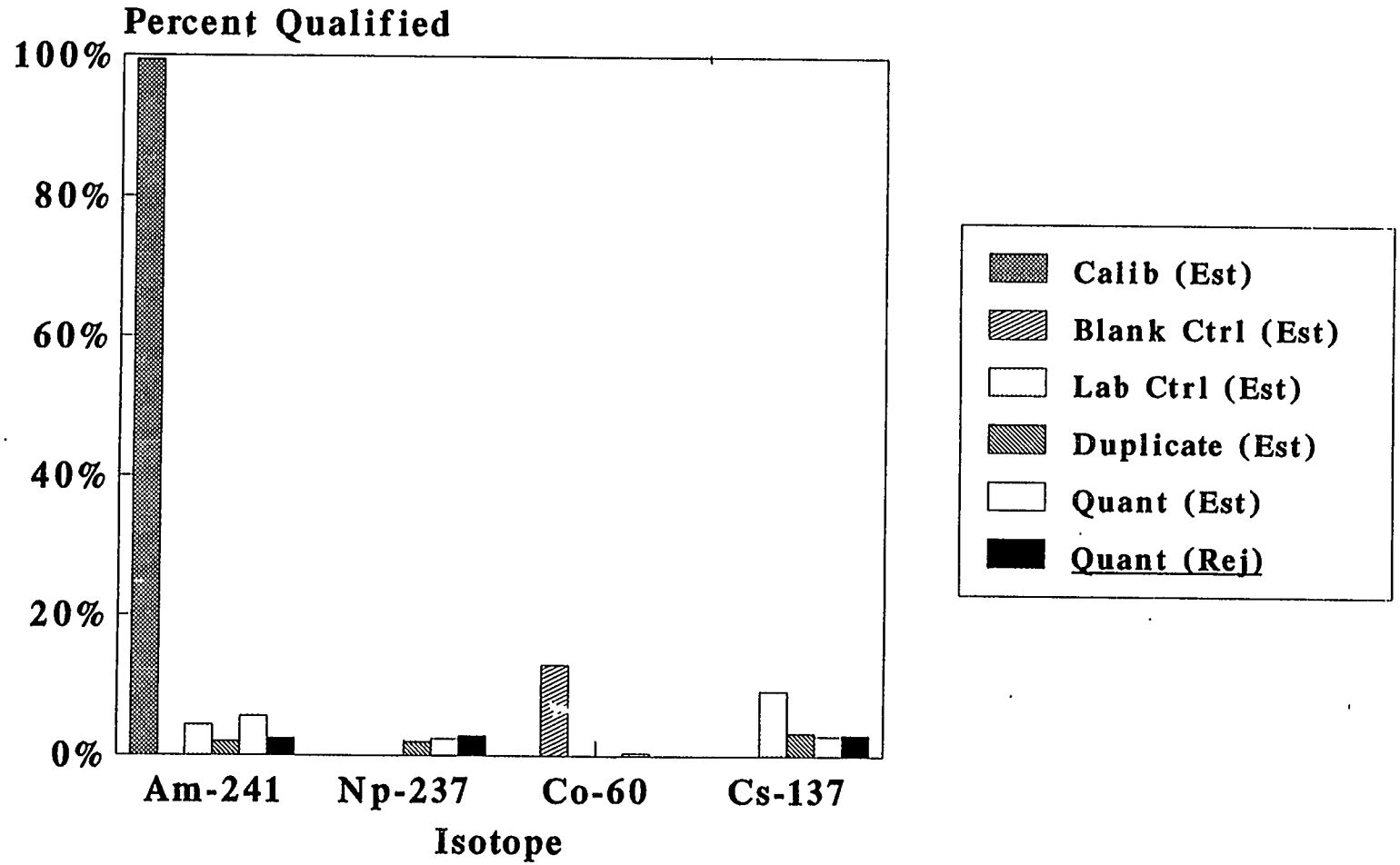


Fig. 3.142. Phase Ia gamma spectroscopy analysis results data validation major qualifier summary.

Alpha Spectroscopy Analyses. Analyses for $^{234,235,238}U$ were performed by ion exchange chemical separations and alpha spectroscopy for Phase Ia. Some results for Phase Ia were reported as total uranium rather than by isotope. Although most uranium analyses for Phase Ib were performed by NAA, some analyses for $^{234,235,238}U$ (as well as for $^{228,230,232}Th$ and ^{237}Np) were performed by liquid-liquid extraction separations and alpha spectroscopy. Isotopic thorium and ^{237}Np were not analyzed by alpha spectroscopy in Phase Ia, although ^{237}Np was measured by analysis of its daughter by gamma spectroscopy in both Phases Ia and Ib.

Because ion exchange and liquid-liquid extraction separations are complex and rely on oxidation state adjustments, chemical isotopic tracers are used to determine the sample-specific chemical recovery. Each analysis result is corrected for this chemical recovery. However, when the chemical recovery is very low, the correction factor can be very large and lead to significant errors due to recovery uncertainties. Therefore, recoveries less than 50% for water samples and less than 40% for soil/sediment samples were qualified as usable but estimated, and recoveries less that 20% for aqueous samples and less than 10% for soil/sediment samples were qualified as unusable. (It should be noted that the water limits were used for both soil and water in Phase Ib.) This resulted in about 50% of the isotopic uranium results being qualified as usable but estimated and 25% being qualified as unusable for Phase Ia (summarized in Fig. 3.143). The percentages qualified were approximately the same for water and soil/sediment samples.

By contrast, isotopic uranium analyses performed by alpha spectroscopy in Phase Ib had 6% of the results qualified as usable but estimated, and 6% also were qualified as unusable due to low chemical recovery. However, isotopic thorium analyses performed by alpha spectroscopy in Phase Ib had 35% of the results qualified as usable but estimated, and 12% were qualified as unusable due to low chemical recovery. The ^{237}Np analyses performed by alpha spectroscopy in Phase Ib resulted in no data being qualified as usable but estimated, but 8% qualified as unusable due to low chemical recovery. The chemical tracer utilized for neptunium analyses was ^{234}Th, which is not chemically similar to neptunium; therefore, there is uncertainty as to the actual recovery. Errors in the chemical recovery correction caused 61% of the neptunium results to be qualified as usable but estimated because the laboratory control was outside limits.

Detection sensitivity is generally better by a factor of ten for the alpha spectroscopy measurement than for the gamma spectroscopy measurement. However, this advantage is lost when there is very low chemical recovery. The ^{237}Np alpha spectroscopy results for Phase Ib have been compared with the ^{233}Pa (daughter) gamma spectroscopy results on a sample-by-sample

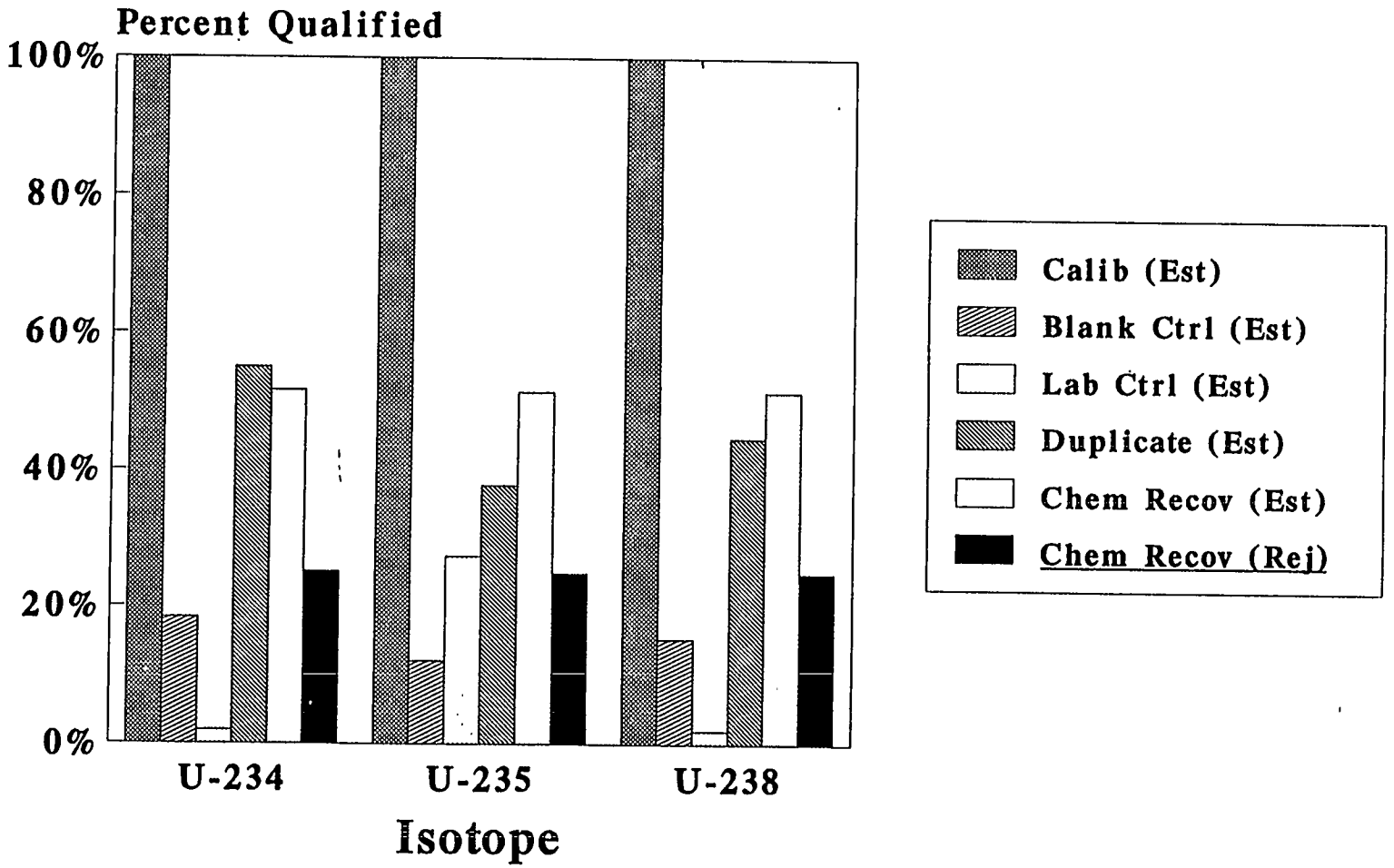


Fig. 3.143. Phase Ia uranium analysis results data validation major qualifier summary

basis. Three of the ^{237}Np results by alpha spectroscopy were greater than 1 pCi/g. However, the gamma spectroscopy results for these three samples showed less than 0.2 pCi/g (with 95% confidence). Therefore, the higher alpha spectroscopy results were not confirmed by the gamma spectroscopy results.

A significant portion of the isotopic uranium results in both Phases Ia (±40%) and Ib (±30%) were qualified as usable but estimated due to disagreement of duplicate analysis results. Also, a portion of the isotopic thorium results was qualified as unusable because either the duplicate (±15%), MS (±30%), laboratory control (10-50%), or a combination thereof was outside control limits. The high percentage of the ^{235}U results outside the control limits for laboratory controls and MSs in both Phases Ia and Ib is due to the lower concentration of ^{235}U in the control samples.

Strontium and Radium Analyses. Analyses for $^{89,90}Sr$ and total radium were performed in Phase Ia by chemical separation using precipitation techniques and gas proportional counting. An inactive strontium carrier was used for sample-specific chemical recovery. Analyses for total radium were performed by sulfate precipitation, using barium as a carrier for chemical recovery. The percentages of the strontium and radium results that were qualified as either usable but estimated, or unusable due to calibration errors, chemical recovery, blank contamination, disagreement of duplicate results, or calculational errors are summarized in Fig. 3.144. As with Phase Ia ^{241}Am and uranium isotopic results, all of the strontium and radium results were qualified as usable but estimated due to calibration uncertainty resulting from an error in the preparation of the strontium calibration standard and other calibration errors. A portion of the strontium results also was qualified as either usable but estimated, or unusable due to low chemical recovery. Qualification due to other reasons was relatively low for strontium and radium analyses.

NAA. Most of the uranium analyses for Phase Ib were performed by NAA. This technique involved the irradiation of the sample in a reactor, measurement of the ^{235}U by delayed neutron counting, and measurement of the ^{238}U by gamma spectroscopy of its activation product, ^{239}Np. Interference correction had to be made for mercury. However, due to the nondestructive nature of this analysis, which required no chemical separations, this technique gave better results than the determinations of uranium by alpha spectroscopy. The percentage of the NAA results that were qualified as unusable (due to quantitation errors, or because the LCS and MSS were outside control limits) is summarized in Table 3.37.

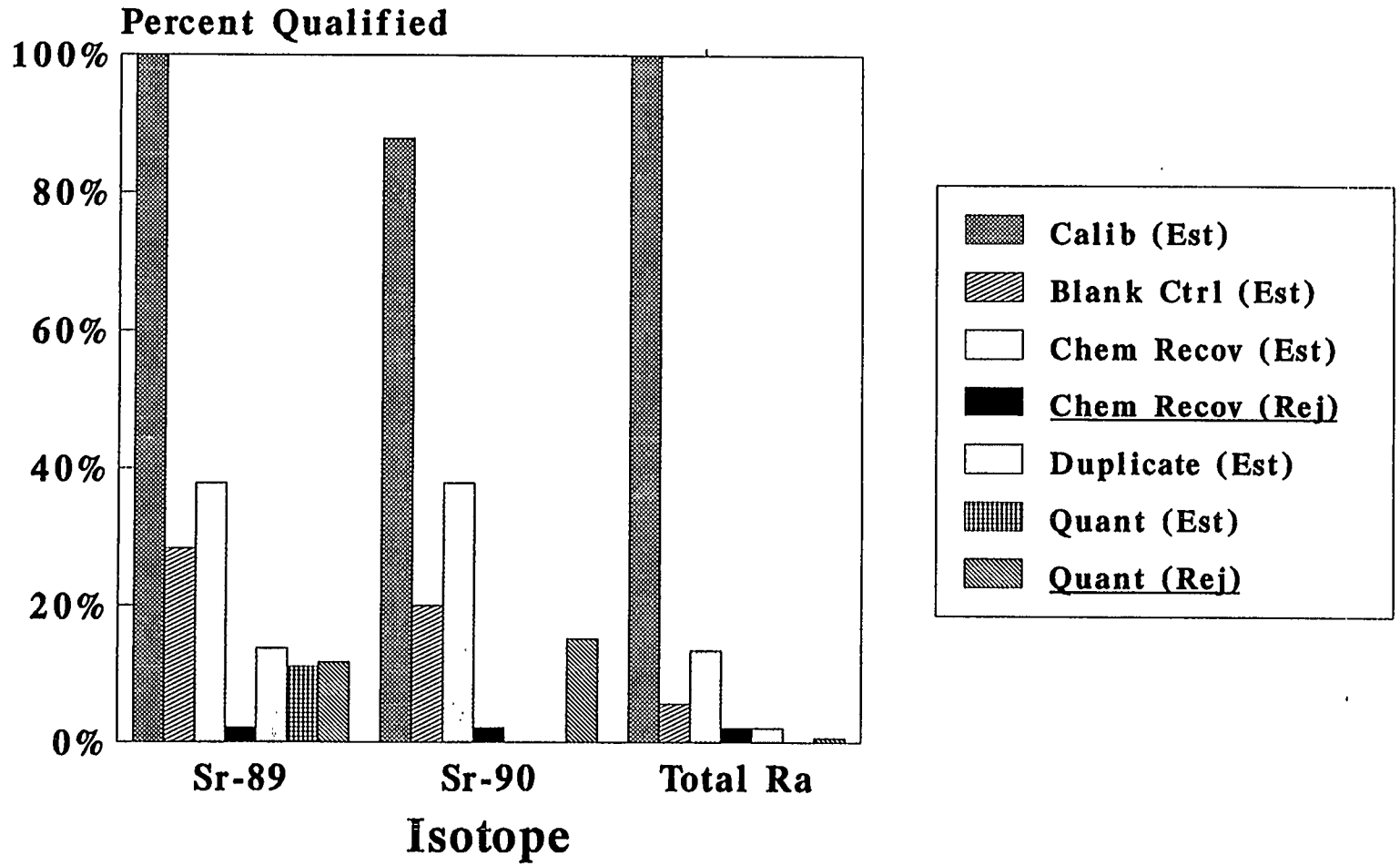


Fig. 3.144. Phase Ia strontium and radium results data validation major qualifier summary

Uncertainties reported for these measurements were rounded to the same decimal place as the results. All results that were not reported as "less than" at the contract required quantitation limit were qualified as "JE"; however, this qualification does not reflect on the quality of the results, but rather only on the reported uncertainties. Also, all "less than" results were qualified as usable but estimated because the reported values are not a true estimate of the value as normally determined by radiological analyses. These qualifications, however, do not exclude any potential use of the data within the EFPC RI.

3.3.3.2 Evaluation of detection sensitivity

It is desirable for analyses to be performed with a sensitivity adequate to give detection limits equivalent to the concentrations that would produce a lifetime risk for incidence of cancer at the 10^{-5} level. If this level of sensitivity is achieved, there is satisfactory probability that all sources contributing significantly to lifetime risk of 10^{-4} will be detected and adequately quantified. The detection limits that are equivalent to 10^{-5} risk and the detection limits that were achieved are summarized below. Risk slope factors were obtained from the EPA Health Effects Assessment Summary Tables (1991). As can be seen from the table, detection limits equivalent to 10^{-5} risk were not always achieved in the performance of this work. However, it should be recognized that the natural background levels for uranium, thorium, radium, and cesium are higher than the 10^{-5} risk equivalent concentration, and detection limits lower than natural background levels are not required. Furthermore, it is not likely that lower detection limits can be achieved in a production laboratory setting (as opposed to a research-oriented laboratory) with high throughput demands.

Analysis	10^{-5} Risk concentration	Phase Ia detection limit	Phase Ib detection limit
^{60}Co by gamma spectroscopy	0.007 pCi/g 13 pCi/L	0.08 pCi/g 80 pCi/L	0.12 pCi/g 70 pCi/L
^{137}Cs by gamma spectroscopy	0.029 pCi/g 7 pCi/L	0.06 pCi/g 100 pCi/L	0.12 pCi/g 100 pCi/L
^{233}Pa by gamma spectroscopy	0.075 pCi/g 0.12 pCi/L	0.2 pCi/g 200 p Ci/L	0.5 pCi/g 200 pCi/L
^{241}Am by gamma spectroscopy	0.5 pCi/g 0.15 pCi/L	0.6 pCi/g 240 pCi/L	240 pCi/L

Analysis	10^{-5} Risk concentration	Phase Ia detection limit	Phase Ib detection limit
$^{234,235,238}U$ by alpha spectroscopy	0.7 pCi/g 1.3 pCi/L	0.04 pCi/g 0.1 pCi/L	0.1 pCi/g 0.1 pCi/L
$^{228,230,232}Th$ by alpha spectroscopy	1.5 pCi/g		0.05 pCi/g
^{237}Np by alpha spectroscopy	0.075 pCi/g		0.04 pCi/g
$^{89,90}Sr$	2 pCi/L	2 pCi/L	
Total radium	1.6 pCi/L	1 pCi/L	
^{238}U by NAA	2 μg/g		8 μg/g
^{235}U by NAA	0.3 μg/g		0.01 μg/g

3.3.3.3 Overall evaluation of data usability

It is appropriate to make professional judgments on the validity of the overall data for a case. A general evaluation of the data can provide guidance concerning data quality and data limitations to avoid inappropriate use of the data, while not precluding any consideration of the data.

Data are qualified as usable but estimated when there is an indication that either accuracy or precision is less than is expected. Data are qualified as unusable when significant errors are expected or known to be present. Unusable data may not be expected to be representative of the range of true values but may still be useful in making broad observations and conclusions.

When data are qualified as usable but estimated because data review guidance for **precision** is not met, the data, may be summed or averaged with other data, resulting in an improvement in the usability of the data. When data are qualified as estimated because data review guidance for **accuracy** is not met, summing or averaging the data does not reduce the bias. It is important to distinguish between errors due to a lack of precision and those resulting from a bias.

Evaluation of QC Data. QC charts for radiological analyses are presented in Appendix J, and summary results for duplicate sample/duplicate error ratio and LCSs are shown in Tables 3.42 and 3.43. When data for a case are reviewed as a whole, a distinction between accuracy and precision can often be determined. While duplicate evaluations monitor precision only, LCS and MSS results reflect both precision and accuracy. When LCS and MSS control charts show a spread of data widely but evenly distributed around a mean of close to 100% recovery, and duplicate results show a general lack of precision, summed and averaged data can

Table 3.42. Mean laboratory duplicate sample analysis duplicate error ratio

Sample media	Analytical method	Parameter	Lower control limit	Upper control limit	Number of observations	Average percentage recovery	Minimum percent recovery	Maximum percent recovery	Standard deviation
Soil	Alpha spec	Np-237		1	18	0.3	0.0	0.9	0.2
		U-234		1	24	1.1	0.0	4.2	1.3
		U-235		1	21	1.1	0.0	5.7	1.3
		U-238		1	24	0.9	0.0	4.3	1.1
Soil	Fluorimetric	Total uranium		1	10	3.3	0.4	8.2	2.6
Soil	Gamma spec	Am-241		1	23	0.2	0.0	0.6	0.2
		Co-60		1	18	0.3	0.0	0.6	0.2
		Cs-137		1	23	0.3	0.0	2.6	0.5
Water	Alpha spec	Np-237		1	16	0.4	0.1	0.8	0.3
		U-234		1	19	1.1	0.0	4.7	1.1
		U-235		1	19	0.6	0.1	1.8	0.5
		U-238		1	19	0.9	0.0	3.9	0.9
Water	Beta	Sr-89		1	17	0.3	0.0	1.2	0.3
		Sr-90		1	17	0.2	0.0	0.6	0.2
Water	Fluorimetric	Total uranium		1	1	0.2	0.1	0.1	
Water	Gamma spec	Am-241		1	19	0.2	0.0	1.1	0.2
		Co-60		1	15	0.3	0.0	0.7	0.2
		Cs-137		1	19	0.2	0.0	0.8	0.2
Water	Gross alpha	Total radium		1	16	0.4	0.0	1.1	0.3

Source: EFPC Phase Ia and Ib QA/QC data on 04/01/93.

Table 3.43. Mean LCS analysis percent recovery

Sample media	Analytical method	Parameter	Lower control limit	Upper control limit	Number of observations	Average percentage recovery	Minimum percent recovery	Maximum percent recovery	Standard deviation
Soil	Alpha spec	Np-237	80	120	7	54.5	34.7	99.3	23.3
		Th-228	80	120	7	42.3	0.0	106.1	52.3
		Th-230	80	120	7	152.5	47.2	380.3	114.6
		Th-232	80	120	7	44.9	0.0	97.1	45.2
		U-234	80	120	21	99.0	40.2	111.4	14.6
		U-235	80	120	15	102.9	57.1	164.7	30.1
		U-238	80	120	19	103.9	34.4	128.1	19.3
Soil	Gamma spec	Cs-137	80	120	19	100.1	92.1	123.7	7.9
Water	Alpha spec	Np-237	80	120	5	111.8	104.8	118.5	5.5
		U-234	80	120	16	101.7	79.1	125.3	14.1
		U-235	80	120	16	104.1	61.8	142.9	23.4
		U-238	80	120	16	104.7	80.1	124.4	11.4
Water	Gamma spec	Cs-137	80	120	14	110.8	94.1	120.2	9.5

Source: EFPC Phase Ia and Ib QA/QC data on 04/01/93.

be expected to have little or no bias. However, when LCS and MSS control charts show a mean that is significantly different from 100% recovery, even summed and averaged data can be expected to contain a bias. The extent of the bias can be determined from the difference between the mean and 100%.

Review of the QC charts shows that all analyses performed by gamma spectroscopy in both Phases Ia and Ib had acceptable accuracy and precision, except for one batch of soil samples for both Phases Ia and Ib. While all analyses performed by alpha spectroscopy in both Phases Ia and Ib, showed a significant lack of precision (see Table 3.42), most of the alpha spectroscopy analyses showed no significant overall bias (except for neptunium and thorium results from Phase Ib, both of which showed a significant negative bias; see Table 3.43). Strontium and radium control results generally showed both acceptable precision and accuracy. Uranium results performed by NAA generally showed poor precision, especially for ^{238}U. However, the NAA uranium results showed no significant overall bias.

Completeness of the Radiological Data. Results that have been qualified as estimated for various reasons may be considered to have encountered minor problems with limited impact on data quality. These results are considered usable. However, all results qualified as unusable have serious data quality problems and should be considered highly suspect. Their use in site characterization is limited, although broad observations and conclusions may still be possible based on them.

The percentage of analyses that have no qualifications or are estimated provides a measure of the completeness of the radiological data for the EFPC RI (Table 3.44). The DQO for laboratory completeness was set at 90%. Overall, the DQO for completeness was not met for radiological analyses. However, the DQO was met for many radiological analytes in either Phase Ia or Phase Ib or both. More than 93% of the isotopic analysis from gamma spectroscopy (^{241}Am, ^{237}Np, ^{137}Cs, ^{233}Pa, and ^{60}Co) and the total radium results were usable. Three-fourths of the ^{90}Sr results and 96% of the ^{89}Sr results were usable. Approximately 70% of the analyses for ^{234}U, ^{235}U, and ^{238}U from Phase Ia by alpha spectroscopy were usable and 80$\pm$% of the analyses from Phase Ib for ^{234}U and ^{238}U were usable, but only 40% of the ^{235}U were acceptable. In contrast, 90% of the uranium analyses performed by NAA in Phase Ib were acceptable (Table 3.38). However, for analyses of thorium performed by alpha spectroscopy during Phase Ib, less than 50% of the results were acceptable, and all of the ^{237}Np results were qualified (but considered usable).

Table 3.44. EFPC summary of rejected radiologic parameters

Radiologic parameter	Phase Ia			Phase Ib			Combined		
	Rejected	Not rejected	OK	Rejected	Not rejected	OK	Rejected	Not rejected	OK
Am-241	20	432	95.6		4	100	20	436	95.6
Co-60	1	424	99.8		98	100	1	522	99.8
Cs-137	16	436	96.5		98	100	16	534	97.1
Np-237	14	411	96.7	12	44	78.6	26	455	94.6
Pa-233				3	91	96.8	3	91	96.8
Radium, total	9	132	93.6				9	132	93.6
Sr-89	5	137	96.5				5	137	96.5
Sr-90	33	109	76.8				33	109	76.8
Th-228				27	25	48.1	27	25	48.1
Th-230				35	17	32.7	35	17	32.7
Th-232				27	25	48.1	27	25	48.1
U-234	138	311	69.3	8	56	87.5	146	367	71.5
U-235	125	324	72.2	39	25	39.1	164	349	68.0
U-238	130	320	71.1	13	51	79.7	143	371	72.2
Uranium, total	26	88	77.2				26	88	77.2
Totals	517	3124	85.8	164	534	76.5	681	3658	84.3

In summary, the radiological isotopes of most interest were the uranium series. From the combined use of NAA and alpha spectroscopy, large amounts of uranium data are available for these isotopes. The thorium isotope series was added during Phase Ib based on inferences of the processes that occurred at Y-12. Of all the results, those for thorium were the most disappointing; however, the available results do not indicate that a problem exists. Moreover, because thorium is expected to accumulate in the same general area as uranium, results for uranium can act as a surrogate in remedial decisions concerning thorium. The availability of acceptable results is more than sufficient for the intended purposes of the EFPC RI.

3.3.4 Field Results

During all phases of the EFPC RI sampling program, QC samples were collected to gauge the impacts from various components of field activities. Approximately 15% (709/4723) of the samples taken during the program were QC samples obtained to determine the degree of cross-contamination, ensure successful decontamination, or determine effects of media heterogeneity on results.

3.3.4.1 Field duplicates

Field duplicate samples are collocated sample pairs that are taken to ascertain the contribution of variability (i.e., precision) due to the environmental media. The EFPC RI collected field duplicates at a rate of one duplicate per 20 field samples. Table 3.45 provides a summary, by medium and by analyte, of the RPD and absolute difference for field duplicates. Specific control limits for field precision were not established, in part because the natural heterogeneity of the environmental media was much greater than the variability imparted by field activities. For a basis of comparison, Table 3.45 includes lower and upper limits that are three standard deviations above and below the mean. As one might expect, soil and sediment heterogeneity imparts a large degree of uncertainty to what might be considered representative values. Average RPDs in soils range from roughly 20 to 200% for CLP metals, 15 to 200% for NAA metals, and 100 to 200% for CLP organics. Average RPD values for CLP sediment metal analyses are generally less than 100%, but fewer duplicates were taken for this media. Average CLP organics are mostly in the 200% range.

Unexpectedly, average RPD values for water demonstrate large differences between duplicates for surface water and groundwater samples. In fact, the soil duplicates were no more variable than water duplicates as deduced from average values.

Table 3.45. RPD between field duplicates

Parameter	Method of RPD Calculation	Units	Average RPD	RPD Limits		Number results within limits
				Lower	Upper	
Inorganic	*Matrix: Soil*					
Lead	Rel. % Difference	%	25.02	7.76	69.87	13/20
Manganese	Rel. % Difference	%	26.78	6.29	56.61	21/27
Mercury	Abs. Difference		66.61	38.34	345.12	1/4
	Rel. % Difference	%	39.65	11.79	106.19	58/82
Nickel	Abs. Difference		4.66	2.26	20.36	7/20
	Rel. % Difference	%	103.63	32.12	289.12	10/26
Silver	Abs. Difference		2.93	1.23	11.11	1/3
	Rel. % Difference	%	106.28	31.25	281.32	3/7
Arsenic	Abs. Difference		1.45	0.42	3.81	15/23
Beryllium	Abs. Difference		0.08	0.02	0.25	8/11
	Rel. % Difference	%	200.00	0.00	0.00	8/18
Cadmium	Abs. Difference	mg/kg	0.90	0.31	2.87	3/5
	Rel. % Difference	%	82.50	28.67	258.03	6/11
Chromium	Rel. % Difference	%	16.35	5.04	45.41	17/27
Copper	Abs. Difference	mg/kg	1.70	0.45	4.05	2/2
	Rel. % Difference	%	41.79	18.03	162.33	12/27
Vanadium	Rel. % Difference	%	20.14	7.31	65.85	13/27
Zinc	Rel. % Difference	%	38.59	18.22	164.04	9/27
NAA	*Matrix: Soil*					
U235	Rel. % Difference	%	14.49	5.04	45.39	10/18
Mercury	Abs. Difference	mg/kg	6.00	1.51	13.63	2/3
	Rel. % Difference	%	101.49	32.84	295.56	4/7
Arsenic	Abs. Difference	mg/kg	1.21	0.38	3.42	13/16
Chromium	Abs. Difference	mg/kg	6.29	2.06	18.58	11/17
U238	Abs. Difference	mg/kg	3.76	1.36	12.25	5/15
	Rel. % Difference	%	200.00	0.00	0.00	5/17
Zinc	Abs. Difference	mg/kg	33.00	3.66	32.95	0/3
	Rel. % Difference	%	200.00	0.00	0.00	0/5
Organic	*Matrix: Soil*					
Aroclor-1260	Abs. Difference	mg/kg	1.40	0.65	5.85	1/3
	Rel. % Difference	%	21.58	4.29	38.68	3/5
Aroclor-1254	Rel. % Difference	%	133.33	0.00	0.00	0/3
Pyrene	Abs. Difference		152.53	112.99	1016.95	1/7
	Rel. % Difference	%	137.83	20.72	186.48	2/9

Table 3.45 (continued)

Parameter	Method of RPD Calculation	Units	Average RPD	RPD Limits		Number results within limits
				Lower	Upper	
Indeno(1,2,3-c,d)pyrene	Abs. Difference		112.12	74.60	671.42	1/5
	Rel. % Difference	%	200.00	0.00	0.00	1/8
Benzo(b)fluoranthene	Abs. Difference	mg/kg	130.22	98.65	887.89	0/8
	Rel. % Difference	%	70.12	0.00	0.00	0/9
Benzo(k)fluoranthene	Abs. Difference	mg/kg	100.39	74.66	671.94	0/8
	Rel. % Difference	%	70.12	0.00	0.00	0/9
Chrysene	Abs. Difference		99.34	79.70	717.38	0/8
Benzo(a)pyrene	Abs. Difference		134.47	109.55	986.03	1/7
	Rel. % Difference	%	200.00	0.00	0.00	1/8
Dibenzo(a,h)anthracene	Abs. Difference		0.06	36.11	325.00	1/3
	Rel. % Difference	%	200.00	0.00	0.00	1/4
Benzo(a)anthracene	Abs. Difference		105.66	87.56	788.11	0/8
Carbazole	Rel. % Difference	%		0.00	0.00	1
Radionuclide	*Matrix: Soil*					
U234	Rad Err		6.91	3.11	28.05	3/13
PA233	Rad Err		0.55	0.04	0.41	0/3
NP237	Rad Err		0.72	0.13	1.24	11/13
U235	Rad Err		155.71	177.46	1597.13	0/13
U238	Rad Err		5.89	2.84	25.60	4/13
Inorganic	*Matrix: Sediment*					
Lead	Rel. % Difference	%	23.00	4.17	37.59	2/3
Manganese	Rel. % Difference	%	18.74	6.03	54.33	5/5
Mercury	Rel. % Difference	%	58.95	18.13	163.20	3/5
Nickel	Abs. Difference		4.00	1.17	10.56	3/4
	Rel. % Difference	%	4.30	0.00	0.00	3/5
Arsenic	Abs. Difference		3.62	1.17	10.54	3/5
Beryllium	Abs. Difference	mg/kg		0.00	0.00	1
	Rel. % Difference	%	103.44	32.18	289.65	1/3
Cadmium	Abs. Difference		0.40	0.23	2.10	1/2
	Rel. % Difference	%	200.00	0.00	0.00	1/3
Chromium	Rel. % Difference	%	37.16	5.51	49.66	4/5
Copper	Rel. % Difference	%	18.44	9.04	81.37	4/5
Vanadium	Rel. % Difference	%	21.90	3.25	29.33	4/5
Zinc	Rel. % Difference	%	5.60	3.24	29.17	4/5

Table 3.45 (continued)

Parameter	Method of RPD Calculation	Units	Average RPD	RPD Limits		Number results within limits
				Lower	Upper	
Organic	*Matrix: Sediment*					
Aroclor-1260	Rel. % Difference	%		0.00	0.00	1
Aroclor-1254	Rel. % Difference	%		0.00	0.00	1
Pyrene	Abs. Difference		0.08	34.95	314.61	1/2
	Rel. % Difference	%	200.00	0.00	0.00	1/3
Indeno(1,2,3-c,d)pyrene	Abs. Difference			0.00	0.00	1
Benzo(b)fluoranthene	Abs. Difference			0.00	0.00	1
	Rel. % Difference	%	200.00	0.00	0.00	0/3
Benzo(k)fluoranthene	Abs. Difference			0.00	0.00	1
	Rel. % Difference	%	200.00	0.00	0.00	0/2
Chrysene	Abs. Difference		0.10	15.78	142.09	1/2
	Rel. % Difference	%	200.00	0.00	0.00	1/3
Benzo(a)pyrene	Abs. Difference			0.00	0.00	1
	Rel. % Difference	%	200.00	0.00	0.00	0/2
Benzo(a)anthracene	Abs. Difference		0.09	13.78	124.10	1/2
	Rel. % Difference	%	200.00	0.00	0.00	1/3
Radionuclide	*Matrix: Sediment*					
U234	Rad Err		1.91	1.79	16.19	3/4
PA233	Rad Err		0.26	0.01	0.14	0/2
NP237	Rad Err		0.20	0.27	2.51	2/4
U235	Rad Err		2.19	1.19	10.79	4/4
U238	Rad Err		1.85	1.55	13.95	3/4
Inorganic	*Matrix: Surface Water*					
Manganese	Rel. % Difference	%		0.00	0.00	1
Organic	*Matrix: Surface Water*					
Methylene Chloride	Rel. % Difference	%		0.00	0.00	1
Radionuclide	*Matrix: Surface Water*					
U234	Rad Err			0.00	0.00	1
NP237	Rad Err		0.39	0.09	0.82	1/2
U235	Rad Err			0.00	0.00	1
U238	Rad Err			0.00	0.00	1
Inorganic	*Matrix: Groundwater*					
Lead	Abs. Difference		1.03	0.39	3.56	3/3
	Rel. % Difference	%	118.44	27.18	244.66	5/5
Manganese	Rel. % Difference	%	66.12	23.96	215.67	4/7
Mercury	Abs. Difference		0.01	0.00	0.03	1/2

Table 3.45 (continued)

Parameter	Method of RPD Calculation	Units	Average RPD	RPD Limits		Number results within limits
				Lower	Upper	
	Rel. % Difference	%	117.64	27.45	247.05	3/4
Nickel	Abs. Difference			1.11	10.05	1/2
	Rel. % Difference	%	123.06	25.64	230.80	3/4
Arsenic	Rel. % Difference	%		0.00	0.00	1
Beryllium	Abs. Difference			0.00	0.00	1
	Rel. % Difference	%	200.00	0.00	0.00	0/3
Cadmium	Abs. Difference			0.00	0.00	1
Chromium	Rel. % Difference	%	133.33	22.82	205.41	3/3
Copper	Abs. Difference			0.00	0.00	1
	Rel. % Difference	%	111.78	29.86	268.80	3/5
Vanadium	Abs. Difference		1.15	0.23	2.10	1/2
	Rel. % Difference	%	123.83	25.38	228.48	3/4
Zinc	Rel. % Difference	%	67.31	28.41	255.69	2/3
Dissolved Inorganic	*Matrix: Groundwater*					
Lead	Rel. % Difference	%	133.33	0.00	0.00	0/3
Manganese	Rel. % Difference	%	41.42	28.05	252.48	2/4
Nickel	Rel. % Difference	%		0.00	0.00	1
Beryllium	Rel. % Difference	%		0.00	0.00	1
Copper	Rel. % Difference	%	100.00	0.00	0.00	0/2
Vanadium	Rel. % Difference	%		0.00	0.00	1
Zinc	Abs. Difference			0.00	0.00	1
	Rel. % Difference	%	200.00	0.00	0.00	0/3
Organic	*Matrix: Groundwater*					
Acetone	Abs. Difference			0.00	0.00	1
	Rel. % Difference	%	180.18	9.34	84.08	0/4
Radionuclide	*Matrix: Groundwater*					
NP237	Rad Err		0.48	0.22	2.05	4/7
U235	Rad Err			0.00	0.00	1
U238	Rad Err			0.00	0.00	1

In calculating the RPD, rejected results were not included.
The RPD is an absolute difference when the sample and duplicate results are < 5 times the CRDL

A conclusion of the EFPC RI is that field duplicates play a minor role in judging the media component of variability. For solid matrices such as soil and sediments, the lack of precision due to the media overwhelms the other components of precision (sampling activities, laboratory methods, etc.). A recommendation would be for future studies to omit the field duplicates but design a specific task to measure media and laboratory precision. The EFPC RI recognized this early in the program and relied upon a pilot study (Sect. 3.2) to characterize the heterogeneity of the soil media and compare analytical methods for overall effect upon results.

3.3.4.2 Field QC blanks

Three types of field QC blanks were obtained during sampling activities along EFPC. Field blanks were bottled in the field to assess cross-contamination from improper sampling and handling of the samples. Trip blanks were bottled in the staging area/warehouse to determine potential cross-contamination of samples submitted for VOC analysis. Equipment rinsate blanks were sampled in the field after decontamination of sampling/field equipment to ensure that no cross-contamination was occurring due to improper cleaning.

Field blanks consisting of deionized water were bottled in the field for samples collected for CLP and radiological analyses. Field blanks for NAA were composed of surface soil samples obtained at the Hinds Creek reference site. The latter field blanks were incorporated because NAA is not amenable to water samples and the soil from a noncontaminated site would suffice for most analytes, given the relatively high detection limit of NAA. A review of Table 3.46 indicates that no significant contamination was observed in the Phase Ia field blanks. Common elements such as aluminum, calcium, manganese, sodium, and zinc were noted several times but at much lower concentrations than would be expected in natural waters. Potential contaminants (arsenic, lead, mercury, and nickel) were observed once for each analyte but near the analytical detection limit. Other than common laboratory contaminants, no organics were seen at levels and frequencies that might bias analytical results. Phase Ib field blanks are listed in Table 3.47. The blank results are derived from CLP analysis (metals-total and organics) and NAA (as noted). No undue results are seen in the analyses of Phase Ib field blanks, with one exception. Mercury has one detection (at 21 mg/kg) out of 164 analyses. It is extremely unlikely that this concentration came from the reference site, which indicates either cross-contamination or an inadvertent swap with a field sample.

Table 3.46. EFPC Phase Ia results for field blank mean contaminant concentrations

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation >detection limit	Grand mean (<DL = 0)
Aluminum, total	µg/L	10/25	109	54.1	101	208	46.3	40.4
Arsenic, total	µg/L	1/25	4.46	4.7	4.7	4.7	.	0.188
Barium, total	µg/L	3/25	1.15	1.1	1.73	2.5	0.709	0.208
Calcium, total	µg/L	14/25	130	39.5	137	289	87.5	76.7
Iron, total	µg/L	11/25	31.9	10.5	147	1030	297	64.6
Lead, total	µg/L	1/25	2.83	4.5	4.5	4.5	.	0.18
Manganese, total	µg/L	5/25	1.7	1.7	30.3	143	63	6.06
Mercury, total	µg/L	1/32	0.2	0.21	0.21	0.21	.	0.00656
Nickel, total	µg/L	1/25	13.7	13.9	13.9	13.9	.	0.556
Sodium, total	µg/L	11/25	642	359	520	760	151	229
Zinc, total	µg/L	12/25	7.54	3.2	11	33.1	9.04	5.29
Diethylphthalate	µg/L	1/21	9.55	2	2	2	.	0.0952
bis(2-Ethylhexyl)phthalate	µg/L	2/21	9.53	2	14	26	17	1.33
Acetone	µg/L	1/10	20	95	95	95	.	9.5
Bromodicholoromethane	µg/L	4/10	5.83	2	2.5	4	1	1
Carbon disulfide	µg/L	1/10	6.67	1	1	1	.	0.1
Chloroform	µg/L	6/10	11.7	15	26.7	43	9.48	16
Methylene chloride	µg/L	5/10	6	2	283	1400	625	141

Results less than detection limit were set to zero to compute grand mean.
Source: EFPC Phase Ia validated data on 25MAR93.

Table 3.47. EFPC Phase Ib results for field blank mean contaminant concentrations

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation > detection limit	Grand mean (< DL = 0)
Lead, total	µg/L	2/4	2.8	2.8	3.5	4.2	0.99	1.75
Zinc, total	µg/L	2/4	3.75	16.1	17.4	18.6	1.77	8.67
Antimony (NAA)	mg/kg	55/257	3.28	0.14	0.297	0.48	0.0852	0.104
Arsenic (NAA)	mg/kg	87/138	2.96	0.98	2.68	12	1.25	1.69
Chromium (NAA)	mg/kg	149/150	44	33	54.2	90	8.27	53.8
Mercury (NAA)	mg/kg	1/164	3.18	21	21	21	.	0.128
Selenium (NAA)	mg/kg	20/163	10.7	5.8	29.7	60	20.8	3.64
U235 (NAA)	mg/kg	161/161	.	0.02	0.0244	0.16	0.0122	0.0244
U238 (NAA)	mg/kg	97/151	3.58	3.1	4.88	7.7	0.911	3.14
Zinc (NAA)	mg/kg	5/164	97.8	22	51.8	89	26.5	1.58
Endosulfan sulfate	µg/L	1/2	0.1	0.021	0.021	0.021	.	0.0105
Di-n-butylphthalate	µg/L	1/6	10	1	1	1	.	0.167

Results less than detection limit were set to zero to compute grand mean.
Source: EFPC Phase Ib validated data on 25MAR93.

Trip blanks were taken to determine if cross-contamination of volatile organics occurred during field handling or shipment to the laboratory or as a result of laboratory handling. With minor exceptions, volatiles were selected for analysis only during Phase Ia. Table 3.48 shows that only acetone and methylene chloride, two common laboratory contaminants, were noted with any frequency or at levels of concern. Early during Phase Ia, an improper laboratory practice resulted in cross-contamination. This condition was noted and corrected.

The third type of field QC sample was equipment rinsates. Rinsate samples were collected after the sampling equipment underwent thorough cleaning and decontamination. Randomly selected pieces of equipment representing each type of utensil employed in the sampling and sample preparation were rinsed with deionized water. The water was collected and submitted for inorganic and organic CLP analysis. Phase Ia results are tabulated in Table 3.49. As with field blanks, only major elements are noted at levels significantly different from the analytical detection limit. Mercury is typical of the potential trace contaminants in that it was detected (by atomic absorption) several times, but the maximum concentration was 0.26 μg/L, compared to a detection limit of 0.20 μg/L. A number of common laboratory contaminants such as acetone, phthalate, and methylene chloride were noted. Phase Ib rinsate results are listed in Table 3.50. The large majority of rinsates from Phase Ib were from sampling the floodplain soils and submittal for NAA. Mercury was selected as the primary contaminant to be screened for cross-contamination. Of 334 analyses, only 13 reported detectable levels of mercury. The maximum concentration was 0.24 μg/L, compared to a mean detection limit of 0.05 μg/L; however, the mean detection limit for mercury by NAA is 3.8 mg/kg (equivalent to 3800 μg/L).

With one exception (mercury field blank), no cross-contamination was evident from field, trip, or equipment rinsate blanks.

3.3.4.3 Completeness summary

Table 3.51 is a summary of the main sampling events undertaken during the EFPC RI. For each sampling event, a breakdown is provided for the number of field samples and the number and type of QC samples obtained. Total numbers of samples taken to characterize each of the primary media within the EFPC OU were as follows:

Table 3.48. EFPC Phase Ia results for trip blank mean contaminant concentrations

Parameter	Measurement units	Proportion of results >detection limit	Mean detection limit	Minimum result >detection limit	Mean result >detection limit	Maximum result >detection limit	Standard deviation >detection limit	Grand mean (<DL = 0)
1,1,1-Trichloroethane	µg/L	1/71	7.79	1	1	1	.	0.0141
2-Butanone	µg/L	1/71	11.3	17	17	17	.	0.239
4-Methyl-2-pentanone	µg/L	1/71	11.3	3	3	3	.	0.0423
Acetone	µg/L	16/70	13.5	2	56.8	290	75.4	13
Carbon disulfide	µg/L	1/71	7.79	1	1	1	.	0.0141
Chloroform	µg/L	2/71	7.75	1	1	1	0	0.0282
Ethylbenzene	µg/L	1/71	7.79	1	1	1	.	0.0141
Methylene chloride	µg/L	37/70	9.03	1	274	3100	627	145
Styrene	µg/L	1/71	7.79	3	3	3	.	0.0423

Results less than detection limit were set to zero to compute grand mean.
Source: EFPC Phase Ia validated data on 25MAR93.

Table 3.49. EFPC Phase Ia results for rinsate mean contaminant concentrations

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation > detection limit	Grand mean (< DL = 0)
Calcium, dissolved	µg/L	1/1	.	210	210	210	.	210
Sodium, dissolved	µg/L	1/1	.	810	810	810	.	810
Aluminium, total	µg/L	10/25	108	40.6	86.6	110	21.7	34.7
Arsenic, total	µg/L	1/25	4.33	2.7	3.7	3.7	.	0.148
Barium, total	µg/L	2/25	1.2	1.2	1.3	1.4	0.141	0.104
Calcium, total	µg/L	14/25	121	61.4	198	620	157	111
Chromium, total	µg/L	1/25	4.83	22.2	22.2	22.2	.	0.888
Copper, total	µg/L	2/25	3.83	4.5	5.45	6.4	1.34	0.436
Iron, total	µg/L	11/25	40.1	18.4	44.9	130	33.5	19.8
Lead, Total	µg/L	1/25	2.83	7.8	7.8	7.8	.	0.312
Magnesium, total	µg/L	1/25	37.1	37.7	37.7	37.7	.	1.51
Manganese, total	µg/L	5/25	1.71	1	1.8	2.6	0.596	0.36
Mercury, total	µg/L	5/32	0.2	0.2	0.222	0.26	0.0303	0.0347
Selenium, total	µg/L	1/25	6.18	7.8	7.8	7.8	.	0.312
Sodium, total	µg/L	10/25	624	407	592	914	172	237
Zinc, total	µg/L	12/25	6.75	3.9	11	31.4	8.04	5.3
Heptachlor	µg/L	1/24	0.0504	0.051	0.051	0.051	.	0.00212
Di-n-butylphthalate	µg/L	1/20	10	4	4	4	.	0.2
bis(2-Ethylhexyl)phthalate	µg/L	2/20	9.72	1	2	2	0.707	0.15
Acetone	µg/L	2/9	15.6	8	65	65	40.3	8.11
Bromodichloromethane	µg/L	4/9	4.4	2	2	2	0	0.889
Chloroform	µg/L	7/9	16	13	22.7	40	10.6	17.7
Methylene chloride	µg/L	3/9	4.83	1	2	3	1	0.667

Results less than detection limit were set to zero to compute grand mean.
Source: EFPC Phase Ia validated data on 25MAR93.

Table 3.50. EFPC Phase Ib results for rinsate mean contaminant concentrations

Parameter	Measurement units	Proportion of results > detection limit	Mean detection limit	Minimum result > detection limit	Mean result > detection limit	Maximum result > detection limit	Standard deviation > detection limit	Grand Mean (< DL = 0)
Mercury, total	µg/L	13/334	0.05	0.05	0.114	0.24	0.066	0.00443
Lead, total	µg/L	2/4	7.1	2.3	3.35	4.4	1.48	1.68
Zinc, total	µg/L	2/4	15.8	16	22.6	29.2	9.33	11.3
Endosulfan sulfate	µg/L	1/2	0.1	0.007	0.007	0.007	.	0.0035
gamma-Chlordane	µg/L	1/2	0.05	0.0029	0.0029	0.0029	.	0.00145
Di-n-butylphthalate	µg/L	1/6	10	3	3	3	.	0.5
Diethylphthalate	µg/L	2/6	10	1	1.5	2	0.707	0.5

Results less than detection limit were set to zero to compute grand mean.
Source: EFPC Phase Ib validated data on 25MAR93.

Table 3.51. Summary of main sampling events during the EFPC RI

	Field Sample	Field Blank	Field Duplicate	Equipment Rinsate	Trip and Blank	Total
Phase Ia						
Creek/trib. sediment	20	2	-	2	-	24
Surface water	44	1	2	-	20	67
Soil transects	124	9	8	9	-	150
Spatial variability	17	1	119	1	-	138
GW borings-soil	37	3	9	4	-	53
Groundwater	85	8	8	4	54	159
Geotechnical creek sediments	51	2	4	2	-	59
Geotechnical soil	134	4	8	4	-	150
Montessori School	10	7	1	1	-	19
Girls Club	40	2	2	2	1	47
Occurrence	2	-	-	-	-	2
Pore water	5	-	-	-	-	5
Subtotal	569	39	161	29	75	873
Phase Ib						
Soil transects-NAA	2680	158	46	159	-	3043
Sewerline Beltway-NAA	448	9	-	9	-	466
Soil-CLP	56	2	2	2	-	62
Creek sediment-CLP	104	3	2	3	-	112
Surface water-CLP	4	-	-	-	1	5
Disturbed water-CLP	5	-	-	-	-	5
Vertical integration-NAA	95	-	-	-	-	95
Mercury Form Analysis	20	-	-	-	-	20
Methylmercury	3	-	1	-	-	4
Church of God	30	4	2	2	-	38
Subtotal	3445	176	53	175	1	3850
TOTAL	4014	215	214	204	76	4723

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Media	Number of samples
groundwater	159.0
surface water	77.0
floodplain soils	4181.0
creek sediments	195.0
miscellaneous	111.0
TOTAL	4723.0

Table 3.52 shows, for Phases Ia and Ib, the number of samples planned and collected for each major sampling event, the number of samples submitted and analyzed for each analytical category, the number of analyses accepted/rejected from the analyses in each major category, and the reason for rejection. The completeness DQO was more than met for the majority of the data needs.

3.3.5 Assessment Summary

The EFPC RI has been a project that spanned more than two years and collected nearly 5000 samples, resulting in an analytical data base of over 100,000 individual analytes. With such a large effort and so many data needs, failures do occur. The primary failures are as follows:

The EFPC storm sampling was originally planned for three separate events. After the second event, it became apparent that it would be random luck to sample a major storm event significantly larger than the previous two events. The third storm event was canceled.

A number of attempts were made with ceramic cup vacuum lysimeters to obtain soilbound pore water for the ecological assessment and site characterization. The lysimeter sampling was unsuccessful in obtaining adequate volumes for analysis. This sampling was replaced with bulk soil sampling for total methylmercury analysis.

Of the positive aspects, the EFPC RI field efforts provided larger percentages of the planned samples than originally anticipated and more than an adequate number to complete the assessment. From the analytical laboratories, the mass of results from CLP analysis and NAA were usable and fulfilled the needs of the EFPC RI. Only the radiological analyses for certain isotopes (thorium, in particular) were less than planned. NAA proved to be a suitable alternative that provided a large number of analyses at a reduced cost. The significant efforts that went into the data review and validation process resulted in superior data quality for use in the human health and ecological risk assessments as well as the site characterization study.

Table 3.52. Completeness Summary Report
East Fork Poplar Creek

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
Creek Sediments		20/20	HERBS	3/3	3/9	
			INOAS	20/20	5/20	
			INOHG	20/20	0/20	
			INOICP	20/20	0/366	
			INOPB	14/14	0/14	
			INOSE	20/20	1/20	
			INOTL	20/20	0/20	
			ORPPB	20/20	0/540	
			ORSVO	20/20	0/1300	
			PETHY	3/3	0/3	
			RGAMM	20/20	0/80	
			RISOU	20/20	0/60	
Geotech Creek		51/51	GEOCM	7/7	0/77	
Sediments			GEOTC	9/9	0/198	
			INOAS	9/9	0/9	
			INOHG	30/30	0/30	
			INOICP	9/9	3/163	
			INOPB	8/8	0/8	
			INOSE	9/9	2/9	
			INOTL	9/9	0/9	
			ORPB	18/21	0/146	A:2, I:1
			ORPPB	8/9	0/216	A:1
			ORSVO	8/9	0/520	A:1
			RGAMM	9/9	0/36	
			RISOU	9/9	0/27	
			RTOTU	17/21	0/17	A:2, I:2
			TCLPIN	5/5	0/40	
			TCLPPP	5/5	0/35	
			TCLPSV	5/5	40/85	
			TCLPVO	5/5	0/50	
Geotech Soil		134/190	GEOCM	6/6	0/308	
			GEOTC	29/29	0/4339	
			INOAS	19/19	0/19	
			INOHG	90/99	0/90	?:9

Table 3.52 (continued)

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			INOICP	19/19	0/342	
			INOPB	19/19	0/19	
			INOSE	19/19	0/19	
			INOTL	19/19	0/19	
			RISOU	1/1	0/1	
			RTOTU	89/98	24/89	?:9
Girl's Club		40/43	INOAS	24/25	1/24	A:1
			INOCYA	5/5	0/5	
			INOHG	40/40	0/40	
			INOICP	24/25	2/437	A:1
			INOPB	19/20	2/19	A:1
			INOSE	24/25	0/24	A:1
			INOTL	24/25	0/24	A:1
			ORPB	16/16	0/105	
			ORPPB	6/7	0/162	A:1
			ORSVO	6/7	0/130	A:1
			ORVOA	1/1	0/34	
			RGAMM	40/40	3/160	
			RISOU	40/40	3/120	
GW Wells		85/93	ANICL	73/84	0/73	A:10, I:1
			ANIFL	73/84	0/73	A:10, I:1
			ANISO4	73/84	0/73	A:10, I:1
			ANSULF	72/84	20/72	A:12
			INDAS	80/81	0/80	A:1
			INDCYA	1/1	0/1	
			INDHG	83/84	25/83	A:1
			INDICP	83/84	0/1497	A:1
			INDPB	83/84	0/83	A:1
			INDSE	83/84	0/83	A:1
			INDTL	83/84	0/83	A:1
			INOAS	83/84	4/83	A:1
			INOCYA	80/84	0/80	A:3, P:1
			INOHG	83/84	0/83	A:1

Table 3.52 (continued)

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			INOICP	83/84	0/1496	A:1
			INOPB	81/82	2/81	A:1
			INOSE	83/84	12/83	A:1
			INOTL	83/84	0/83	A:1
			NAMMON	72/84	1/72	A:11, I:1
			NRA_IT	74/84	1/74	A:10
			ORPPB	81/84	0/2201	A:1, I:2
			ORSVO	82/84	121/4964	A:1, I:1
			ORVOA	85/85	1/2679	
			RADUM	82/85	4/82	A:3
			RGAMM	83/85	6/332	A:2
			RISOU	77/85	51/231	A:7, I:1
			RT_SR	83/85	30/166	A:2
GW Wells - Soils		37/85	GEOTC	0/1	0/0	?:1
			INOAS	37/37	9/37	
			INOCYA	37/37	0/37	
			INOHG	37/37	0/37	
			INOICP	37/37	8/676	
			INOPB	27/27	1/27	
			INOSE	37/37	7/37	
			INOTL	37/37	14/37	
			ORPPB	12/12	0/323	
			ORSVO	12/12	0/780	
			ORVOA	14/14	0/476	
			RGAMM	37/37	23/106	
			RISOU	37/37	48/111	
Montessori		10/10	INOAS	5/5	0/5	
			INOCYA	1/1	0/1	
			INOHG	10/10	0/10	
			INOICP	5/5	0/90	
			INOPB	5/5	0/5	
			INOSE	5/5	0/5	
			INOTL	5/5	0/5	

Table 3.52 (continued)

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			ORPB	5/5	0/35	
			ORPPB	1/1	0/27	
			ORSVO	1/1	0/65	
			RGAMM	10/10	8/40	
			RISOU	10/10	3/30	
Occurrence		2/2	ANICL	1/1	0/1	
Sampling			ANIFL	1/1	0/1	
			ANISO4	1/1	0/1	
			ANSULF	1/1	0/1	
			HERBS	1/1	0/3	
			INDAS	1/1	0/1	
			INDHG	1/1	0/1	
			INDICP	1/1	0/18	
			INDPB	1/1	0/1	
			INDSE	1/1	0/1	
			INDTL	1/1	0/1	
			INOAS	2/2	0/2	
			INOHG	2/2	0/2	
			INOICP	2/2	2/36	
			INOPB	2/2	0/2	
			INOSE	2/2	0/2	
			INOTL	2/2	0/2	
			ORPPB	2/2	0/56	
			ORSVO	2/2	6/129	
			ORVOA	2/2	0/66	
			PETHY	2/2	0/2	
			RADUM	1/1	0/1	
			RGAMM	1/1	2/4	
			RISOU	1/1	0/3	
			RT_SR	1/1	0/2	
			TCLPHB	1/1	0/2	
			TCLPIN	1/1	0/8	
			TCLPPP	1/1	7/14	

Table 3.52 (continued)

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			TCLPSV	1/1	0/7	
			TCLPVO	0/1	0/0	?:1
Pore Waters		5/7	INOHG	2/5	0/2	?:3
Soil Transects		124/150	INOAS	124/124	1/124	
			INOCYA	41/43	0/41	I:1, L:1
			INOHG	124/124	0/124	
			INOICP	124/124	31/2265	
			INOPB	91/91	0/91	
			INOSE	124/124	19/124	
			INOTL	124/124	0/124	
			ORPPB	29/33	0/783	A:3, I:1
			ORSVO	29/33	0/1885	A:3, I:1
			RGAMM	123/124	6/492	I:1
			RISOU	123/124	144/369	I:1
Spatial Variability		17/17	INOHG	17/17	1/17	
Surface Water		44/59	ANICL	33/33	15/33	
			ANIFL	33/33	0/33	
			ANISO4	33/33	15/33	
			ANSULF	30/33	12/30	A:3
			HERBS	6/6	0/18	
			INDAS	33/33	0/33	
			INDHG	33/33	1/33	
			INDICP	33/33	0/594	
			INDPB	33/33	0/33	
			INDSE	33/33	0/33	
			INDTL	33/33	0/33	
			INOAS	43/44	13/43	I:1
			INOHG	43/44	0/43	I:1
			INOICP	43/44	0/775	I:1
			INOPB	42/43	2/42	I:1
			INOSE	43/44	0/43	I:1
			INOTL	43/44	0/43	I:1
			ORPPB	43/44	0/1081	A:1

Table 3.52 (continued)

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			ORSVO	43/44	0/2794	A:1
			ORVOA	43/44	1/1461	A:1
			PETHY	6/6	0/6	
			RADUM	33/33	3/33	
			RGAMM	44/44	1/176	
			RISOU	44/44	43/132	
			RT_SR	33/33	0/66	
Creek Sediments	FB	2/2	INOAS	2/2	0/2	
			INOHG	2/2	0/2	
			INOICP	2/2	0/36	
			INOPB	2/2	0/2	
			INOSE	2/2	0/2	
			INOTL	2/2	0/2	
			ORPPB	2/2	0/54	
			ORSVO	2/2	0/130	
			RGAMM	2/2	0/8	
			RISOU	2/2	6/6	
Geotech Creek	FB	2/2	INOAS	1/1	0/1	
Sediments			INOHG	2/2	0/2	
			INOICP	1/1	0/18	
			INOPB	1/1	0/1	
			INOSE	1/1	0/1	
			INOTL	1/1	0/1	
			ORPB	1/1	0/7	
			ORPPB	1/1	0/27	
			ORSVO	1/1	0/65	
			RGAMM	1/1	0/4	
			RISOU	1/1	0/3	
			RTOTU	1/1	1/1	
Geotech Soil	FB	4/7	INOHG	4/4	0/4	
			RISOU	2/2	0/6	
			RTOTU	2/2	0/2	
Girl's Club	FB	2/2	INOAS	2/2	0/2	

Table 3.52 (continued)

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			INOCYA	2/2	0/2	
			INOHG	2/2	0/2	
			INOICP	2/2	0/36	
			INOPB	2/2	2/2	
			INOSE	2/2	0/2	
			INOTL	2/2	0/2	
			ORPPB	2/2	0/54	
			ORSVO	2/2	0/130	
			RGAMM	2/2	0/8	
			RISOU	2/2	3/6	
GW Wells	FB	8/8	ANICL	7/8	0/7	A:1
			ANIFL	7/8	0/7	A:1
			ANISO4	7/8	0/7	A:1
			ANSULF	7/8	2/7	A:1
			INOAS	8/8	0/8	
			INOCYA	8/8	0/8	
			INOHG	8/8	0/8	
			INOICP	8/8	0/144	
			INOPB	8/8	0/8	
			INOSE	8/8	0/8	
			INOTL	8/8	0/8	
			NAMMON	7/8	0/7	A:1
			NRA_IT	7/8	0/7	A:1
			ORPPB	8/8	0/220	
			ORSVO	8/8	0/516	
			ORVOA	8/8	0/268	
			RADUM	8/8	0/8	
			RGAMM	8/8	0/32	
			RISOU	8/8	7/24	
			RT_SR	8/8	2/16	
GW Wells - Soils	FB	3/7	INOAS	3/3	0/3	
			INOCYA	3/3	0/3	
			INOHG	3/3	0/3	

Table 3.52 (continued)

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			INOICP	3/3	0/54	
			INOPB	3/3	0/3	
			INOSE	3/3	0/3	
			INOTL	3/3	0/3	
			ORPPB	3/3	0/54	
			ORSVO	3/3	0/65	
			ORVOA	3/3	1/34	
			RGAMM	3/3	0/10	
			RISOU	3/3	0/9	
Montessori	FB	1/1	INOAS	1/1	0/1	
			INOCYA	1/1	0/1	
			INOHG	1/1	0/1	
			INOICP	1/1	0/18	
			INOPB	1/1	1/1	
			INOSE	1/1	0/1	
			INOTL	1/1	0/1	
			ORPPB	1/1	0/27	
			ORSVO	1/1	0/65	
			RGAMM	1/1	0/4	
			RISOU	1/1	0/3	
Soil Transects	FB	9/9	INOAS	7/8	0/7	A:1
			INOCYA	6/8	0/6	A:2
			INOHG	8/9	0/8	A:1
			INOICP	7/8	0/126	A:1
			INOPB	7/8	0/7	A:1
			INOSE	7/8	0/7	A:1
			INOTL	7/8	0/7	A:1
			ORPPB	8/8	0/189	
			ORSVO	8/8	0/325	
			RGAMM	8/8	0/32	
			RISOU	8/8	18/24	
			RTOTU	1/1	0/1	
Spatial Variability	FB	1/1	INOHG	1/1	0/1	

Table 3.52 (continued)

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing; no. affected[c]
Surface Water	FB	1/3	ANICL	1/1	1/1	
			ANIFL	1/1	0/1	
			ANISO4	1/1	1/1	
			ANSULF	1/1	1/1	
			INOAS	1/1	1/1	
			INOHG	1/1	0/1	
			INOICP	1/1	0/18	
			INOPB	1/1	0/1	
			INOSE	1/1	0/1	
			INOTL	1/1	0/1	
			ORPPB	1/1	0/27	
			ORSVO	1/1	0/65	
			ORVOA	1/1	0/34	
			RADUM	1/1	1/1	
			RGAMM	1/1	0/4	
			RISOU	1/1	0/3	
			RT_SR	1/1	0/2	
Geotech Creek	OT	4/4	INOAS	3/4	0/3	A:1
Sediments			INOHG	3/4	0/3	A:1
			INOICP	3/4	2/54	A:1
			INOPB	3/4	1/3	A:1
			INOSE	3/4	1/3	A:1
			INOTL	3/4	0/3	A:1
			ORPPB	3/4	0/81	A:1
			ORSVO	3/4	0/195	A:1
			RGAMM	4/4	0/16	
			RISOU	4/4	0/12	
Girl's Club	OT	2/2	INOAS	1/1	0/1	
			INOCYA	1/1	0/1	
			INOHG	2/2	0/2	
			INOICP	1/1	0/19	
			INOSE	1/1	0/1	
			INOTL	1/1	0/1	

Table 3.52 (continued)

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			ORPB	1/1	0/7	
			ORPPB	1/1	0/27	
			ORSVO	1/1	0/0	
			RGAMM	2/2	0/8	
			RISOU	2/2	0/6	
GW Wells	OT	8/8	ANICL	6/8	0/6	A:2
			ANIFL	6/8	0/6	A:2
			ANISO4	6/8	0/6	A:2
			ANSULF	6/8	1/6	A:2
			INDAS	8/8	0/8	
			INDHG	8/8	3/8	
			INDICP	8/8	0/144	
			INDPB	8/8	0/8	
			INDSE	8/8	0/8	
			INDTL	8/8	0/8	
			INOAS	8/8	0/8	
			INOCYA	8/8	0/8	
			INOHG	8/8	0/8	
			INOICP	8/8	0/144	
			INOPB	8/8	0/8	
			INOSE	8/8	1/8	
			INOTL	8/8	0/8	
			NAMMON	5/8	0/5	A:3
			NRA_IT	6/8	0/6	A:2
			ORPPB	8/8	0/220	
			ORSVO	8/8	0/451	
			ORVOA	8/8	0/234	
			RADUM	8/8	0/8	
			RGAMM	8/8	0/32	
			RISOU	7/8	13/21	A:1
			RT_SR	8/8	2/16	
GW Wells - Soils	OT	9/10	INOAS	9/9	2/9	
			INOCYA	9/9	0/9	

Table 3.52 (continued)

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			INOHG	9/9	0/9	
			INOICP	9/9	3/165	
			INOPB	6/6	0/6	
			INOSE	9/9	2/9	
			INOTL	9/9	4/9	
			RGAMM	9/9	0/30	
			RISOU	9/9	15/27	
Montessori	OT	1/1	INOAS	1/1	0/1	
			INOCYA	1/1	0/1	
			INOHG	1/1	0/1	
			INOICP	1/1	0/19	
			INOSE	1/1	0/1	
			INOTL	1/1	0/1	
			ORPPB	1/1	0/27	
			ORSVO	1/1	0/65	
			RGAMM	1/1	1/4	
			RISOU	1/1	0/3	
Soil Transects	OT	8/8	INOAS	8/8	0/8	
			INOCYA	7/7	0/7	
			INOHG	8/8	0/8	
			INOICP	8/8	2/147	
			INOPB	5/5	0/5	
			INOSE	8/8	1/8	
			INOTL	8/8	0/8	
			ORPPB	7/7	0/189	
			ORSVO	7/7	0/455	
			RGAMM	8/8	1/32	
			RISOU	8/8	3/24	
Spatial Variability	OT	119/119	INOHG	17/119	0/17	?:102
Surface Water	OT	2/2	HERBS	2/2	0/6	
			INOAS	2/2	0/2	
			INOHG	2/2	0/2	
			INOICP	2/2	0/36	

Table 3.52 (continued)

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			INOPB	2/2	0/2	
			INOSE	2/2	0/2	
			INOTL	2/2	0/2	
			ORPPB	2/2	0/54	
			ORSVO	2/2	0/130	
			ORVOA	2/2	0/68	
			PETHY	2/2	0/2	
			RGAMM	2/2	0/8	
			RISOU	2/2	3/6	
Creek Sediments	OT	2/2	INOAS	2/2	0/2	
			INOHG	2/2	0/2	
			INOICP	2/2	0/36	
			INOPB	2/2	0/2	
			INOSE	2/2	0/2	
			INOTL	2/2	0/2	
			ORPPB	2/2	0/54	
			ORSVO	2/2	0/130	
			RGAMM	2/2	0/8	
			RISOU	2/2	0/6	
Geotech Creek	RI	2/2	INOAS	1/1	0/1	
Sediments			INOHG	2/2	0/2	
			INOICP	1/1	0/18	
			INOPB	1/1	0/1	
			INOSE	1/1	0/1	
			INOTL	1/1	0/1	
			ORPB	1/1	0/7	
			ORPPB	1/1	0/27	
			ORSVO	1/1	0/65	
			RGAMM	1/1	0/4	
			RISOU	1/1	0/3	
			RTOTU	1/1	1/1	
Geotech Soil	RI	4/7	INOHG	4/4	0/4	
			RISOU	2/2	0/6	

Table 3.52 (continued)

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			RTOTU	2/2	0/2	
Girl's Club	RI	2/2	INOAS	2/2	0/2	
			INOCYA	2/2	0/2	
			INOHG	2/2	0/2	
			INOICP	2/2	0/36	
			INOPB	2/2	2/2	
			INOSE	2/2	0/2	
			INOTL	2/2	0/2	
			ORPPB	2/2	0/54	
			ORSVO	2/2	0/130	
			RGAMM	2/2	0/8	
			RISOU	2/2	3/6	
GW Wells	RI	8/8	ANICL	7/8	0/7	A:1
			ANIFL	7/8	0/7	A:1
			ANISO4	7/8	0/7	A:1
			ANSULF	7/8	3/7	A:1
			INDAS	1/1	0/1	
			INDHG	1/1	1/1	
			INDICP	1/1	0/18	
			INDPB	1/1	0/1	
			INDSE	1/1	0/1	
			INDTL	1/1	0/1	
			INOAS	8/8	1/8	
			INOCYA	8/8	0/8	
			INOHG	8/8	0/8	
			INOICP	8/8	0/144	
			INOPB	8/8	0/8	
			INOSE	8/8	0/8	
			INOTL	8/8	0/8	
			NAMMON	7/8	1/7	A:1
			NRA_IT	7/8	0/7	A:1
			ORPPB	8/8	0/220	
			ORSVO	8/8	0/451	

Table 3.52 (continued)

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			ORVOA	8/8	0/234	
			RADUM	8/8	1/8	
			RGAMM	8/8	0/32	
			RISOU	8/8	9/24	
			RT_SR	8/8	4/16	
GW Wells - Soils	RI	4/7	INOAS	3/4	0/3	A:1
			INOCYA	3/4	0/3	A:1
			INOHG	3/4	0/3	A:1
			INOICP	3/4	0/54	A:1
			INOPB	3/4	0/3	A:1
			INOSE	3/4	0/3	A:1
			INOTL	3/4	0/3	A:1
			ORPPB	3/4	0/81	A:1
			ORSVO	3/4	0/130	A:1
			ORVOA	4/4	0/102	
			RGAMM	3/4	0/8	A:1
			RISOU	3/4	3/9	A:1
Montessori	RI	1/1	INOAS	1/1	0/1	
			INOCYA	1/1	0/1	
			INOHG	1/1	0/1	
			INOICP	1/1	0/18	
			INOPB	1/1	1/1	
			INOSE	1/1	0/1	
			INOTL	1/1	0/1	
			ORPPB	1/1	0/27	
			ORSVO	1/1	0/65	
			RGAMM	1/1	0/4	
			RISOU	1/1	0/3	
Soil Transects	RI	9/9	INOAS	8/8	0/8	
			INOCYA	8/8	0/8	
			INOHG	9/9	0/9	
			INOICP	8/8	0/144	
			INOPB	8/8	0/8	

Table 3.52 (continued)

PHASE Ia						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			INOSE	8/8	0/8	
			INOTL	8/8	0/8	
			ORPPB	8/8	0/189	
			ORSVO	8/8	0/325	
			RGAMM	8/8	0/32	
			RISOU	8/8	18/24	
			RTOTU	1/1	0/1	
Spatial Variability	RI	1/1	INOHG	1/1	0/1	
Girl's Club	TB	1/1	ORVOA	1/1	2/34	
GW Wells	TB	54/54	ORVOA	52/54	0/1705	?:2
Surface Water	TB	20/20	ORVOA	19/20	0/645	?:1

PHASE Ib						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
CLP Soils		56/56	INOAS	56/56	0/56	
			INOHG	56/56	O/56	
			INOICP	56/56	41/1030	
			INOPB	34/34	0/34	
			INOSE	56/56	0/56	
			INOTL	56/56	0/56	
			ORPPB	56/56	0/1568	
			ORSVO	56/56	19/3584	
			RGAMM	55/55	10/147	
			RISOP	55/55	2/55	
			RISOT	37/37	51/111	
			RISOU	37/37	34/111	
Church of God		30/30	INOHG	30/30	30/30	
			ORPB	21/30	0/147	A:9
			ORSVO	21/30	0/1344	A:9
Creek Sediments		104/104	INOAS	27/27	0/27	

Table 3.52 (continued)

PHASE Ib						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			INOHG	27/27	0/27	
			INOICP	27/27	3/489	
			INOPB	24/24	0/24	
			INOSE	27/27	0/27	
			INOTL	27/27	0/27	
			NOANA	0/77		R:77
			ORPPB	27/27	0/756	
			ORSVO	27/27	12/1728	
			RGAMM	27/27	1/67	
			RISOP	27/27	0/27	
			RISOT	13/13	34/39	
			RISOU	13/13	9/39	
Disturbed Water		5/5	HARDNS	0/5		R:5
Samples			INOAS	5/5	0/5	
			INOHG	5/5	0/5	
			INOICP	5/5	0/90	
			INOPB	5/5	0/5	
			INOSE	5/5	0/5	
			INOTL	5/5	0/5	
			ORPBB	5/5	0/140	
			ORSVO	5/5	0/320	
Mercury Form		20/20	PETROG	0/20		R:20
			SELEMI	0/20		R:20
			UPROBE	0/20		R:20
Methyl Mercury		3/3	T_MHHG	0/3		N:3
Sewer Line		448/457	NAA	188/188	181/1504	
Beltway			NOANA	0/260		R:260
Soil Transects		2680/2744	BLANK	0/1		R:1
(NAA)			NAA	2676/2679	2218/21408	?:2,B:1
Surface Water		4/4	ANICL	4/4	0/4	
			ANISO4	4/4	0/4	
			DORPHO	4/4	0/4	
			INOALK	4/4	0/4	
			INOAS	4/4	0/4	

Table 3.52 (continued)

PHASE Ib						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			INOBOD	4/4	0/4	
			INOHG	4/4	0/4	
			INOICP	4/4	0/72	
			INOPB	4/4	0/4	
			INOSE	4/4	0/4	
			INOTL	4/4	0/4	
			INOTSS	4/4	0/4	
			NRA_IT	4/4	0/4	
			ORDOC	4/4	0/4	
			ORPPB	4/4	0/112	
			ORSVO	4/4	0/256	
			ORTOC	4/4	0/4	
			ORVOA	4/4	0/132	
			RGAMM	4/4	0/16	
			RISOU	4/4	1/12	
Vertical		95/95	BLKVI	0/5		R:5
Integration			NAA	90/90	311/720	
CLP Soils	FB	2/2	INOAS	2/2	0/2	
			INOHG	2/2	0/2	
			INOICP	2/2	0/36	
			INOPB	2/2	0/2	
			INOSE	2/2	0/2	
			INOTL	2/2	0/2	
			ORPPB	2/2	1/56	
			ORSVO	2/2	1/128	
			RGAMM	2/2	0/4	
			RISOP	2/2	0/2	
Church of God	FB	4/4	INOHG	2/2	2/2	
			ORPB	2/2	0/14	
			ORSVO	2/2	0/128	
Creek Sediments	FB	3/3	INOAS	2/3	0/2	K:1
			INOHG	2/3	0/2	K:1
			INOICP	2/3	0/36	K:1
			INOPB	2/3	0/2	K:1

Table 3.52 (continued)

PHASE Ib						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			INOSE	2/3	0/2	K:1
			INOTL	2/3	0/2	K:1
			ORPB	2/2	0/14	
			ORPPB	0/1		K:1
			ORSVO	2/3	1/128	K:1
			RGAMM	2/2	0/4	
			RISOP	2/2	1/2	
Sewer Line	FB	9/9	NAA	8/9	9/64	?:1
Beltway						
Soil Transects	FB	158/162	BLANK	0/1		R:1
(NAA)			NAA	157/157	130/1256	
CLP Soils	OT	2/2	INOAS	2/2	0/2	
			INOHG	2/2	0/2	
			INOICP	2/2	2/36	
			INOPB	2/2	0/2	
			INOSE	2/2	0/2	
			INOTL	2/2	0/2	
			ORPPB	2/2	0/56	
			ORSVO	2/2	1/128	
			RGAMM	2/2	0/4	
			RISOP	2/2	0/2	
Church of God	OT	2/2	INOHG	2/2	2/2	
			ORPB	2/2	0/14	
			ORSVO	2/2	0/128	
Creek Sediments	OT	2/2	INOAS	2/2	0/2	
			INOHG	2/2	0/2	
			INOICP	2/2	1/37	
			INOPB	1/1	0/1	
			INOSE	2/2	0/2	
			INOTL	2/2	0/2	
			ORPPB	2/2	0/56	
			ORSVO	2/2	0/128	
			RGAMM	2/2	0/5	
			RISOP	2/2	0/2	

Table 3.52 (continued)

PHASE Ib						
Sampling event	Sample type[a]	Samples collected/ planned	Analysis category[b]	Samples analyzed/ collected	Analytes rejected	Reason missing: no. affected[c]
			RISOT	1/1	1/3	
			RISOU	1/1	0/3	
Methyl Mercury	OT	1/1	T_MHHG	0/1		N:1
Soil Transects	OT	46/46	NAA	46/46	29/368	
CLP Soils	RI	2/2	INOAS	2/2	0/2	
			INOHG	2/2	0/2	
			INOICP	2/2	0/36	
			INOPB	2/2	0/2	
			INOSE	2/2	0/2	
			INOTL	2/2	0/2	
			ORPPB	2/2	0/56	
			ORSVO	2/2	0/128	
			RGAMM	2/2	0/4	
			RISOP	2/2	0/2	
Church of God	RI	2/2	INOHG	2/2	2/2	
			ORPB	2/2	0/14	
			ORSVO	2/2	0/128	
Creek Sediments	RI	3/3	INOAS	2/3	0/2	K:1
			INOHG	2/3	0/2	K:1
			INOICP	2/3	0/36	K:1
			INOPB	2/3	0/2	K:1
			INOSE	2/3	0/2	K:1
			INOTL	2/3	0/2	K:1
			ORPB	2/2	0/14	
			ORPPB	0/1		K:1
			ORSVO	2/3	1/128	K:1
			RGAMM	2/2	1/5	
			RISOP	2/2	0/2	
			RISOT	1/1	3/3	
			RISOU	1/1	0/3	
Sewer Line	RI	9/9	INOHG	9/9	0/9	
Beltway						
Soil Transects	RI	159/161	INOHG	156/159	0/156	?:1
(NAA)						
Surface Water	TB	1/1	ORVOA	1/1	0/33	

Table 3.52 (continued)

[a]QC Sample Type:

FB - Field Blank
RI - Equipment Rinsate
TB - Trip Blank
OT - Field Duplicate

[b]Analysis Definitions:

ANICL - Anions - Chloride
ANIFL - Anions - Fluoride
ANISO4 - Anions - Sulfate
ANSULF - Anions - Sulfide
GEOCM - Geochemical Analysis
GEOTC - Geotechnical Analysis
HERBS - Herbicides
INDAS - Dissolved Arsenic
INDCYA - Dissolved Cyanide
INDHG - Dissolved Mercury
INDICP - Dissolved Metals by ICP
INDPB - Dissolved Lead
INDSE - Dissolved Selenium
INDTL - Dissolved Thallium
INOAS - Arsenic
INOCYA - Cyanide
INOHG - Mercury
INOICP - Metals by ICP
INOPB - Lead
INOSE - Selenium
INOTL - Thallium
NAMMON - Ammonia
NRA_IT - Nitrate/Nitrite
ORPB - PCBs
ORPPB - Pesticides and PCBs
ORSVO - Semivolatile Organics
ORVOA - Volatile Organics
PETHY - Total Petroleum Hydrocarbons
RADUM - Radium
RGAMM - Gamma Scan
RISOU - Isotopic Uranium
RTOTU - Total Uranium
RT_SR - Total Strontium
TCLPIN - TCLP, Inorganics
TCLPPP - TCLP, Pesticides/PCBs
TCLPSV - TCLP, Semivolatiles
TCLPVO - TCLP, Volatiles

Table 3.52 (continued)

[a]Missing Analysis Codes:

- ? - Unknown
- A - Analyses Not Requested on COC
- B - Sample Not Sent to Lab
- I - Insufficient Sample/Analysis Not Requested
- K - Analysis Cancelled, Different Sample Substituted
- L - Requested, but Lab Did Not Analyze
- N - Data Packages Not Yet Received
- P - No Preservative
- R - No Analytic Results for This Analysis

4. ARARs

CERCLA of 1980 was passed by Congress and signed into law on December 11, 1980 (Public Law 96-510). This act was intended to provide for "liability, compensation, cleanup, and emergency response for hazardous substances released into the environment and the cleanup of inactive waste disposal sites." SARA, adopted on October 17, 1986 (Public Law 99-499), did not substantially alter the original structure of CERCLA but provided extensive amendments to it.

In particular, Sect.121 of CERCLA specifies that remedial actions for cleanup of hazardous substances must comply with requirements or standards under federal or more stringent state environmental laws that are ARARs to the hazardous substances or particular circumstances at a site.. Inherent in the interpretation of ARARs is the assumption that protection of human health and the environment is ensured.

Applicable requirements are "those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site" (40 *CFR* 300.5).

Relevant and appropriate requirements are "those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental and state environmental or facility siting law that, while not applicable to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site" (40 *CFR* 300.5).

Requirements under federal or state law may be *either* applicable *or* relevant and appropriate to CERCLA cleanup actions, but not both. However, requirements must be *both* relevant *and* appropriate for compliance to be necessary. In the case where a federal and a state ARAR are available, or where there are two potential ARARs addressing the same issue, the more stringent regulation must be selected. However, CERCLA § 121(d)(4) provides several ARAR waiver options that may be invoked, providing that the basic premise of protection of human health and the environment is not ignored. A waiver is available for state standards that have not be applied uniformly in similar circumstances across the state. In addition, CERCLA

§121(d)(2)(C) forbids state standards that effectively prohibit land disposal of hazardous substances.

CERCLA on-site remedial response actions must only comply with the substantive requirements of a regulation and not the administrative requirements to obtain federal, state, or local permits [CERCLA §121(e) and FFA §XXII]. In order to ensure that CERCLA response actions proceed as rapidly as possible, EPA has reaffirmed this position in the final NCP (55 *FR* 8756). **Substantive requirements** pertain directly to the actions or conditions at a site, while **administrative requirements** facilitate their implementation. EPA recognizes that certain of the administrative requirements, such as consultation with state agencies, reporting, etc., are accomplished through the state involvement and public participation requirements of the NCP. These administrative requirements should be observed if they are useful in determining cleanup standards at the site (55 *FR* 8757).

In the absence of federal- or state-promulgated regulations, there are many criteria, advisories, guidance values, and proposed standards that are not legally binding but may serve as useful guidance for setting protective cleanup levels. These are not potential ARARs but are **"to-be-considered" (TBC)** guidance.

The purpose of this report is to supply a preliminary list of available federal and state chemical- and location-specific ARARs that might be considered for EFPC. Remediation alternatives have not been selected yet for the EFPC system; however, given that dredge and fill of certain areas may be considered as a potential source removal option, the COE regulations governing dredging activities are summarized here. This list will be revised as contamination of environmental media at EFPC is more accurately characterized. Action-specific ARARs will be developed when a preliminary selection of remedial alternatives has been made; however, ARARs for certain general construction activities are discussed here.

It is understood that DOE will comply with the requirements of NEPA as specified in DOE Order 5440.1E (*National Environmental Policy Act Compliance Program*). Further, DOE Order 5400.4 (*Comprehensive Environmental Response, Compensation, and Liability Act Requirements*) calls for integration of NEPA and CERCLA requirements for DOE remedial actions at CERCLA sites. This issue has been reaffirmed in the FFA Sect.I(A)(3) and Sect.III(A)(2) and Secretary of Energy Notice (SEN) of February 5, 1990 (SEN-15-90), which was issued to ensure that DOE's NEPA activities are carried out in a centralized and uniform manner. Therefore, the regulations found in NEPA will not be addressed in this report as ARARs.

Similarly, DOE addresses occupational safety in DOE Orders 5480.11 (*Radiation Protection for Occupational Workers*), 5480.4 (*Environmental Protection, Safety, and Health Protection Standards*), 5483.1A (*Occupational Safety and Health Program for Contractors at GOCO Facilities*), 5480.9 (*Construction Safety and Health Program*), and 5480.10 (*Contractor Industrial Hygiene Program*). However, ARARs apply to those federal and state regulations that are designed to protect the environment, and do not generally apply to occupational safety regulations. These requirements are addressed in the Health and Safety Plan for this site.

CERCLA on-site remedial response actions must only comply with the substantive requirements of a regulation and not the administrative requirements to obtain federal, state, or local permits [CERCLA Sect.121(e) and FFA Sect.XXII]. To ensure that CERCLA response actions proceed as rapidly as possible, EPA has reaffirmed this position in the final NCP (55 *FR* 8756, March 8, 1990). **Substantive requirements** pertain directly to the actions or conditions at a site, while **administrative requirements** facilitate their implementation. EPA recognizes that certain of the administrative requirements such as consultation with state agencies, reporting, etc., are accomplished through the state involvement and public participation requirements of the NCP. These administrative requirements should be observed if they are useful in determining cleanup standards at the site (55 *FR* 8757).

Over the years, various amounts of both treated and untreated wastewater from the Y-12 Plant have been discharged to EFPC, which originates as a surface water drainage ditch on the Y-12 site. These wastewaters resulted from normal operations at the facility and were radioactive and/or chemically hazardous in nature. However, it is impossible to determine the actual source of the wastes present in EFPC, and therefore, pursuant to the NCP (55 *FR* 8758), it may be assumed that the waste is not a RCRA-listed waste. In addition, none of the wastes are RCRA-characteristic wastes. Therefore, none of the RCRA regulations is assumed to be applicable to remedial action at EFPC.

4.1 CHEMICAL-SPECIFIC ARARs

"Chemical-specific requirements set health or risk-based concentration limits or discharge limitations in various environmental media for specific hazardous substances, pollutants, or contaminants" (52 *FR* 32496). These requirements generally set protective cleanup levels for the chemicals of concern in the designated media or else indicate a safe level of discharge that may be incorporated when considering a specific remedial activity. COCs identified for EFPC include metals, organic compounds including PAHs and PCBs, and radionuclides.

4.1.1 Groundwater and Surface Water

TDEC has issued a proposed guidance, currently in review, on state groundwater classification. The draft guidance classifies groundwater protected as a current or future source of drinking water as Class A. Groundwater in the EFPC watershed has not been given a use classification as yet; in the event groundwater in the EFPC watershed is Class A under the state of Tennessee guidelines as a current or potential source of drinking water, ARARs for the cleanup of that groundwater would be federal SDWA MCLs and action levels [TDEC 1200-1-13-.08(4)(a) - proposed rule]. Until that time, federal SDWA MCLs and nonzero MCLGs, although not legally applicable to groundwater cleanup, are relevant and appropriate for cleanup of groundwater that may be used as a drinking water source. Final determination of ARARs for site-specific cleanup of groundwater at EFPC will depend on the chosen groundwater classification.

EPA has revised its drinking water standards for lead and copper, eliminating the MCL and replacing it with a treatment technique requirement (56 *FR* 26460, June 7, 1991). If an "action level" of 15 or 1300 μg/L, for lead or copper, respectively, is exceeded at the tap, a state is required to analyze source water samples and to decide what treatment levels are necessary to minimize lead or copper levels delivered to users from the affected distribution system. In the instance of contaminated groundwater at EFPC, the treatment technique for lead or copper is neither legally applicable nor relevant and appropriate; the MCLG of 1300 μg/L for copper is relevant and appropriate. The EPA Office of Solid Waste and Emergency Response (OSWER) has recommended that a final cleanup level of 15 μg/L for lead in groundwater usable for drinking water (footnoted in Table 4.1) is protective of sensitive populations (OSWER memorandum dated June 21, 1990). This might be considered TBC guidance for remediation of lead-contaminated groundwater, and will serve as TBC to ensure the precision of analytical detection limits. TDEC has proposed a cleanup criterion of 15 μg/L for lead in groundwater (TDEC Rule 1200-1-13-.08). When promulgated this criterion will be applicable to cleanup of groundwater at EFPC.

National Secondary Drinking Water Standards (NSDWS) regulate contaminants that affect the aesthetic qualities related to public acceptance of drinking water and are implemented in 40 *CFR* 143.3 as secondary maximum contaminant levels (SMCLs). Tennessee has promulgated an SMCL for zinc and manganese in Chap. 1200-5-1.12 of the Rules of the TDEC (see Table 4.1). These regulations are designed to provide water to the consumer which is aesthetically pleasing, and they apply to all community water systems and to those noncommunity

Table 4.1. Maximum contaminant levels and water quality criteria for designated water uses (μg/L)

Chemical	SDWA MCLs/MCLGs[a]	Recreation[b]	Fish and aquatic life[b]	
			CMC[c]	CCC[d]
Arsenic (total)	50	NA	360[e]	190[e]
Barium	2000/2000	NA	NA	NA
Beryllium	4[f]/4	1.3	NA	NA
Cadmium	5/5	NA	4[g]	1[g]
Chromium (total)	100/100	670,000[h]	NA	100
Chromium (hexavalent)	NA	NA	16	11
Copper	TT[i]/1300	NA	18[g]	12[g]
Lead	TT[i]/0	NA	82[g]	3[g]
Manganese	50[j]	NA	NA	NA
Mercury	2/2	0.15	2.4	0.012
Nickel	100[j]/100	4600	1400	160
PAHs				
Benzo(a)anthracene	NA	0.3	NA	NA
Benzo(a)pyrene	0.2[f]/0	0.3	NA	NA
Benzo(b)fluoranthene	NA	NA	NA	NA
Benzo(g,h,i)perylene	NA	NA	NA	NA
Benzo(k)fluoranthene	NA	0.3	NA	NA
Chrysene	NA	0.03	NA	NA
Dibenzo(a,h)anthracene	NA	NA	NA	NA
Indeno(1,2,3-cd)pyrene	NA	NA	NA	NA
Pyrene	NA	0.03	NA	NA
PCBs	0.5/0	0.001	NA	0.001
Silver	50[k]	NA	4[g]	NA
Vanadium	NA	NA	NA	NA
Zinc	5000[j]	NA	117[g]	106[g]

[a]SDWA MCL = federal Safe Drinking Water Act maximum contaminant level; MCLG= maximum contaminant level goal.
[b]Rules of the TDEC, Chapter 1200-4-3. Recreational values based on a 10^{-5} risk level for carcinogens.
[c]CMC = criterion maximum concentration.
[d]CCC = criterion continuous concentration.
[e]Arsenic III.
[f]Final federal MCL (57 *FR* 31776, July 17, 1992). Effective January 17, 1994.
[g]Calculated for a water hardness of 100 mg/L, the approximate average hardness of the Clinch River.
[h]Chromium III.
[i]TT = treatment technology; 56 *FR* 26460 (June 7, 1991). When the "action level" of 1300 μg/L or 15 μg/L for copper or lead, respectively, measured in the 90th percentile at the consumer's tap, is exceeded, corrosion control studies and treatment requirements are triggered. However, an OSWER memorandum (dated June 21, 1990) recommends that a final cleanup level of 15 μg/L for lead in groundwater usable for drinking water is protective of sensitive subpopulations; this is TBC, not an ARAR.
[j]Secondary MCL; Rules of the TDEC, Chapter 1200-5-1.12.
[k]Federal SDWA secondary MCL; federal primary MCL was revoked for this chemical (56 *FR* 3526, January 30, 1991).
NA = Not available

water systems "as may be deemed necessary" by TDEC. In that context, they would not be legally applicable to cleanup of groundwater or surface water, but may be considered as relevant and appropriate in the absence of an MCL.

Under the Tennessee Water Quality Control Act, the Tennessee Water Quality Control Board has classified EFPC from creek mile 0.0 to Lake Reality, for protection of uses for fish and aquatic life, recreation, irrigation, and livestock watering and wildlife (TDEC Rules, Chap. 1200-4-4). The TDEC includes water quality criteria (WQC) for protection of recreational uses; these criteria are human health criteria derived to protect the consumer from consumption of contaminated fish; these criteria are the WQC for the protection of human health from consumption of fish alone. For carcinogens, the TDEC WQC are based on a risk of 10^{-5} rather than the 10^{-6} risk on which the federal WQC are based. These criteria, along with the TDEC WQC for the protection of freshwater aquatic life, are also listed in Table 4.1 for COCs at EFPC.

4.1.2 Soil and Sediment

There is no legislation available governing cleanup criteria for contaminated soils or sediments at CERCLA sites. RCRA has addressed land disposal of treated hazardous wastes in its land disposal restrictions (40 *CFR* 268); however, there are no RCRA-listed or RCRA-characteristic wastes present at the site. The TDEC has proposed a new Chapter 1200-1-13 (*Hazardous Substance Site Remedial Action*) to the Rules of the TDEC. In this proposed rule are three approaches for the establishment of cleanup levels: 1) use of listed soil cleanup levels for residential and industrial sites; 2) use of a site-specific human health and environmental risk assessment; and 3) use of background levels [1200-1-13-.08(3)(a)]. In cases where site-specific risk-based cleanup levels are proposed, the TDEC must review and approve those levels [1200-1-13-.08(3)(b)].

Although not an ARAR, EPA has published a TSCA PCB spill cleanup policy (52 *FR* 10688) which recommends cleanup standards for PCBs of 25-50 ppm for sites with restricted access; a 10-ppm cleanup level is recommended for residential and unrestricted access rural areas. In this latter case, a 10-in. cap of clean soil must cover the site. In the EPA guidance report for remedial actions at Superfund sites containing PCBs, preliminary remediation goals are set at 1 ppm for residential land use (a risk of 10^{-5}) and between 10 and 25 ppm for industrial and/or remote areas (a risk of 10^{-4}) (EPA 1990). Alternatives should reduce concentrations to these levels or limit exposures. In this report, EPA also presents an approach to deriving cleanup levels of PCBs in sediments. This approach results in "sediment quality criteria" as a function

of organic carbon concentrations, and is meant to protect wildlife consumers of freshwater benthic species. Values estimated using this approach are "to be considered" (TBC) guidance, not ARARs.

EPA has suggested cleanup values for lead in soils based on studies of blood lead levels in exposed children. The EPA OSWER Directive 9355.4-02 (dated September 7, 1989) recommends a cleanup level for soils of 500 to 1000 ppm lead.

EPA Region IV has made available a summary of chemical-specific concentrations that may be used to flag contaminant levels of concern in sediments. The values which may be applicable for COCs at EFPC are given in Table 4.2. These values have been calculated by NOAA and are **not intended as cleanup standards**. Biological effects-based testing using highly sensitive organisms is recommended for contaminants which have exceeded the NOAA "action levels."

4.2 RADIATION PROTECTION STANDARDS

Very few applicable standards are available for the cleanup of radioactively contaminated CERCLA sites. The Atomic Energy Act (AEA) of 1954 and its amendments delegated authority for control of nuclear energy to DOE, NRC, and EPA.

DOE is authorized to control all types of nuclear materials at sites under its jurisdiction and is exempt from the NRC licensing and regulatory requirements. Although NRC regulations are not considered to be applicable to CERCLA cleanup at DOE facilities, they may be relevant and appropriate for certain circumstances. However, they are not considered to be relevant and appropriate for cleanup of residual radioactive contamination at EFPC. DOE regulations for handling and cleanup of radioactive materials are outlined in a series of internal DOE orders that are contractually binding to DOE contractors but are not considered by EPA to be ARARs. Therefore, for the purposes of development of ARARs, DOE orders will be treated as TBC guidance.

4.2.1 EPA Regulations

EPA has promulgated MCLs for radionuclides in community water systems (see Table 4.3). These MCLs appear in two forms—concentration limits for certain alpha-emitting radionuclides (40 *CFR* 141.15) and an annual dose limit for the ingestion of certain beta- and gamma-emitting radionuclides (40 *CFR* 141.16). MCLs and maximum contaminant level goals (MCLGs) were proposed for radon and uranium, beta emitters, and photon emitters on

Table 4.2. Summary of NOAA[a] action levels for contaminants in sediment (ppb)[b]

Chemical	Low effects range	Median effects range	Overall apparent effects threshold	Degree of confidence
Acetone	NA[c]	NA	NA	
Aldrin	NA	NA	NSD[d]	
Arsenic	33 (ppm)	85 (ppm)	50 (ppm)	Low/moderate
Beryllium	NA	NA	NA	
Cadmium	5 (ppm)	9 (ppm)	5 (ppm)	High/high
Chromium (total)	80 (ppm)	145 (ppm)	None	Moderate/ moderate
Copper	70 (ppm)	390 (ppm)	300 (ppm)	High/high
DDE	2	15	NSD	Low/low
DDT (total)	3	350	No	Moderate/- moderate
Dieldrin	0.02	8	No	Low/low
Heptachlor	NA	NA	NA	
Heptachlor epoxide	NA	NA	NA	
Lead	35 (ppm)	110 (ppm)	300 (ppm)	Moderate/high
Manganese	NA	NA	NA	
Mercury	0.15 (ppm)	1.3(ppm)	1 (ppm)	Moderate/high
Methylene chloride	NA	NA	NA	
Nickel	30 (ppm)	50 (ppm)	NSD	Moderate/- moderate
Polyaromatic hydro-carbons (total)	4000	35,000	22,000	Low/low
Benzo(a)anthracene	230	1600	550	Low/moderate
Benzo(a)pyrene	400	2500	700	Moderate/- moderate
Benzo(b)fluoranthene	NA	NA	NA	
Benzo(g,h,i)perylene	NA	NA	NA	
Benzo(k)fluoranthene	NA	NA	NA	
Chrysene	400	2800	900	Moderate/- moderate
Dibenzo(a,h)anthracene	60	260	100	Moderate/- moderate
Indeno(1,2,3-cd)pyrene	NA	NA	NA	
Pyrene	350	2200	1000	Moderate/- moderate
Silver	1 (ppm)	2.2 (ppm)	1.7 (ppm)	Moderate/- moderate
PCBs (total)	50	400	370	Moderate/ moderate

Table 4.2 (continued)

Chemical	Low effects range	Median effects range	Overall apparent effects threshold	Degree of confidence
PCBs (total)	50	400	370	Moderate/ moderate
Selenium	NA	NA	NA	
Toxaphene	NA	NA	NA	
Vanadium	NA	NA	NA	
Zinc	120 (ppm)	270 (ppm)	200 (ppm)	High/high

[a]NOAA = National Oceanic and Atmospheric Administration
[b]EPA Region IV Memorandum from Catherine Fox, Coastal Programs Unit, dated April 15, 1991, *Suggested Guidance for Evaluating Sediment Concentration Data.*
[c]NA = Not available.
[d]NSD = Not sufficient data.

Table 4.3. Radionuclide-specific ARARs for groundwater and surface water contamination at EFPC

Radionuclide	Current SDWA MCLs[a]	Proposed SDWA MCLs[b]
Radium[c]	5 pCi/L	20 pCi/L
Gross alpha[d]	15 pCi/L	15 pCi/L
Gross beta	4 mrem/year	4 mrem/year
Natural uranium		20 μg/L[e]
^{222}Rn		300 pCi/L
^{90}Sr	8 pCi/L	8 pCi/L
Tritium	20,000 pCi/L	20,000 pCi/L
All other manmade radionuclides	4 mrem/year[f]	4 mrem/year[f]

[a]SDWA MCL = Safe Drinking Water Act maximum contaminant level.
[b]Proposed rule, July 18, 1991 (56 *FR* 33050); final rule expected April 1993.
[c]The present MCL applies to combined ^{226}Ra and ^{228}Ra; the proposed MCL applies to each separately.
[d]The present MCL excludes radon and uranium but includes ^{226}Ra; the proposed MCL excludes all three radionuclides.
[e]Approximately equal to 30 pCi/L.
[f]If two or more radionuclides are present, the sum of their annual dose equivalent to the total body or to any organ shall not exceed 4 mrem/year.

July 18, 1991, and are included in Table 4.3. Final promulgation of the concentration limits is not expected until April 1993. As with the chemical-specific MCLs, these concentration limits may be relevant and appropriate for cleanup of contaminated groundwater at EFPC.

4.2.2 DOE Orders

DOE orders are not promulgated regulations and thus are not considered to be ARARs by EPA. They are, however, contractually binding between DOE and Energy Systems. The radiation exposure limits defined in DOE Order 5400.5 (*Radiation Protection of the Public and the Environment*, February 8, 1990) are: an effective dose equivalent (EDE) of 100 mrem/year from all exposure pathways and all DOE sources of radiation and a EDE of less than 500 mrem/year as a temporary maximum exemption under specially-permitted and DOE-approved circumstances. In addition, effluent releases to surface water must not result in exposures to aquatic organisms which exceed an absorbed dose of 1 rad/d. The overriding principle of the DOE Order is that all releases of radioactive material shall be ALARA.

DOE Order 5820.2A (*Radioactive Waste Management*, September 9, 1988) states that the management of low-level radioactive waste must ensure that external exposure to the waste and concentrations of radioactive material that may be released into surface water and soil does not exceed 25 mrem/year to any member of the public. Releases to the atmosphere shall not exceed 10 mrem/year. Reasonable effort should be made to maintain releases to the environment to ALARA levels.

These DOE Orders will be analyzed further as TBC guidance during selection of remedial alternatives.

4.3 LOCATION-SPECIFIC ARARs

Location-specific requirements "set restrictions upon the concentration of hazardous substances or the conduct of activities solely because they are in special locations" (53 *FR* 51394). Table 4.4 lists the major federal and state location-specific ARARs that might be pertinent to remedial actions at EFPC.

4.3.1 Aquatic Resources and Natural Areas (NAs)

The ORR is located within the Clinch River drainage basin and is bounded on the south and west by the Clinch River. EFPC, situated primarily in the valley between East Fork Ridge and Black Oak Ridge, is located in the EFPC watershed. In addition to floodplains, portions of EFPC are characterized by associated wetlands.

Table 4.4. Tentative location-specific ARARs for EFPC

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Floodplains			
Within "lowland and relatively flat areas adjoining inland and coastal waters and other floodprone areas such as offshore islands, including at a minimum, that area subject to a one percent or greater chance of flooding in any given year." [Executive Order 11988 Sect. 6(c) and 40 *CFR* 6, Appendix A Sect. 4(d)]	Action which involves: - acquiring, managing, and disposing of lands and facilities - providing federally undertaken, financed, or assisted construction and improvements - conducting federal activities and programs affecting land use	Action shall be taken to reduce the risk of flood loss, minimize the impact of floods on human safety, health and welfare, and restore and preserve the natural and beneficial values of floodplains. The potential effects of actions in floodplains shall be evaluated and consideration of flood hazards and floodplain management ensured. If action is taken in floodplains, alternatives that avoid adverse effects and incompatible development and minimize potential harms shall be considered.	Executive Order (EO) 11988 40 *CFR* 6.302(b) 40 *CFR* 6 (Appendix A) 10 *CFR* 1022
Wetlands			
Presence of wetlands as defined in Executive Order 11990 Sect. 7(c) and 40 *CFR* 6, Appendix A Sect. 4(j)	Agency action that involves: - acquiring, managing, and disposing of lands and facilities - providing federally undertaken, financed, or assisted construction and improvements - conducting federal activities and programs affecting land use	Whenever possible, actions must avoid or minimize adverse impacts on wetlands and act to preserve and enhance their natural and beneficial values. New construction in wetlands areas should be particularly avoided unless there are no practicable alternatives. Wetlands protection considerations shall be incorporated into planning, regulating, and decision-making processes.	Executive Order 11990 40 *CFR* 6.302(a) 40 *CFR* 6, Appendix A 10 *CFR* 1022

Table 4.4 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Presence of wetlands as defined in 40 *CFR* 230.3(t) and 33 *CFR* 328.3(b)	Action involving discharge of dredge or fill material into wetlands	Action to avoid degradation or destruction of wetlands must be taken to the extent possible. Discharges for which there is a practicable alternative with less adverse impacts or those which would cause or contribute to significant degradation are prohibited. If adverse impacts are unavoidable, action must be taken to enhance, restore, or create alternative wetlands.	CWA Sect. 404 40 *CFR* 230 33 *CFR* 320-330
Aquatic resources and Natural Areas			
Within area encompassing or affecting waters of the state of Tennessee as defined in TCA[a]69-3-103(32) and the presence of wildlife or aquatic life	Action involving the discharge of any pollutants into the waters of the state [see TCA 69-3-103(18) and (21) for noninclusive list]	Discharge of "substances" which "will result or will likely result in harm, potential harm or detriment to the health of animals, birds, fish, or aquatic life" is prohibited.	Tennessee Water Quality Control Act of 1977 (TCA[b] 69-3-101 *et seq.*) Stream Use Classifications (TDEC Rules - Chap. 1200-4-4)
Within area affecting stream or river *-and-* presence of fish or wildlife resources	Action which results in the control or structural modification of a natural stream or body of water	The effects of water-related projects on fish and wildlife resources must be considered. Action must be taken to prevent, mitigate, or compensate for project-related damages or losses to fish and wildlife resources. Off-site actions that alter a resource require consultation with the FWS[c], NMFS[d], and/or appropriate state agency. Consultation is also strongly recommended for on-site actions.	Fish and Wildlife Coordination Act (16 USC 661 *et seq.*) 40 *CFR* 6.302(g)

Table 4.4 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Location encompassing aquatic ecosystem with dependent fish, wildlife, other aquatic life, or habitat	Action involving the discharge of dredge or fill material into aquatic ecosystem	Degradation or destruction of aquatic ecosystems must be avoided to the extent possible. Discharges which cause or contribute to significant degradation of the water of such ecosystem are prohibited.	CWA Sect. 404 40 *CFR* 230 33 *CFR* 320-330
Location encompassing a state-designated natural area		The scientific, scenic, recreational, and educational values of these areas must be preserved and steps taken to prevent impairment thereof.	TCA 11-14-101 *et seq*
Endangered, Threatened, or Rare Species			
Presence of endangered or threatened species *-or-* critical habitat of such species as designated in 50 *CFR* 17, 50 *CFR* 226, or 50 *CFR* 227	Action which is likely to jeopardize species or destroy or adversely modify critical habitat	Actions that jeopardize species/habitat must be avoided or appropriate mitigation measures taken. Off-site actions that affect species/habitat require consultation with DOI[e], FWS, NMFS, and/or state agencies, as appropriate, to ensure that proposed actions do not jeopardize the continued existence of the species or adversely modify or destroy critical habitat. Consultation is also strongly recommended for on-site actions.	Endangered Species Act of 1973 (16 USC 1531 *et seq.*) 50 *CFR* 402 40 *CFR* 6.302(h) Fish and Wildlife Coordination Act (16 USC 661 *et seq.*)
Presence of endangered or threatened species or critical habitat (see above citation) of same within an aquatic ecosystem as defined in 40 *CFR* 230.3(c)	Action involving discharge of dredge or fill material into aquatic ecosystem	Dredge or fill material shall not be discharged into an aquatic ecosystem if it would jeopardize such species or would likely result in the destruction or adverse modification of a critical habitat of the species.	CWA Sect. 404 40 *CFR* 230.10(b)

Table 4.4 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Presence of Tennessee state-listed endangered or threatened animal species as created and amended pursuant to TCA 70-8-105		Protected species may not be taken, possessed, transported, exported, processed, sold, offered for sale, or shipped. Certain exceptions may be allowed such as for educational, scientitfic, etc., reasons or where necessary to alleviate property damage or protect human health or safety. These exceptions require a permit if the remedial action or its attendant effects are off site.	Tennessee Nongame and Endangered or Threatened Wildlife Species Conservation Act of 1974 (TCA 70-8-101 *et seq.*)
Archeologic and Historic Resources			
Presence of archeological resources on public land	Action which would impact resource	Steps must be taken to protect archeological resources and sites.	Archaeological Resources Protection Act of 1979 (16 USC 470aa-ll) 43 *CFR* 7
Presence of archeologic or historic resources	Action involving dam construction or other alteration of terrain which might cause irreparable loss or destruction of significant scientific, prehistoric, historic, or archaeologic data	The Secretary of Interior must be advised of the presence of the data. A survey of affected areas for resources and data must be conducted and steps taken to recover, protect, and preserve data therefrom or request that DOI do so.	Archaeological and Historic Preservation Act (16 USC 469a-c) 40 *CFR* 6.301

Table 4.4 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Presence of federally owned, administered, or controlled prehistoric or historic resources *-or-* the likelihood of undiscovered resources		Cultural resources included on or eligible for inclusion on the National Register of Historic Places (36 *CFR* 60) or National Historic Landmark Program (36 *CFR* 65) must be identified. Action(s) that will affect such resources must be identified and alternatives to the action(s) examined and considered. When alteration or destruction of the resource is unavoidable, steps must be taken to minimize or mitigate the impacts and to preserve records and data of the resource. When all or part of a remedial action is off site, the consultation requirements of 16 USC 470f must be completed. Consultation is also strongly recommended for on-site actions.	National Historic Preservation Act (16 USC 470a-w) EO 11593 40 *CFR* 6.301 36 *CFR* 800
Cemetery located on property within Tennessee		Destruction or degradation of property in a graveyard or cemetery is prohibited.	Tennessee General Cemetery Act of 1968 (TCA 46-1-101 *et seq.*)

[a]TCA = Tennessee Code Annotated.
[b]TDEC = Tennessee Department of Environment and Conservation
[c]FWS = Fish and Wildlife Service.
[d]NMFS = National Marine Fisheries Service.
[e]DOI = Department of Interior.

If any remedial alternatives are selected which would impact floodplains, the requirements found in Executive Order 11988, 40 *CFR* 6.302(b), 40 *CFR* 6 (Appendix A), and 10 *CFR* 1022 would provide ARARs for EFPC. If wetlands are affected, consideration should be given to Executive Order 11990, 40 *CFR* 6.302(a), 40 *CFR* 6 (Appendix A), 10 *CFR* 1022, CWA Sect.404, 40 *CFR* 230, and 33 *CFR* 320-330 for applicable requirements.

There are no designated wilderness areas, wildlife refuges, or scenic rivers on ORR. However, portions of ORR, including part of EFPC, have been designated as Tennessee and DOE National Environmental Research Park (NERP) NAs and Reference Areas (RAs). Approximately the last 3 miles of EFPC, before it converges with Poplar Creek, is within the DOE NERP. In addition, two areas on EFPC have been designated as RAs, BMAP sites.

If remedial actions are contemplated that would impact the NAs or RAs, the Tennessee Natural Areas Preservation Act of 1971 may provide ARARs. In addition, if any remedial action is taken to alter EFPC, because of its designation for protection of fish and aquatic life, recreation, irrigation, livestock watering, etc., the Fish and Wildlife Coordination Act and the TDEC Water Quality Control Act (Tennessee Code Annotated 69-3-101 *et seq.*) may be ARARs (see Table 4.4).

4.3.2 Historic Sites and Archeological Findings

If any remedial action is taken which would cause irreparable harm, loss, or destruction to any historic or archeological site, the provisions of the Archeological Resources Protection Act (16 USC 470aa-ll), 43 *CFR* 7, the Archaeological and Historic Preservation Act (16 USC 469a-c) and 40 *CFR* 6.301, as well as Executive Order 11593, 40 *CFR* 6.301 and 36 *CFR* 800 *et seq.* may be ARAR. In addition, identification of cultural resources eligible for the National Register of Historic Places (36 *CFR* 60) or the National Historic Landmark Program (36 *CFR* 65) is mandated by the National Historic Preservation Act (16 USC 470a-w). See Sect. 2.1.1.2 (Archeology) for a discussion of an archeological and historical reconnaissance of the floodplain conducted from December 1991 to March 1992. Finally, should any cemeteries be located on the EFPC remedial site, the Tennessee Cemetery Protection Act (TCA 46-1-101 *et seq.*), which prohibits the destruction or degradation thereof, may apply.

4.3.3 Rare, Threatened, or Endangered Species

If a site investigation reveals the presence of any rare, threatened, or endangered animals or plants, or designated critical habitats at EFPC, the Endangered Species Act of 1973, the

Tennessee Rare Plant Protection and Conservation Act of 1985, and the Tennessee Non-Game and Endangered or Threatened Wildlife Species Act of 1974 may be ARARs (Table 4.4). Habitat modifications impacting any species designated by the state as "in need of management" may also trigger the state endangered species act.

4.4 ACTION-SPECIFIC ARARs

Performance, design, or other action-specific requirements set controls or restrictions on particular kinds of activities related to the management of hazardous waste (52 *FR* 32496). Selection of a particular remedial action at a site will invoke the appropriate action-specific ARARs that may specify particular performance standards or technologies, as well as specific environmental levels for discharged or residual chemicals; action-specific ARARs will be analyzed when remedial alternatives are addressed.

4.4.1 Dredge and Fill Activities

CERCLA Sect. 121(e) stipulates that permits are not required for on-site CERCLA cleanup. In general, this will apply to remedial actions taken on the Clinch River system, including EFPC, since CERCLA defines "on-site" to mean "the areal extent of contamination and all suitable areas in very close proximity" (40 *CFR* 300.5).

The COE requires permits for structures or work in or affecting navigable waters of the United States under Sect. 10 of the Rivers and Harbors Act. In addition, the discharge of dredged or fill material into waters of the United States or navigable waters is regulated under CWA Sect. 404 and implemented through 33 *CFR* 320-330 and 40 *CFR* 230. 33 *CFR* Sects. 322.2 and 328 define "waters of the United States" as those waters of the United States that are subject to the ebb and flow of the tide toward the mean high water mark and which have been at any time, or may be, used for interstate commerce. This definition includes all impoundments of such waters [40 *CFR* 328.3(a)(4)]. The COE has established the ordinary high water mark for impoundments to be the normal summer pool elevation (elev. 741 for the Watts Bar impoundment), which includes any slackwater areas. Any activity above this elevation would not require approval pursuant to Sect. 10 of the Rivers and Harbors Act. A regional survey by the COE identified "navigable waters" in the area; Poplar Creek from its mouth to River Mile 18.3 has been designated a navigable water. However, no tributaries to Poplar Creek have received such a designation (Claud 1992). If any areas of EFPC fall below elev. 741 (i.e., the slackwater areas of Watts Bar), the substantive requirements of the COE permitting program may be ARARs for remedial actions.

Discharge of fill material into EFPC or its adjacent wetland areas may require a CWA Sect. 404 permit, and would be regulated by the requirements of 40 *CFR* 230 *et seq.* which are designed to prevent potential impacts on aquatic ecosystems. Table 4.4 gives a brief summary of the content of these regulations.

In the event that streambed modifications occur during remediation, the substantive requirements of the TDEC Aquatic Resources Alteration Permitting (ARAP) process (Chapter 1200-4-7 *et seq.*) will be applicable to this response action.

4.4.2 On-site Construction/Excavation

Certain on-site construction and/or excavation activities may be necessary to prepare the site for remediation. These might include the development of additional roads for vehicular traffic, movement of soils, site grading, or site cleaning activities. Airborne pollutants may result from these construction activities. The primary concern is elevation of particulate concentrations resulting from earth-moving and site-grading activities. The TDEC, Division of Air Pollution Control, has promulgated regulations governing fugitive dust emissions. Fugitive dust may not be emitted as visible emissions beyond property boundary lines for more than 5 min/h or 20 min/d. In addition, reasonable precautions must be taken to prevent particulate matter from becoming airborne (Rules of the TDEC, Chapter 1200-3-8-.01).

4.4.3 Surface Water Control

Storm water discharges from activities at industrial sites involving construction operations that result in the disturbance of five acres or more total land have been included in the final rule for NPDES permits for storm water discharges (40 *CFR* 122). Consultation with TDEC is required to ensure compliance with the substantive requirements of the NPDES permitting process for stormwater discharges during construction activities (Chapter 1200-4-10-.05 of the Rules of the TDEC).

4.5 COMPARISON OF ARARs

This information will be addressed in fuller detail in the subsequent draft. See Tables 4.5 through 4.7 for comparison data.

Table 4.5. Mean contaminant concentrations (μg/L) at base flow in Hinds Creek reference site compared to Tennessee water quality criteria

Parameter	Proportion of results >detection limit	Mean result	95% Upper confidence limit of mean	Maximum result	Tennessee water quality criteria			
					Maximum contaminant level	Recreation criteria	Maximum fish-aquatics	Continuous fish-aquatics
Arsenic	0/3	1.83	2.81	2.5	50	.	360	190
Barium	3/3	42.8	65.5	58.3	2000	.	.	.
Beryllium	0/3	0.5	0.5	0.5	4	1.3	.	.
Cadmium	0/3	2.17	2.65	2.5	5	.	4	1
Chromium	0/3	2.33	2.82	2.5	100	670000	.	100
Copper	1/3	2.53	4.04	3.1	1300	.	18	12
Lead	0/3	1.33	1.82	1.5	15	.	82	3
Manganese	3/3	16	28.5	23.1	50	.	.	.
Mercury	0/3	0.1	0.1	0.1	2	0.15	2.4	0.012
Nickel	0/3	5	6.46	5.5	100	4600	1400	160
Silver	0/3	2.33	3.31	3	50	.	4	.
Vanadium	0/3	2.33	3.31	3	.	.	.	.
Zinc	1/3	12.3	21.3	15.8	5000	.	117	106
Benzo(a)anthracene	0/3	5	5	5	.	0.3	.	.
Benzo(a)pyrene	0/3	5	5	5	0.2	0.3	.	.
Benzo(b)fluoranthene	0/3	5	5	5	.	.	.	.
Benzo(g,h,i)perylene	0/3	5	5	5	.	.	.	.
Benzo(k)fluoranthene	0/3	5	5	5	.	0.3	.	.
Chrysene	0/3	5	5	5	.	0.03	.	.

Results less than the detection limit were set to one half the detection limit.
Source: EFPC Phase Ia and Ib validated results on December 18, 1992.

Table 4.6. Mean contaminant concentrations (μg/L) at baseflow in East Fork Poplar Creek compared to Tennessee water quality criteria

Parameter	Proportion of results > detection limit	Mean result	95% Upper confidence limit of mean	Maximum result	Tennessee water quality criteria			
					Maximum contaminant level	Recreation criteria	Maximum fish-aquatics	Continuous fish-aquatics
Arsenic	0/14	2.21	2.44	2.5	50	.	360	190
Barium	14/14	41.2	45.6	60	2000	.	.	.
Beryllium	0/14	0.5	0.5	0.5	4	1.3	.	.
Cadmium	0/14	2.36	2.47	2.5	5	.	4	1
Chromium	0/14	2.14	2.25	2.5	100	670000	.	100
Copper	0/14	3.07	3.43	4.6	1300	.	18	12
Lead	0/13	1.5	1.91	4.15	15	.	82	3
Manganese	13/14	24.3	32.4	66.6	50	.	.	.
*Mercury	4/14	0.215	0.312	0.72	2	0.15	2.4	0.012
Nickel	0/14	4.43	4.76	5.5	100	4600	1400	160
Silver	0/14	2.71	2.94	3	50	.	4	.
Vanadium	0/14	2.71	2.94	3	.	.	.	.
Zinc	12/14	25.8	32.2	59.7	5000	.	117	106
Benzo(a)anthracene	0/13	5	5	5	.	0.3	.	.
Benzo(a)pyrene	0/13	5	5	5	0.2	0.3	.	.
Benzo(b)fluoranthene	0/13	5	5	5	.	.	.	.
Benzo(g,h,i)perylene	0/13	5	5	5	.	.	.	.
Benzo(k)fluoranthene	0/13	5	5	5	.	0.3	.	.
Chrysene	0/13	5	5	5	.	0.03	.	.

* Upper confidence limit of the mean exceeds at least one of the water quality criteria, and at least one result is greater than the detection limit.
Results less than the detection limit were set to one half the detection limit.
Source: EFPC Phase Ia and Ib validated results on December 18, 1992.

Table 4.7 Mean contaminant concentrations (μg/L) measured quarterly in groundwater from 22 shallow wells in the EFPC floodplain compared to Tennessee water quality criteria

Parameter	Proportion of results >detection limit	Mean result	95% upper confidence limit of mean	Maximum result	Tennessee water quality criteria		Maximum fish-aquatics	Continuous fish-aquatics
					Maximum contaminant level	Recreation criteria		
Arsenic (Dissolved)	19/83	10.3	17.2	219	50	.	360	190
Arsenic (Total)	23/79	3.97	5.57	76.4	50	.	360	190
Barium (Dissolved)	83/83	163	192	1110	2000	.	.	.
Barium (Total)	82/83	395	485	3150	2000	.	.	.
Beryllium (Dissolved)	2/83	0.658	0.798	6.9	4	1.3	.	.
*Beryllium (Total)	16/83	1.88	2.56	28.1	4	1.3	.	.
*Cadmium (Dissolved)	2/83	2.07	2.2	6.3	5	.	4	1
*Cadmium (Total)	7/83	3.51	5.15	75.1	5	.	4	1
Chromium (Dissolved)	5/83	3.29	4.01	35.5	100	670000	.	100
Chromium (Total)	60/83	33	41	268	100	670000	.	100
Copper (Dissolved)	13/83	3.98	6.12	108	1300	.	18	12
*Copper (Total)	62/83	167	324	6320	1300	.	18	12
Lead (Dissolved)	7/83	1.44	1.69	9.2	15	.	82	3
*Lead (Total)	59/81	26.8	35.3	299	15	.	82	3
*Manganese (Dissolved)	80/83	2950	3650	27600	50	.	.	.
*Manganese (Total)	81/83	3740	4420	21000	50	.	.	.
*Mercury (Dissolved)	4/58	0.577	1.33	26.1	2	0.15	2.4	0.012
*Mercury (Total)	57/83	13.9	21.8	280	2	0.15	2.4	0.012

Table 4.7 (continued)

Parameter	Proportion of results >detection limit	Mean result	95% upper confidence limit of mean	Maximum result	Tennessee water quality criteria		Maximum fish-aquatics	Continuous fish-aquatics
					Maximum contaminant level	Recreation criteria		
Nickel (Dissolved)	16/83	10.6	13.9	160	100	4600	1400	160
Nickel (Total)	56/83	48	64.3	657	100	4600	1400	160
Silver (Dissolved)	0/83	2.84	2.97	4	50	.	4	.
Silver (Total)	0/83	2.77	2.87	3.5	50	.	4	.
*Vanadium (Dissolved)	6/83	5.11	8.91	191	.	.	.	.
*Vanadium (Total)	56/83	39.1	49	225	.	.	.	.
Zinc (Dissolved)	41/83	10.8	15.5	210	5000	.	117	106
*Zinc (Total)	54/83	103	129	743	5000	.	117	106
*Benzo(a)anthracene	1/82	5.04	5.12	8.5	.	0.3	.	.
*Benzo(a)pyrene	1/82	5.02	5.12	8.5	0.2	0.3	.	.
*Benzo(b)fluoranthene	1/82	5.04	5.12	8.5	.	.	.	.
Benzo(g,h,i)perylene	0/82	5.06	5.14	8.5	.	.	.	.
*Benzo(k)fluoranthene	1/82	5.02	5.12	8.5	.	0.3	.	.
*Chrysene	1/82	5.04	5.12	8.5	.	0.03	.	.
Dibenzo(a,h)anthracene	0/82	5.06	5.14	8.5	.	.	.	.

* Upper confidence limit of the mean exceeds at least one of the water quality criteria, and at least one result is greater than the detection limit.
Results less than the detection limit were set to one half the detection limit.
Source: EFPC Phase Ia validated results on December 18, 1992.

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