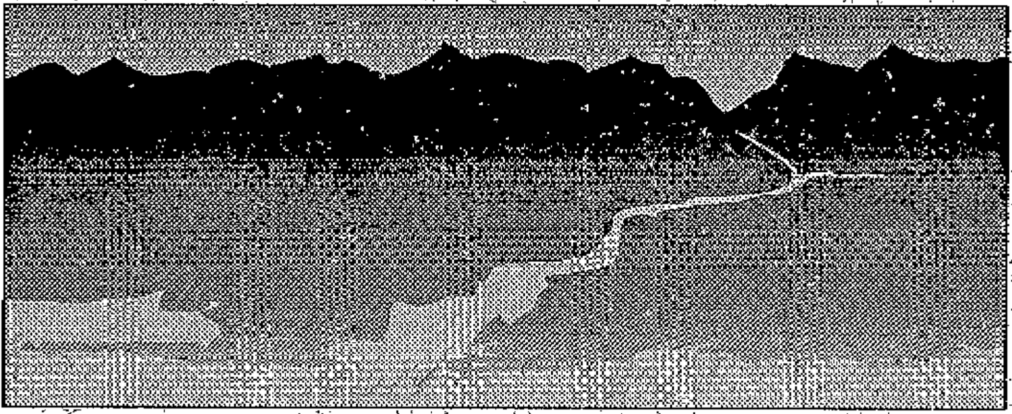
FINAL REPORT
8526-06

LOWER COLUMBIA RIVER



BI-STATE PROGRAM

RECONNAISSANCE SURVEY OF THE LOWER COLUMBIA RIVER

TASK 6: RECONNAISSANCE REPORT

MAY 17, 1993

Prepared By:
TETRA TECH

In Association With:
EVS CONSULTANTS
DAVID EVANS & ASSOCIATES

TETRA TECH

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FINAL REPORT
VOLUME I

RECONNAISSANCE SURVEY OF THE LOWER COLUMBIA RIVER

TASK 6: RECONNAISSANCE REPORT

MAY 1993

Prepared For:

The Lower Columbia River
Bi-State Water Quality Program

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The following laboratories provided analytical services for this project:

- Alden Analytical Labs - Semi-volatile and volatile organics, pesticides/PCBs
- Precision Analytics, Inc. - Metals, nutrients, sediment grain size
- Keystone/NEA - Dioxins/furans, lipids
- Analytical Resources, Inc. - Sediment conventionals, organotins
- Weyerhaeuser Labs - AOX
- Washington Department of Health - Radionuclides
- Coffey Labs - Bacteria
- EVS Consultants, Inc - Invertebrate taxonomy
- Aquatic Analysts - Phytoplankton

This report was reviewed by members of the Lower Columbia River Bi-State Steering Committee. Additional comments, which have been addressed in this report, were received from the following groups or individuals:

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EXECUTIVE SUMMARY

The Columbia River is the largest river entering the northeastern Pacific Ocean, and is the second largest river in the United States in terms of volume discharged. The river's drainage basin, which covers 660,480 km^2 (255,000 mi^2) in the U.S. and Canada, is the focus for major fishing, forestry, hydroelectric, mining, shipping, agricultural, manufacturing, and recreational activities. The lower Columbia river consists of the 146 mile stretch of river below Bonneville dam to the river's mouth at the Pacific Ocean. This region contains the most highly industrialized and largest population centers found along the Columbia River.

There is increasing public concern that urbanization, coupled with extensive industrial and agricultural activity along the lower Columbia River and in its upper and lower drainage subbasins, might be having an adverse effect on the river's water quality. Concern has also been expressed regarding the transport and potential impacts of toxic chemicals in the productive estuarine habitats of the river. The Lower Columbia River Bi-State Water Quality Program (Bi-State Program) was initiated in 1990 by the Oregon and Washington state legislatures to address these concerns by assessing the overall water quality of the lower Columbia River.

As part of the Bi-State Program's assessment of water quality, a reconnaissance survey of the lower river was conducted during September to November 1991. The purpose of this survey was to make a preliminary assessment of water quality conditions that could be used to identify potential water quality problems and direct future Bi-State studies. Water, sediment, and tissue samples were collected throughout the lower river and analyzed for an extensive list of chemicals. Benthic organisms were also enumerated at all sediment collection sites to permit examination of the relationships among benthic community indices, sediment contaminant levels, and habitat characteristics. This survey represents the most extensive sampling effort ever conducted on the lower Columbia river. The types of analyses conducted are summarized below.

- **Water:** Samples were collected from 45 locations in the lower Columbia River. Parameters analyzed at all, or some portion of these locations, included temperature, conductivity, pH, dissolved oxygen (DO), total suspended solids, turbidity, hardness, essential plant nutrients, bacteria, and 16 metals and 119 organic chemicals of potential concern.

- **Sediments:** Sediment samples were collected at fifty-four locations in the lower Columbia River. These samples were analyzed for particle size, total organic carbon, 16 metals, 108 organic chemicals, and 7 radionuclides.

- **Tissue:** Tissue samples were collected from 20 locations in the lower Columbia river. These samples were analyzed for the presence of 11 trace metals and 108 organic chemicals of potential concern. Contaminant levels in five species were documented (carp, crayfish, largescale sucker, peamouth, and white sturgeon). These species were selected for analysis because their feeding characteristics (e.g., bottom feeders), fat content, and/or longevity (e.g., white sturgeon) might suggest that they would have higher contaminant levels than other aquatic species.

- **Benthos:** The types and abundance of benthic organisms were recorded at 54 locations in the lower Columbia River. These sites were also analyzed for sediment chemistry.

The map on the following page shows the sites sampled in the 1991 reconnaissance survey and indicates the water quality parameters that were measured at levels of potential concern. It should be noted that there are varying degrees of confidence associated with the designation of parameters of concern. In the case of water, identification of potential problems is relatively straightforward as both Oregon and Washington have established state criteria that can be used to evaluate water quality. Determination of potential problems in sediment, tissue samples, and benthic communities is more problematic as neither Oregon or Washington have established criteria to facilitate identification of problems in these media.

Water quality parameters or chemical concentrations that exceeded these federal or state criteria are indicated on the map as being of potential concern. In general, the water column study of the lower Columbia river indicated a number of potential water quality problems. Measured concentrations of enterococcus bacteria exceeded federal criteria at all the stations surveyed for bacteria, dissolved oxygen levels were below state standards at several stations, and there were indications that the water temperature criterion of 20° C is exceeded regularly in the study area below Bonneville Dam.

In the case of sediment, contaminant concentrations were compared to reference, or guidance, values developed by other regulatory or resource management programs. Sources of these reference values were the recently issued draft U.S. Environmental Protection Agency freshwater sediment criteria which includes criteria for five chemicals, the Ontario Ministry of the Environment's Provincial Sediment Quality Guidelines for freshwater sediments, and data compiled as part of the National Oceanic and Atmospheric Administration's National Status and Trends program that identifies ranges of chemical concentrations in marine and freshwater sediments associated with adverse impacts to benthic organisms. Chemicals with sediment concentrations that exceeded these reference values are identified as being of potential concern on the map of the lower Columbia River. Metals concentrations exceeded the sediment reference levels adopted for this study at a number of stations. Polycyclic aromatic hydrocarbons (PAHs), PCBs, and most pesticides were detected relatively infrequently, but the detected concentrations generally exceeded their effects-based reference values. Dioxins and furans, and organotin compounds were detected frequently at the more limited number of stations sampled for these compounds. However, assessment of the biological significance of the detected levels of dioxins, furans, and organotin compounds is difficult because of the lack of effects-based reference values for these contaminants. It is important to note that reference values were unavailable for many of the chemicals analyzed in sediment samples. It is not possible at present to evaluate the potential impact on water quality from these chemicals.

The reference values used to identify potential chemicals of concern in tissue samples were tissue residue guidance values developed by the New York State Department of Environment Conservation. These values, which are intended only as guidance to New York State regulatory agencies, were developed using toxicological data studies of traditional laboratory animals and wildlife species and are intended to be used to estimate safe levels of contaminants in fish tissue that will protect fish-eating wildlife. These guidance values are available for only a small number of the chemicals measured in tissue samples collected from the lower Columbia River. Chemicals with tissue concentrations that exceeded these reference values are identified as being of potential concern on the map of the lower Columbia River. The tissue data suggests that the contaminants of primary concern in the lower Columbia River are PCBs, dioxin/furans, and chlorinated pesticides. All three of these groups of chemicals are widely distributed throughout the lower river and the concentrations measured in fish from several locations are sufficiently high that they may adversely affect fish-eating wildlife.

Potential impacts to benthic populations were identified by comparing organism abundance and the number of different types of organisms (taxa) with specific reference conditions identified for the lower Columbia River. This required designation of reference conditions for coarse and fine sediment habitats in the freshwater region of the river, and a reference condition for the lower estuary. Sites where both total abundance and the number of taxa were 50 percent lower than these reference conditions are identified on the enclosed map as being of potential concern. Reductions in benthic abundance and numbers of taxa were not correlated with sediment contaminant levels. The limited data collected suggests that changes in these indices may be influenced to a greater extent by physical or habitat characteristics than by water quality. However, the data are not adequate to completely dismiss water quality, or any other factor, as a cause of relatively lower abundance or numbers of taxa in sediments of the lower river.

The primary purpose of the 1991 reconnaissance survey was to collect data that would permit a preliminary assessment of water quality in the lower Columbia River. As indicated on the summary map, several potential water quality problems have been identified that will serve to direct future Bi-State studies. Because of uncertainties associated with reference values for media other than water, the lack of reference values for many of the chemicals measured, and the fact that this survey is only a single snapshot of river conditions during summer low-flow conditions, it is important to recognize that further efforts are needed to confirm and evaluate the potential problems inferred from the reconnaissance survey. Nevertheless, the reconnaissance survey results do provide strong evidence that there is a need for continued concern about water quality in the lower Columbia River.

LIST OF ACRONYMS

ADI	Acceptable daily human intake
AOX	Adsorbable organic halogens
APHA	American Public Health Association
AVS	Acid volatile sulfides
AZ	Arizona
BHC	Benzene hexachloride [or HCH (hexachlorocyclohexane)]
BCF	Bioconcentration factor
BOD	Biochemical oxygen demand
CA	California
cfs	cubic feet per second
Ci	Curie
CLP	Contract Laboratory Protocols
CREDDP	Columbia River Estuary Data Development Program
CSO	Combined storm-sewer overflow
CTD	Conductivity-temperature-depth meter
DDD	Dichloro diphenyl dichloroethane
DDE	Dichloro diphenyl dichloroethylene
DDT	Dichloro diphenyl trichloroethane
DEHP	Di-(2-ethylhexyl)phthalate
° C	Degrees Centigrade
° F	Degrees Fahrenheit
DL	Detection limit
DO	Dissolved oxygen
EDL	Estimated detection limit
EPA	Environmental Protection Agency
ER-L	Effects-range low
ER-M	Effects-range medium

FDA	U.S. Food and Drug Administration
GPS	Global positioning system
HI	Hawaii
HxCDD	Hexachloro-dibenzodioxin
HxCDF	Hexachloro-dibenzofuran
IA	Iowa
L	Liters
ICP/AES	Inductively coupled plasma/atomic emission spectrometer
ICP/MS	Inductively coupled plasma/mass spectrometer
IQR	Inter-quartile range
lb	Pounds
LLD	Lower limit of detection
LC	Lethal concentration
LMCL	Lower method calibration limit
LOEL	Lowest observed effects level
MEI	Maximally exposed individual
MGD	Million gallons per day
MI	Michigan
μg	Micrograms
mg	Milligrams
mMhos	Micromhos
MPN	Most probable number
mrem	Millirems
MS	Matrix spike
MSD	Matrix spike duplicate
NASQUAN	National Stream Quality Accounting Network
NBS	National Bioaccumulation Study
NCASI	National Council of the Paper Industry for Air and Stream Improvement
NCBP	National Contaminant Biomonitoring Program
NOAA	National Oceanic and Atmospheric Administration
NOEL	No observed effects level
NPDES	National pollutant discharge elimination system

NTU	Nephelometric turbidity units
NYS	New York State
OAR	Oregon Administrative Rules
OCDD	Octachloro-dibenzodioxin
OCDF	Octachloro-dibenzofuran
ODEQ	Oregon Department of Environmental Quality
OR	Oregon
P	Probability
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl compound
PCDD	Polychlorinated dibenzodioxin
PCDF	Polychlorinated dibenzofuran
pCi	Picocuries
PeCDD	Pentachloro-dibenzodioxin
PeCDF	Pentachloro-dibenzofuran
PGE	Portland General Electric
pg	Picograms
ppm	Parts per million
ppt	Parts per thousand
ppt	Parts per trillion (pg/g)
QA	Quality assurance
QC	Quality control
r	correlation coefficient
r^2	coefficient of determination
rad	absorbed ionizing radiation
RM	River mile
RPD	Relative percent difference
SM	Standard Methods
STORET	U.S. EPA's data storage and retrieval system database
TBT	Tributyltin
TCDD	Tetrachloro-dibenzodioxin
TCDF	Tetrachloro-dibenzofuran

TEC	Toxicity equivalent concentration
TEF	Toxicity equivalency factor
TKN	Total Kjeldahl nitrogen
TMDL	Total maximum daily load
TOC	Total organic carbon
TP	Total phosphorus
TSS	Total suspended solids
USACOE	U.S. Army Corps of Engineers
USDOE	U.S. Department of Energy
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UT	Utah
WA	Washington
WAC	Washington Administrative Code
WDOE	Washington Department of Ecology
WSDH	Washington State Department of Health
WWTP	Wastewater treatment plant
YSI	Yellow Springs Instruments

1991 Reconnaissance Survey Of The Lower Columbia River

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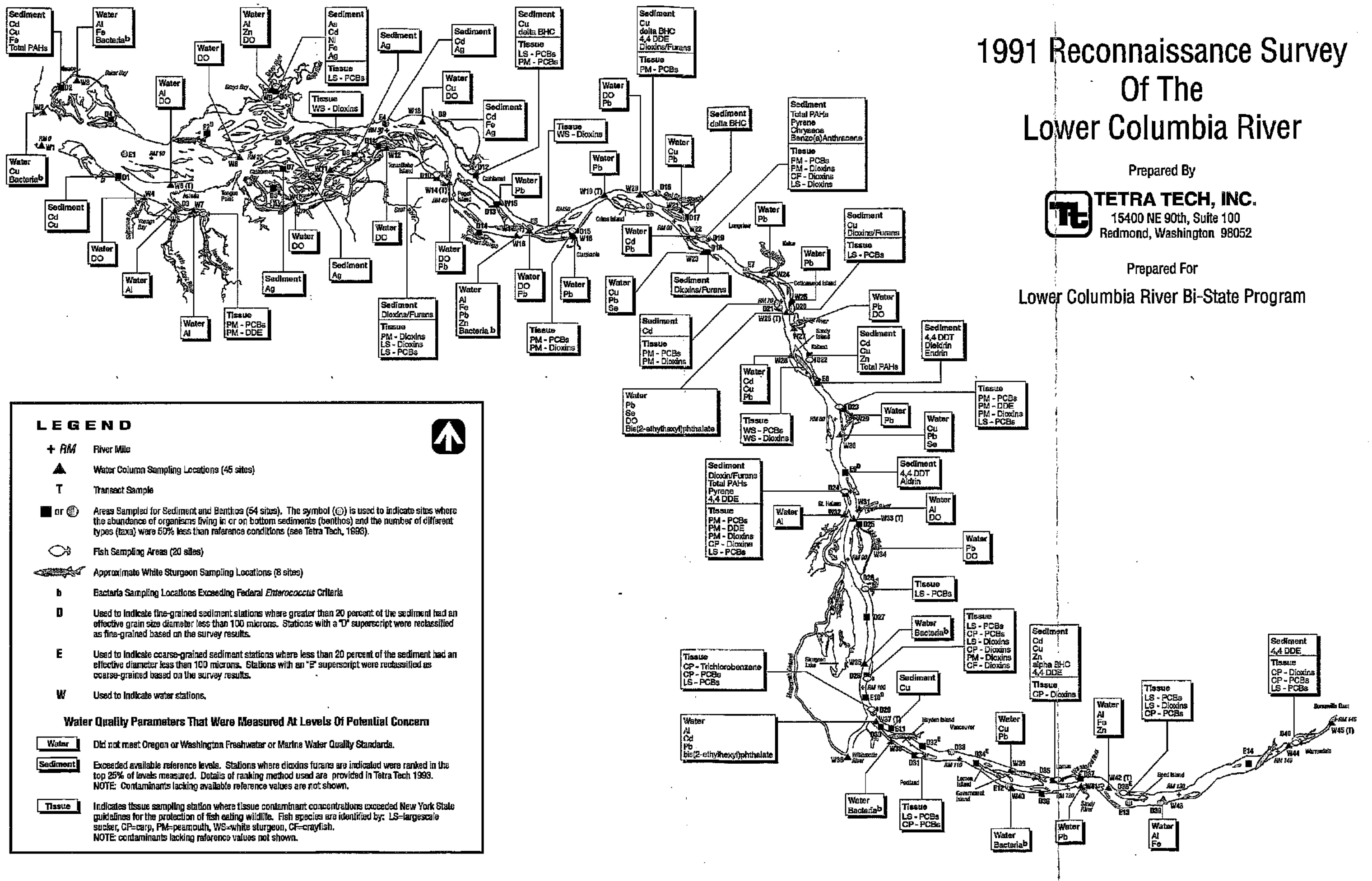
Lower Columbia River Bi-State Program



LEGEND

+ RM — River Mile

▲ — Water Column Sampling Locations (45 sites)

T — Transect Sample

■ or ◎ — Areas Sampled for Sediment and Benthos (54 sites). The symbol (◎) is used to indicate sites where the abundance of organisms living in or on bottom sediments (benthos) and the number of different types (taxa) were 50% less than reference conditions (see Tetra Tech, 1993).

Fish Sampling Areas (20 sites)

Approximate White Sturgeon Sampling Locations (8 sites)

b — Bacteria Sampling Locations Exceeding Federal *Enterococcus* Criteria

D — Used to indicate fine-grained sediment stations where greater than 20 percent of the sediment had an effective grain size diameter less than 100 microns. Stations with a "D" superscript were reclassified as fine-grained based on the survey results.

E — Used to indicate coarse-grained sediment stations where less than 20 percent of the sediment had an effective diameter less than 100 microns. Stations with an "E" superscript were reclassified as coarse-grained based on the survey results.

W — Used to indicate water stations.

Water Quality Parameters That Were Measured At Levels Of Potential Concern

Water — Did not meet Oregon or Washington Freshwater or Marine Water Quality Standards.

Sediment — Exceeded available reference levels. Stations where dioxins furans are indicated were ranked in the top 25% of levels measured. Details of ranking method used are provided in Tetra Tech 1993. NOTE: Contaminants lacking available reference values are not shown.

Tissue — Indicates tissue sampling station where tissue contaminant concentrations exceeded New York State guidelines for the protection of fish eating wildlife. Fish species are identified by: LS=largescale sucker, CP=carp, PM=peamouth, WS=white sturgeon, CF=crayfish.
NOTE: contaminants lacking reference values not shown.

1.0 INTRODUCTION

The Columbia River, the largest river entering the northeastern Pacific Ocean, is the second largest river in the United States in terms of volume discharged (Fox et al. 1984). The river's drainage basin, which covers 660,480 km^2 in the U.S. and Canada (Simenstad et al. 1990), is the focus for major fishing, forestry, hydroelectric, mining, shipping, agricultural, manufacturing, and recreational activities.

The lower Columbia River is the section of the river from the river's mouth near Astoria, Oregon to Bonneville Dam at river mile 146. This section, which forms part of the border between Washington and Oregon, supports the most concentrated population and industrial base along the U.S. portion of the river. The lower river's drainage subbasin contains several major tributaries. Much of the land use in the subbasin is devoted to forestry and, to a lesser extent, agriculture, urban and suburban business, and residential use.

Major population centers on the lower Columbia River include Astoria, Rainier, Portland, St. Helens and Troutdale in Oregon and Longview-Kelso, Kalama, Vancouver, and Camas-Washougal in Washington. The utility of the lower Columbia River as a major shipping channel has encouraged the development of major port facilities and heavy industrial activity in these population centers. The lower Columbia also supports major salmonid and sturgeon fisheries; it is also home to three national wildlife refuges (Lewis and Clark, the Julia Butler Hansen and the Ridgefield National Wildlife Refuges) and a wildlife management area (Sauvie Island Wildlife Management Area). The estuarine portion of the lower Columbia provides critical nursery and feeding habitat for several ecologically and economically important fish and invertebrate species.

There is increasing public concern that urbanization, coupled with extensive industrial and agricultural activity along the lower Columbia River and in its upper and lower drainage subbasins, might be having an adverse effect on the river's water quality. Concern has also been expressed regarding the transport and potential impacts of toxic chemicals in the productive estuarine habitats of the river.

1.1 LOWER COLUMBIA RIVER BI-STATE PROGRAM

The Oregon and Washington state legislatures directed the formation of the Lower Columbia River Bi-State Water Quality Program (Bi-State Program) in 1990. The Bi-State Program is a four-year plan designed to assess overall water quality in the lower Columbia River. The Bi-State Program's overall four-year goals are:

- To identify water quality problems.
- To determine if beneficial/characteristic uses are impaired.
- To develop solutions to problems in the lower river.
- To make recommendations on a long-term bi-state framework.

The Bi-State Program is to accomplish these goals by carrying out the following tasks:

- Involve the public through education and by inviting public participation.
- Develop work plans that identify the studies needed to characterize the river's water quality.
- Evaluate existing data and conduct reconnaissance surveys.
- Carry out baseline studies.
- Conduct advanced studies and recommend long-term monitoring.
- Make recommendations to regulatory agencies.

1.2 LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

In general, reconnaissance surveys are conducted to make a preliminary assessment of environmental conditions of a study area to identify current environmental conditions and contaminant levels, and identify potential contaminants and areas of concern for more specific studies. When coupled with knowledge of historical studies and information on potential pollutant sources, the results of a reconnaissance survey may provide a preliminary assessment of potential environmental problems or reveal additional data gaps that could be filled through more focused studies. Therefore, the reconnaissance survey is typically of broad scope and attempts to sample a large number of contaminants, potential problem areas, and environmental media (i.e., water, sediments, and biota) with the financial and technical resources available. A reconnaissance survey may then be followed by contaminant-, site-, and/or media-specific studies that would allow refinement in the knowledge of problems identified based on the reconnaissance survey. Therefore, reconnaissance survey results do not allow for the complete identification of contaminants of concern, problem areas, or a complete assessment of the environmental health of the study area. These concerns are more appropriately addressed through inter-state and inter-agency coordination of specific environmental investigations and routine monitoring programs.

The reconnaissance survey of the lower Columbia River was conducted to make a preliminary assessment of the environmental conditions of the lower Columbia River and to gather data that would aid in the development and design of future environmental investigations and monitoring programs for the river. The task of conducting a reconnaissance survey of the lower Columbia River was accomplished during September to November 1991 (Tetra Tech 1991a), following the guidance and protocols outlined in the final QA/QC (Tetra Tech 1991b) and sampling plans (Tetra Tech 1991c). The primary objectives of the reconnaissance survey were:

- To provide a reconnaissance of levels of contaminants in water, sediments, and tissue of resident river biota.

- To begin to address data gaps identified from an evaluation of existing water quality data (Tetra Tech 1992a).

- To tentatively identify problem areas in the lower river.

- To provide recommendations for baseline studies to be conducted in subsequent years of the Bi-State Program.

1.2.1 Reconnaissance Survey Sampling Locations

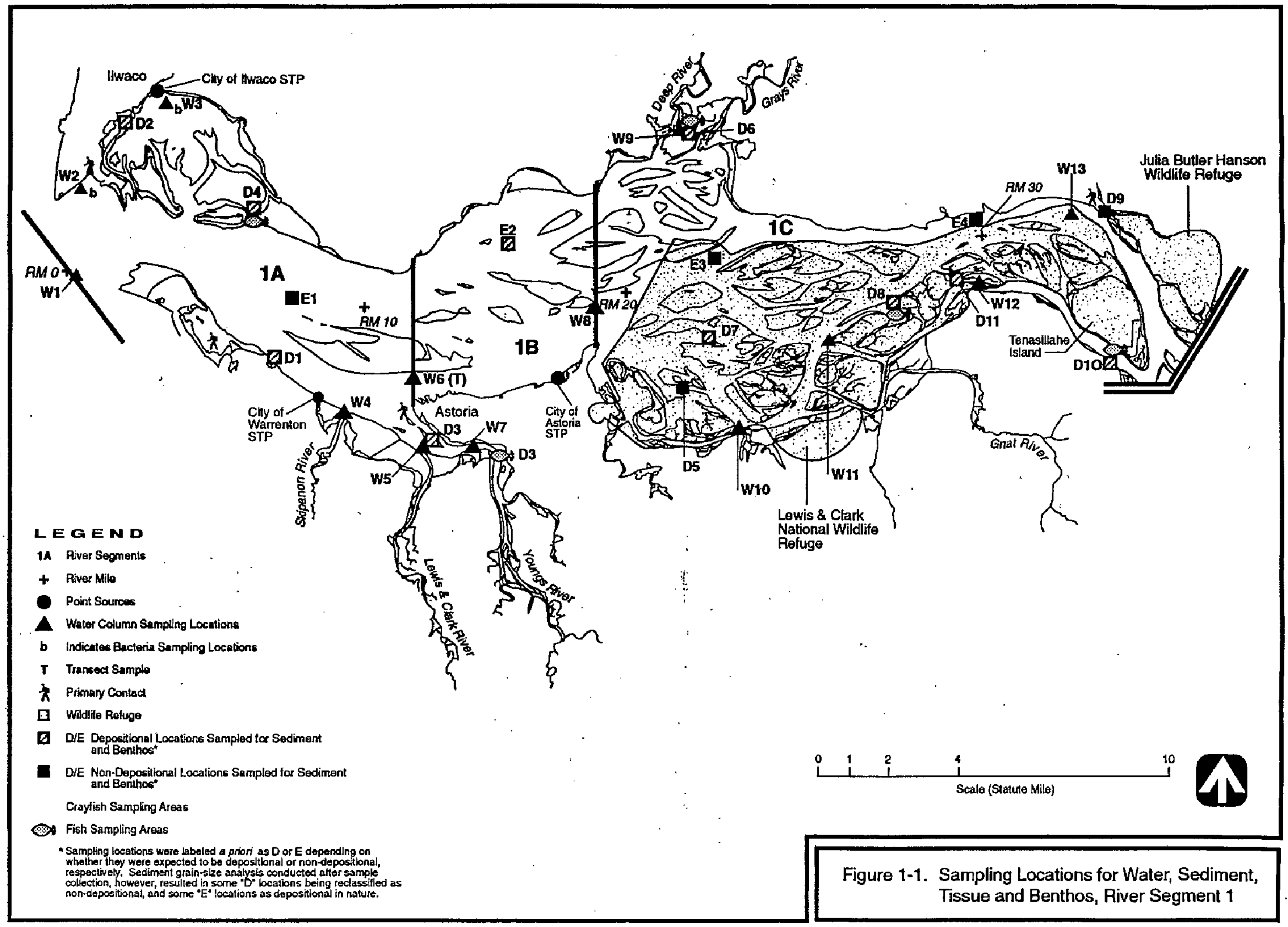
Four environmental media (water, sediments, tissue, and benthic communities) were surveyed to assess water quality in the lower Columbia River. Forty-five locations were sampled for water column characteristics, 54 locations each for sediment chemistry and benthic community assessment, and 20 locations for tissue (fish and/or crayfish) bioaccumulation of contaminants. The sampling locations are shown in Figures 1-1 through 1-4. The rationale for selecting the sampling locations is provided in subsequent sections addressing each of the environmental mediums surveyed. A list of the chemicals of concern analyzed in each environmental medium is provided in Table 1-1.

1.2.2 River Flow and Rainfall Conditions During the Survey

River flow and rainfall conditions prevailing during the reconnaissance survey are important because they can affect the water quality parameters measured. For example, when river flows are low, pollutants discharged from point sources may approach maximum concentrations because dilution by river water will be reduced. When rainfall is high, input to the river of pollutants from non-point sources, such as run-off, increase. Short-term variation in flow and rainfall conditions is expected to affect the levels of pollutants more in the water column than in sediments or fish tissue.

Vessel-based sampling of water, sediment, fish and benthos was performed under low-flow conditions in the lower Columbia River and its tributaries during September and October 1991 (see Figures 1-5 and 1-6). Shore-based bacterial sampling was conducted during the second half of October and the first half of November 1991 under conditions of heavy rainfall and increasing flow in the lower Columbia River and its tributaries (see Figures 1-5 through 1-7).

Monthly average, maximum, and minimum discharge of the Columbia River at The Dalles, OR (RM 188.9) for 1991 is compared with the historical average, maximum, and minimum discharge in Figure 1-5. These data are from the U.S. Geological Survey (USGS) discharge monitoring station located above the Bonneville Dam, and therefore do not reflect the peak winter flows (resulting from heavy



* Sampling locations were labeled *a priori* as D or E depending on whether they were expected to be depositional or non-depositional, respectively. Sediment grain-size analysis conducted after sample collection, however, resulted in some "D" locations being reclassified as non-depositional, and some "E" locations as depositional in nature.

Figure 1-1. Sampling Locations for Water, Sediment, Tissue and Benthos, River Segment 1

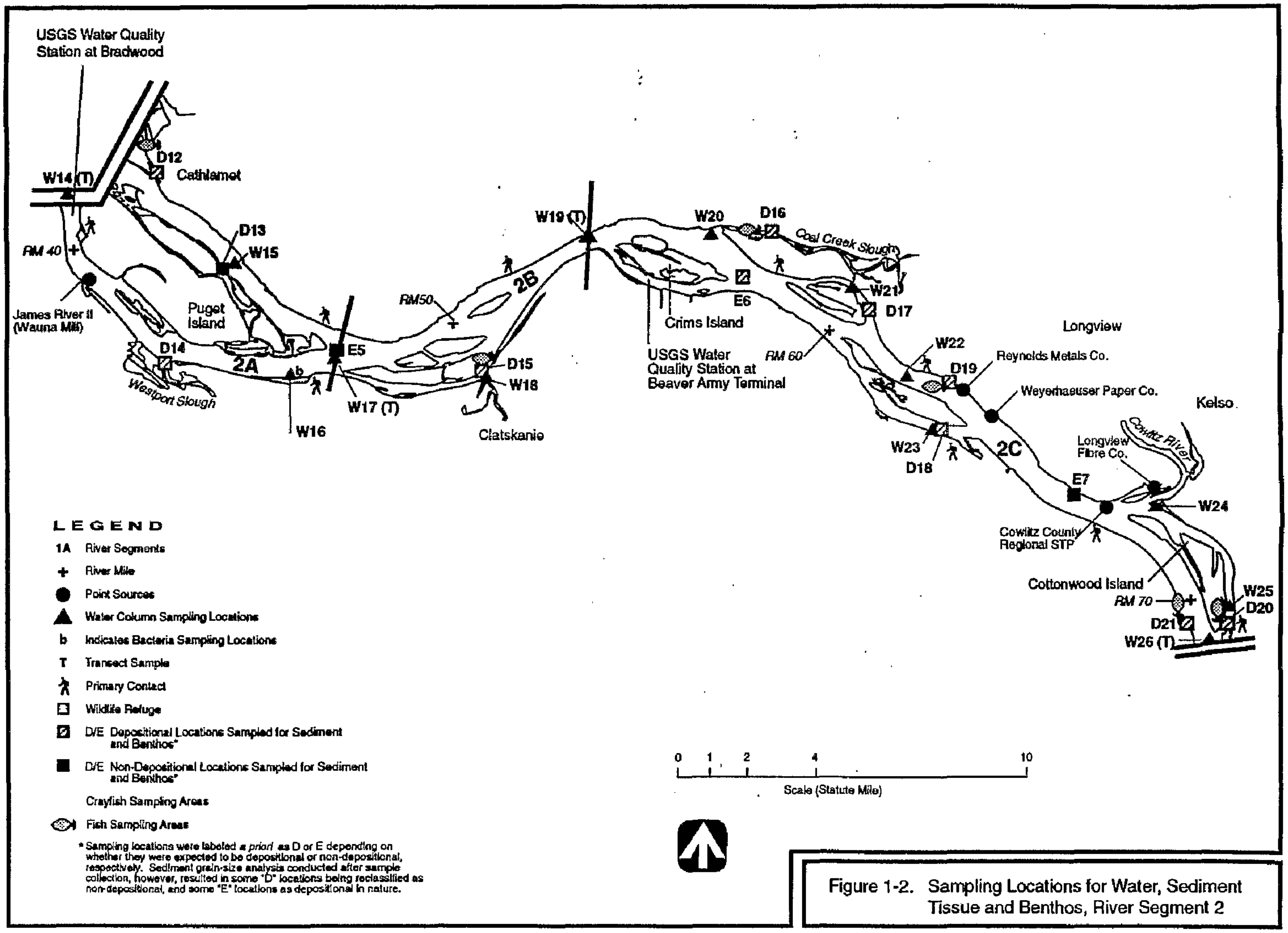
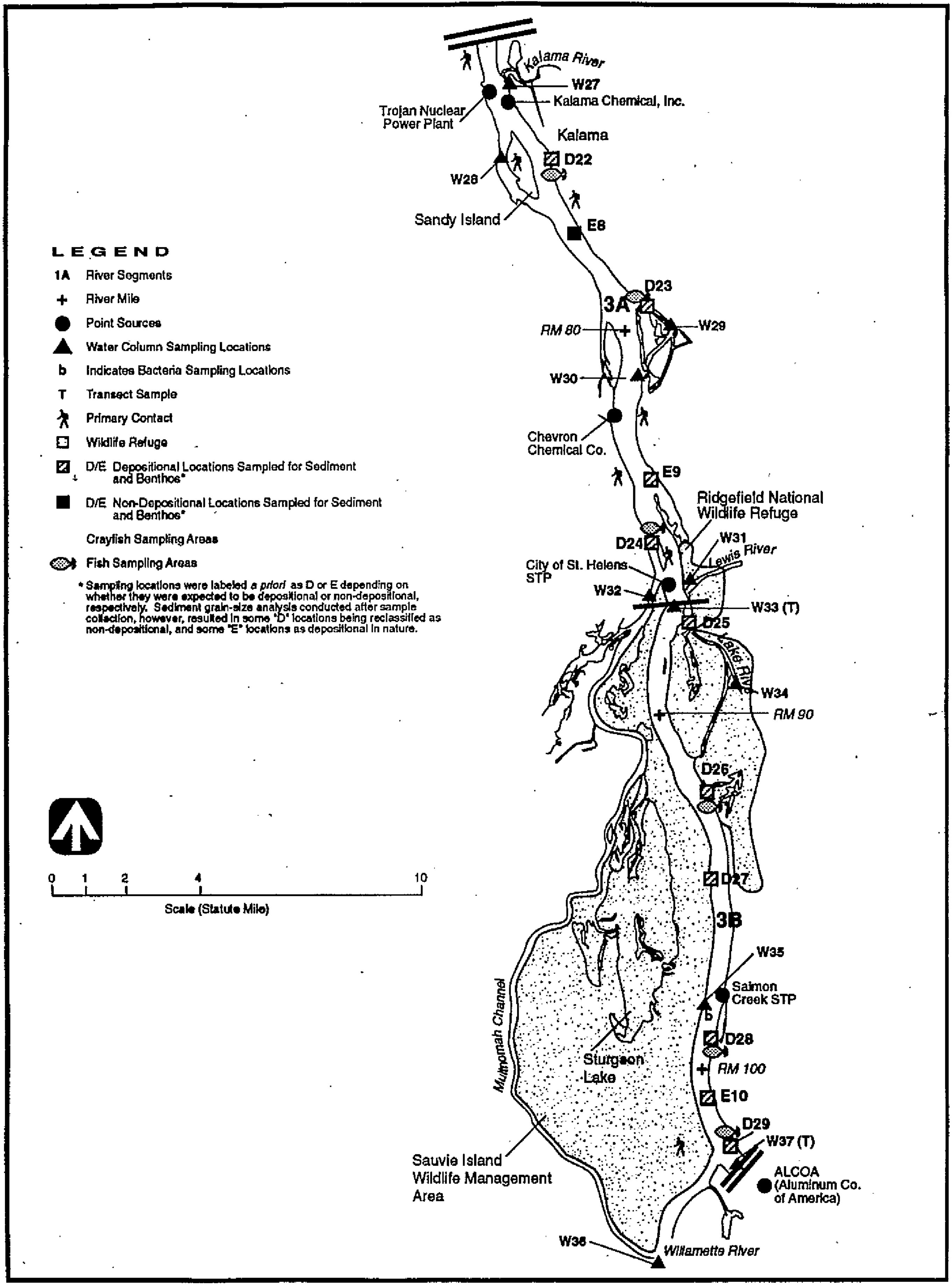
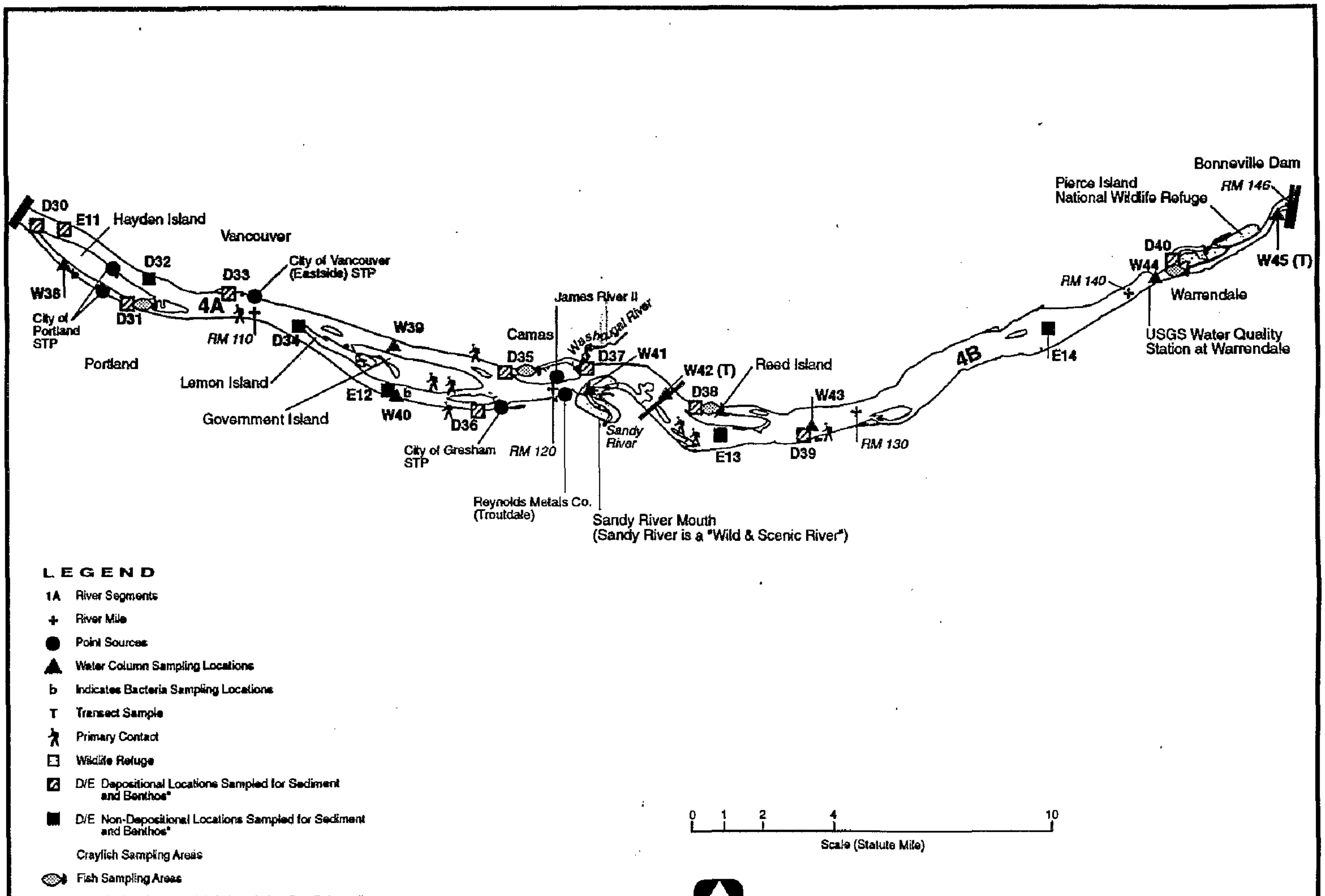


Figure 1-2. Sampling Locations for Water, Sediment Tissue and Benthos, River Segment 2



* Sampling locations were labeled *a priori* as D or E depending on whether they were expected to be depositional or non-depositional, respectively. Sediment grain-size analysis conducted after sample collection, however, resulted in some "D" locations being reclassified as non-depositional, and some "E" locations as depositional in nature.

Figure 1-3. Sampling Locations for Water, Sediment, Tissue and Benthos, River Segment 3



* Sampling locations were labeled *a priori* as D or E depending on whether they were expected to be depositional or non-depositional, respectively. Sediment grain-size analysis conducted after sample collection, however, resulted in some "D" locations being reclassified as non-depositional, and some "E" locations as depositional in nature.

Figure 1-4. Sampling Locations for Water, Sediment, Tissue and Benthos, River Segment 4

TABLE 1-1. CHEMICALS OF CONCERN ANALYZED IN VARIOUS MEDIA DURING THE LOWER COLUMBIA RECONNAISSANCE SURVEY

(Page 1 of 7)

Compound	Number of Samples (Excluding Duplicates)		
	Water	Sediments	Tissues
METALS AND CYANIDE			
Aluminum	45	54	
Antimony[a]	45	54	72
Arsenic[a,b]	45	54	72
Barium	45	54	72
Beryllium[a]	45	54	
Cadmium[a,b]	45	54	72
Chromium[a]	45	54	
Copper[a,b]	45	54	72
Iron	45	54	
Lead[a,b]	45	54	72
Mercury[a,b,d]	45	54	72
Nickel[a]	45	54	72
Selenium[a,b,d]	45	54	72
Silver[a]	45	54	72
Thallium[a]	45	54	
Zinc[a,b,d]	45	54	72
Cyanide[a]	45	54	
ORGANOTINS		10	
VOLATILES			
Vinyl chloride[a]	5		
Methylene chloride[a]	5		
1,1-Dichloroethane[a]	5		
Chloroform[a]	5		
1,1,1-Trichloroethane[a]	5		
Bromodichloromethane	5		
trans-1,3-Dichloropropene	5		
Dibromochloromethane[a]	5		
Benzene[a]	5		
Bromoform[a]	5		

TABLE 1-1. CHEMICALS OF CONCERN ANALYZED IN VARIOUS MEDIA DURING THE LOWER COLUMBIA RECONNAISSANCE SURVEY

(Page 2 of 7)

Compound	Number of Samples (Excluding Duplicates)		
	Water	Sediments	Tissues
Tetrachloroethene[a]	5		
Chlorobenzene[a]	5		
Total xylenes	5		
Chloroethane[a]	5		
1,1-Dichloroethene	5		
trans-1,2-Dichloroethene[a]	5		
1,2-Dichloroethane[a]	5		
Carbon tetrachloride[a]	5		
1,2-Dichloropropane[a]	5		
Trichloroethene[a]	5		
1,1,2-Trichloroethane[a]	5		
cis-1,3-Dichloropropene	5		
1,1,2,2-Tetrachloroethane[a]	5		
Toluene[a]	5		
Ethylbenzene[a]	5		
Methyl chloride[a]	5		
Methyl bromide[a]	5		
ADSORBABLE ORGANIC HALOGENS (AOX)	19		
ACID EXTRACTABLE ORGANICS (SEMIVOLATILES)			
Phenolic Compounds			
Phenol[a]	5	54	72
2-Methylphenol	5	54	
4-Methylphenol	5	54	
2,4-Dimethylphenol[a]	5	54	
Pentachlorophenol[a]	5	54	72
2-Chlorophenol[a]	5	54	72
2,4-Dichlorophenol[a]	5	54	72
2,4-Dinitrophenol[a]	5	54	72
2-Nitrophenol[a]	5	54	72

TABLE 1-1. CHEMICALS OF CONCERN ANALYZED IN VARIOUS MEDIA DURING THE LOWER COLUMBIA RECONNAISSANCE SURVEY
(Page 3 of 7)

Compound	Number of Samples (Excluding Duplicates)		
	Water	Sediments	Tissues
4-Nitrophenol[a]	5	54	
2,4,6-Trichlorophenol[a]	5	54	72
BASE/NEUTRAL EXTRACTABLE ORGANICS (SEMIVOLATILES)			
Halogenated Ethers (Other than those listed elsewhere)			
bis(2-chloroethyl)ether[a]	5	54	72
bis(2-chloroethoxy)methane[a]	5	54	72
bis(2-chloroisopropyl)ether[a]	5	54	72
4-Bromophenylphenylether[a]	5	54	72
4-Chlorophenylphenylether[a]	5	54	72
Nitroaromatics			
2,4-Dinitrotoluene[a]	5	54	72
2,6-Dinitrotoluene[a]	5	54	72
Nitrobenzene[a]	5	54	72
Nitrosamines			
N-nitroso-di-n-propylamine[a]	5	54	72
N-nitrosodiphenylamine[a]	5	54	72
Chlorinated Naphthalene			
2-Chloronaphthalene[a]	5	54	72
Polynuclear Aromatics			
Acenaphthene[a]	5	54	72
Acenaphthylene[a]	5	54	72
Anthracene[a]	5	54	72
Benzo(a)anthracene[a]	5	54	72
Benzofluoranthenes(b,k)[a]	5	54	72
Benzo(a)pyrene[a]	5	54	72
Benzo(g,h,i)perylene[a]	5	54	72
Chrysene[a]	5	54	72
Dibenzo(a,h)anthracene[a]	5	54	72
Fluoranthene[a]	5	54	72
Fluorene[a]	5	54	72

TABLE 1-1. CHEMICALS OF CONCERN ANALYZED IN VARIOUS MEDIA DURING THE LOWER COLUMBIA RECONNAISSANCE SURVEY
(Page 4 of 7)

Compound	Number of Samples (Excluding Duplicates)		
	Water	Sediments	Tissues
Indeno(1,2,3-cd)pyrene[a]	5	54	72
Naphthalene[a]	5	54	72
Phenanthrene[a]	5	54	72
Pyrene[a]	5	54	72
Chlorinated Benzenes			
1,3-Dichlorobenzene[a]	5	54	72
1,2-Dichlorobenzene[a]	5	54	72
1,4-Dichlorobenzene[a]	5	54	72
1,2,4-Trichlorobenzene[a,d]	5	54	72
Hexachlorobenzene[a,d]	5	54	72
Hexachlorinated Organic Compounds			
Hexachlorobutadiene[a,d]	5	54	72
Hexachloroethane[a]	5	54	72
Hexachlorocyclopentadiene[a]	5	54	72
Benzidines			
3,3'-Dichlorobenzidine[a,e]	5	54	72
Phthalate Esters			
Dimethylphthalate[a]	5	54	72
Diethylphthalate[a]	5	54	72
Di-n-butylphthalate[a]	5	54	72
Butylbenzylphthalate[a]	5	54	72
bis-2-(ethylhexyl)phthalate[a,e]	5	54	72
Di-n-octylphthalate[a]	5	54	72
PESTICIDES/PCBs			
Pesticides			
o,p'-DDE	5	54	72
o,p'-DDD	5	54	72
o,p'-DDT	5	54	72
4,4'-DDT[a,b,c,e]	5	54	72

TABLE 1-1. CHEMICALS OF CONCERN ANALYZED IN VARIOUS MEDIA DURING THE LOWER COLUMBIA RECONNAISSANCE SURVEY

(Page 5 of 7)

Compound	Number of Samples (Excluding Duplicates)		
	Water	Sediments	Tissues
4,4'-DDE[a,b,c,d,e]	5	54	72
4,4'-DDD[a,b,c,e]	5	54	72
Heptachlor[a,b,c,d,e]	5	54	72
Heptachlor epoxide[a,b,c,d,e]	5	54	72
Total chlordane[a,b,c,d,e]	5	54	72
Aldrin[a,b,e]	5	54	72
Dieldrin[a,b,c,d,e]	5	54	72
Mirex (dechlorane)[b]	5	54	72
Dacthal[b]	5	54	72
Dicofol	5	54	72
Methyl parathion	5	54	72
Parathion	5	54	72
Malathion	5	54	72
Toxaphene[a,b,e]	5	54	72
Isophorone[a]	5	54	72
Endosulfan I[a]	5	54	72
Endosulfan II[a]	5	54	72
Endosulfan sulfate[a]	5	54	72
Endrin[a,b,c,d]	5	54	72
Endrin aldehyde[a]	5	54	72
Methoxychlor	5	54	72
alpha-BHC[a,b,c,d,e]	5	54	72
beta-BHC[a,e]	5	54	72
delta-BHC[a]	5	54	72
gamma-BHC (Lindane)[a,b,c,d,e]	5	54	72
PCBs			
Aroclor 1016[a,c,e]	5	54	72
Aroclor 1221[a,c,e]	5	54	72
Aroclor 1232[a,c,e]	5	54	72

TABLE 1-1. CHEMICALS OF CONCERN ANALYZED IN VARIOUS MEDIA DURING THE LOWER COLUMBIA RECONNAISSANCE SURVEY
(Page 6 of 7)

Compound	Number of Samples (Excluding Duplicates)		
	Water	Sediments	Tissues
Aroclor 1242[a,b,c,e]	5	54	72
Aroclor 1248[a,b,c,e]	5	54	72
Aroclor 1254[a,b,c,e]	5	54	72
Aroclor 1260[a,b,c,e]	5	54	72
DIOXINS AND FURANS			
2,3,7,8-TCDD[a,c,d,e]		20	44
1,2,3,7,8-PeCDD[c,d]		20	44
1,2,3,4,7,8-HxCDD[d]		20	44
1,2,3,6,7,8-HxCDD[c,d]		20	44
1,2,3,7,8,9-HxCDD[d]		20	44
1,2,3,4,6,7,8-HpCDD[c,d]		20	44
Octachlorodibenzo-p-dioxin[c]		20	44
2,3,7,8-TCDF[c,d]		20	44
1,2,3,7,8-PeCDF[c,d]		20	44
2,3,4,7,8-PeCDF[d]		20	44
1,2,3,4,7,8-HxCDF[d]		20	44
1,2,3,7,8,9-HxCDF[d]		20	44
1,2,3,6,7,8-HxCDF[d]		20	44
2,3,4,6,7,8-HXCDF[d]		20	44
1,2,3,4,6,7,8-HpCDF[d]		20	44
1,2,3,4,7,8,9-HpCDF[d]		20	44
Octachlorodibenzofuran		20	44
RADIONUCLIDES			
Americium-241		6	
Cesium 137		6	
Cobalt-60		6	
Europium-152		6	
Europium-155		6	

TABLE 1-1. CHEMICALS OF CONCERN ANALYZED IN VARIOUS MEDIA DURING THE LOWER COLUMBIA RECONNAISSANCE SURVEY

(Page 7 of 7)

Compound	Number of Samples (Excluding Duplicates)		
	Water	Sediments	Tissues
Plutonium-238		6	
Plutonium-239/240		6	
CONVENTIONALS[f]			
Nitrogen (TKN, NO_3, NO_2, NH_4)	45		
Phosphorus	45		
Total suspended solids	45		
Hardness	45		
Total organic carbon	5	54	
Grain size		54	
Acid volatile sulfides		54	
Total solids		54	
Lipids			72
BACTERIA[g]			
Fecal coliform	30		
Enterococcus	30		

[a] Priority pollutants.

[b] Target compounds of U.S. Fish and Wildlife Service bioconcentration study (Schmitt and Brumbaugh 1990, Schmitt et al. 1990).

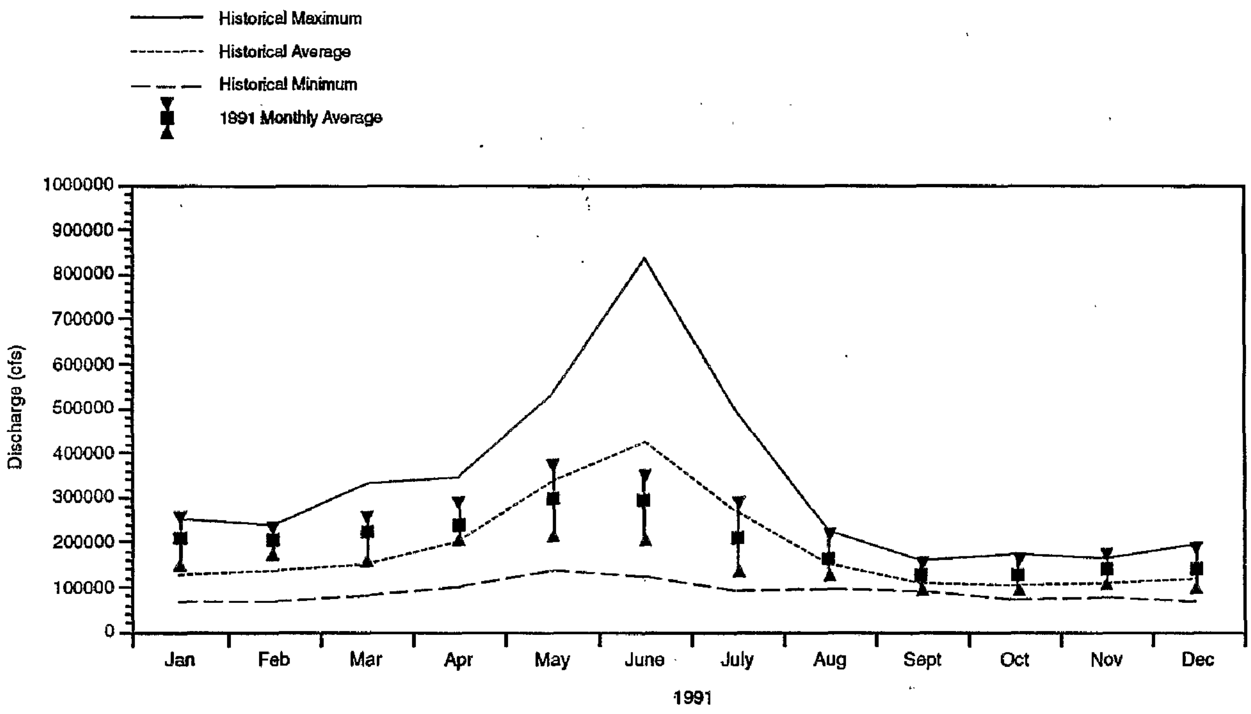
[c] Currently monitored by Oregon Department of Environmental Quality.

[d] Bioconcentrating compounds monitored in the National Bioaccumulation Study (U.S. EPA 1991a).

[e] Chemicals of highest concern listed by U.S. EPA (1991b).

[f] The following measurements were taken at each station in the field: pH, dissolved oxygen, conductivity, water temperature, and turbidity.

[g] Six shore-based bacteria stations were sampled five times over a 30-day period.



Source: Williams and Pearson 1985a, Hubbard et al. 1992, and U.S. Geological Survey, unpublished provisional data.

Figure 1-5. Historical and 1992 Discharge Data for the Columbia River at The Dalles, OR

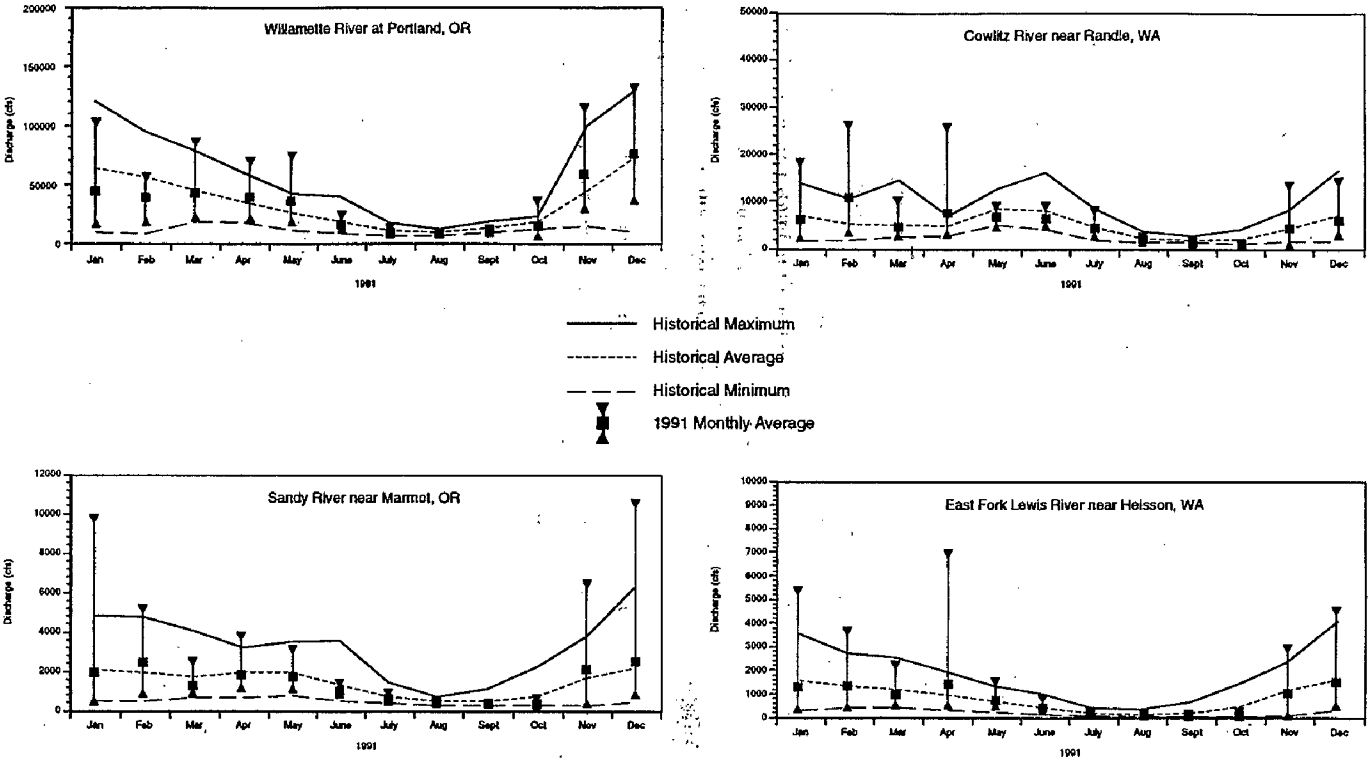
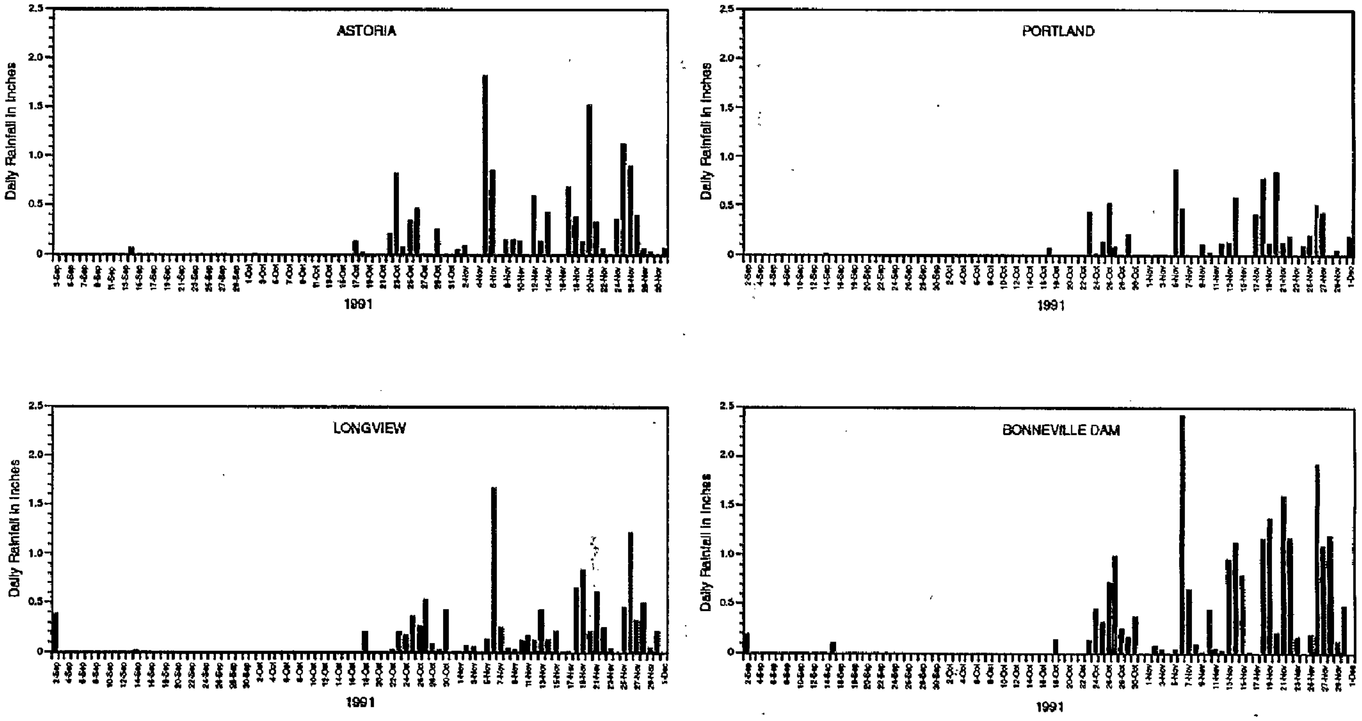


Figure 1-6. Historical and 1991 Discharge Data for the Willamette, Cowlitz, Sandy, and East Fork Lewis Rivers.



Source: NOAA, Climatological Data for Oregon and Washington, 1991.

Figure 1-7. Daily Rainfall at Astoria, Longview, Portland, and Bonneville Dam During the Period of Reconnaissance Survey Sampling.

rainfall) typical of the lower river. This USGS station, however, is the only monitoring station in the lower river with complete discharge information. The provisional discharge data from the USGS monitoring station at Beaver Army Terminal (RM 53.8) are incomplete and not adequate for characterization of discharge in the lower river during October and November of 1991. Discharge data at The Dalles may be fairly representative of conditions at Bonneville Dam, however, since no large tributaries discharge to the Columbia River between The Dalles and Bonneville Dam. Based on the USGS data, monthly average discharge was slightly above the historical average, ranging from 123,300 cubic feet per second (cfs) in September to 137,800 cfs in November, 1991 (see Figure 1-5). The average monthly flow during the water column sampling portion of the survey (September through October) was 124,000 cfs, and the monthly average flow during the entire survey period (September through November) was 128,600 cfs. The maximum and minimum daily average flow for September and October were within historical ranges, but the maximum reported flow for November (171,000 cfs) was slightly higher than the historically recorded maximum (162,700 cfs) (see Figure 1-5).

Monthly average, maximum, and minimum discharge of the four largest lower Columbia River tributaries (Willamette, Cowlitz, East Fork Lewis, and Sandy rivers) for 1991 is compared with their historical average, maximum, and minimum discharge in Figure 1-6. Monthly average, maximum, and minimum discharge in September were within historical measurements. In October and November, however, monthly average, minimum and maximum flows were higher than historical measurements (see Figure 1-6). Higher than normal maximum flows in October and November were due to the higher than normal rainfall that began in mid-October and continued throughout the latter period of the reconnaissance survey (see Figure 1-7). September and October average, maximum, and minimum monthly discharges recorded on the Sandy, East Fork Lewis, and Cowlitz rivers were much lower than historical measurements. In November, the average monthly discharge of these rivers was close to the historical average for those rivers, but the monthly maximum flow was much greater than the historically recorded maximum (see Figure 1-6). Again, the higher than normal maximum flow measured in November was due to higher than normal rainfall that began in mid-October. The lower maximum flows measured in October, relative to historical data on these rivers, may have been due to storage of the initial rainfall in upstream impoundments.

The vessel-based sediment and water sampling portion of the reconnaissance survey (23 September to 16 October 1991) was conducted during an extended period without rainfall (see Figure 1-7). However, the bacterial and fish sampling efforts (15 October to 14 November) were conducted during a relatively wet period of heavy rainfall throughout the study area (see Figure 1-7). Total monthly rainfall in September measured at Astoria, Longview, Portland, and Bonneville Dam was 1.6 to 3.0 inches less than normal (Table 1-2). Although measurable rainfall was recorded during the latter half of October, total monthly rainfall recorded at the four monitoring locations was 1.5 to 3.8 inches less than normal (Table 1-2). However, rain fell throughout the study area in September and total monthly rainfall at the four locations was 0.7 to 2.7 inches greater than normal (Table 1-2).

1.3 REPORT ORGANIZATION

This report presents and interprets the results of the lower Columbia River reconnaissance survey; it is organized by the type of environmental medium surveyed (i.e., water, sediment, and tissue contaminant levels; and benthic community assessment). The results for each medium are presented separately due to the differences in sampling strategy, available reference values or criteria, and the types of analyses conducted among the media. This reporting method facilitates assessment of the state of each medium over the entire study area. Depending on the medium sampled, the levels of contaminants measured were reported, the levels were compared to available criteria or reference values, and problem chemicals and problem areas within the study area were identified. The benthic community assessment characterized the benthic communities present at the sampling locations, and correlations between several environmental variables were explored (e.g., salinity, grain size, and sediment organic carbon content) to explain the variation in the benthic communities that were identified.

The single water column samples collected for the reconnaissance survey are poor indicators of overall water quality in rivers due to (1) the transitory nature of river water and (2) the typically low concentrations of toxic substances in the water column. These concentrations are often below the detection limits of conventional analytical techniques. However, water column criteria are generally well established for water for a variety of toxic compounds and elements. The reconnaissance survey water column data collected during this study were of limited utility for identifying problem chemicals and areas of concern within the study area. The water column data were also limited for identifying the relationship between water contamination and potential effects to aquatic and terrestrial biota or humans, due to the limited parameters that were detected above the laboratory detection limits. Also due to the limited

TABLE 1-2. MONTHLY (SEPTEMBER-NOVEMBER 1991) RAINFALL AT FOUR LOCATIONS ALONG THE LOWER COLUMBIA RIVER

Month	Astoria		Longview		Portland		Bonneville Dam	
	Rainfall (inches)	Departure From Normal (inches)	Rainfall (inches)	Departure From Normal (inches)	Rainfall (inches)	Departure From Normal (inches)	Rainfall (inches)	Departure From Normal (inches)
September	0.007	-3.04	0.41	-1.80	0.02	-1.59	0.29	-2.65
October	2.44	-3.77	2.34	-1.73	1.51	-1.54	3.58	-2.77
November	10.53	+0.65	8.84	+2.56	6.36	+1.19	6.97	+2.43

Source: NOAA, Climatological Data for Washington and Oregon, 1991.

number of detected contaminant concentrations, it was not possible to compare the relative concentrations of contaminants among the stations sampled.

Sediments, especially those in depositional areas that collect the fine sediments that tend to be associated with toxic contaminants, are generally considered to be a good indicator of long-term water quality. Sediments are the record of inputs of toxic substances from point and nonpoint sources to the river. Since toxic substances become concentrated in the sediments, detection of many of the toxic constituents is possible with conventional laboratory techniques. However, sediment criteria or guidelines available for comparison have only recently been developed and are often limited by the medium covered (marine vs. freshwater) and/or the number of chemicals for which standards have been developed. Several sediment standards are also only in the draft stage of development (e.g., state of Washington freshwater sediment standards, EPA sediment criteria). Therefore, identification of potential effects to aquatic and terrestrial biota and human health was much more difficult. Vessel-based sediment sampling during the low-flow period also hampered efforts to enter and collect fine sediments from quiescent areas away from the main channel of the river. However, since many of the toxic constituents were detected, differences among stations could be evaluated. When this information was coupled with the limited sediment standards that were available, both potential problem areas and problem contaminants could be identified.

Tissue contaminant concentrations are also a good indicator of environmental quality since this is a direct measure of the amount of contaminant accumulated by the biota. If the sampled biota spend long periods in a single location in the river, the tissue contaminant levels should reflect long-term exposure to contaminants in a locally polluted area. However, regulatory criteria or guidelines are poorly developed for tissue contaminant levels; this makes it difficult to assess the relative significance of the measured contaminant levels in tissues. However, tissue contaminant levels are of direct concern for human consumption of commercial and game species and of direct concern to carnivorous wildlife, especially fish and birds, that live within and along the river. Therefore, contaminant levels of commercially important fish (e.g., sturgeon and crayfish), fish that are likely important food for piscivorous fish, birds, and mammals (e.g., peamouth and largescale sucker), and fish with a high lipid content (e.g., peamouth and carp) were selected for sampling. Since many of the organic contaminants accumulate in the fat of organisms, animals with higher fat content are likely to accumulate higher contaminant levels. To identify potential problem areas and problem contaminants. Tissue contaminant levels from this study were then compared to tissue contaminant levels measured in national bioaccumulation studies, and available guidance values for tissue contaminant levels were established for the protection of piscivorous wildlife.

Benthic community structure can be an effective means of assessing environmental quality when the influence of both physical and chemical variables are accounted for in the assessment. A presumably unaffected reference area of similar physical character is often chosen for comparison to the potentially affected locations. However, regulatory criteria or guidance are not yet well developed to facilitate the assessment of environmental quality based on benthic community structure. Analysis of sediment benthic community structure was therefore conducted to achieve a broad-scale characterization of the benthic invertebrate communities of the lower river. The data on invertebrate communities were then coupled with physical and chemical data to establish ecological zones in the river. A preliminary assessment was also made to identify individual taxa that could be useful indicators of environmental stress in specific ecological zones of the lower river.

The sections for each medium are also accompanied by a brief review of the quality of the data used in this report. Data that did not meet the quality objectives of this study have been qualified appropriately or have been rejected and not used in this report. The qualification of data does not imply that the overall quality of the data is poor, but it alerts future investigators to the level of confidence in the data reported. The reader should realize that the measurement of trace amounts of environmental contaminants is not a simple exercise and that measurements may be complicated by concentrations of constituents that are at, or very near, the detection limits of conventional laboratory methods and matrix interferences in the media studied. Therefore, results that are acceptable based on currently accepted sampling and analytical protocols and available quality assurance information may be questioned following further investigations and/or improvements in analytical technology.

Results of the water column characterization survey are provided in Section 2.0. Section 3.0 presents the results of the sediment chemistry survey. Tissue bioaccumulation results are presented in Section 4.0 and benthic community assessment results in Section 5.0. Section 6.0 provides an overview of the major findings of the reconnaissance survey. The validated survey data for each medium and QA memoranda are available under separate cover as appendices to this report.

2.0 WATER COLUMN CHARACTERISTICS

2.1 INTRODUCTION

Assessment of water column characteristics has traditionally played a significant role in water quality studies for several reasons. First, contaminants are introduced into aquatic environments primarily through the water column. Second, most contaminant transport in aquatic environments occurs in the suspended, dissolved, and particulate phases (Bero and Gibbs 1990). Predictions of contaminant transport therefore require some knowledge of the levels and types of contaminants in the water column. Third, although some of the suspended contaminants will be deposited in sediments, a portion will remain suspended in dissolved or particulate form for some time. The dissolved contaminants may be available for uptake and accumulation (i.e., bioconcentration) by exposed biota depending on several factors, including hydrophobicity characteristics of the contaminants (Barron 1990). Fourth, the concentration and nature of the contaminants suspended in the water column influence the environmental behavior (e.g., sorption-desorption kinetics, partitioning coefficients) of sediment-associated contaminants, thus potentially affecting bioavailability (Landrum and Robbins 1990; Farrington 1991).

Several broad-scale, conventional water quality studies of the lower Columbia River were conducted prior to 1979 (e.g., Lincoln and Foster 1943; Robeck et al. 1954; Sylvester and Carlson 1961). The earliest water quality data available for the river were reported by Van Winkle (1914). Studies of the transport of sediment (Conomos 1968; Whetten et al. 1969), nutrients (Haertel et al. 1969; Park et al. 1969, 1970, 1972) and phytoplankton (Haertel et al. 1969; Williams and Scott 1962; Williams 1964, 1972) have also been reported. Since 1979, however, water column studies in the lower Columbia River have been quite limited, both in frequency and scope (see Tetra Tech 1992a for a review of these studies). The only exceptions are the long-term USGS water quality monitoring studies at Bradwood, Oregon (1973-1980); Warrendale, Oregon (1972-present); and Beaver Army Terminal (1990-present) (see Figures 1-1 through 1-4). Other recent studies have also described the nutrient and phytoplankton ecology of the Columbia River estuary (Lara-Lara et al. 1990a,b) and organic carbon transport in the river (Dahm et al. 1981;

Hedges et al. 1984). However, most water quality studies conducted in the lower river since 1979 have been sporadic and designed to characterize water quality conditions around specific point source discharges only.

To gain a comprehensive assessment of current water quality conditions in the lower Columbia River, the Bi-State Program directed the inclusion of water column characterization as part of the lower Columbia River reconnaissance survey. The objectives of the water column sampling were to:

- Characterize levels of chemicals of concern in the water column and provide data for the development of conceptual models on contaminant transport in the river.
- Characterize levels of indicator bacteria in water near beneficial use areas.
- Characterize levels of nutrients to address concerns about potential eutrophication of the river.
- Characterize levels of conventional variables (i.e., dissolved oxygen, temperature), metals, and organic contaminants throughout the lower Columbia River and compare these levels with established criteria and standards to assess potential adverse impacts to beneficial uses.
- Characterize levels of adsorbable organic halogens (AOX) as an indicator of the influence of pulp and paper mills on the lower Columbia River.

The water column characteristics section reports on the results of the water-column sampling conducted as part of the lower Columbia River reconnaissance survey. The results are interpreted and discussed in terms of the survey objectives outlined above.

2.2 SAMPLING LOCATIONS

Forty-five water-column stations were sampled during the reconnaissance survey (Figures 1-1 through 1-4; Table 2-1). Geographic coordinates for the stations sampled by boat were obtained using a Magnavox MX200 GPS Navigator System operated by the skipper (Dr. James G. Norris) of the R/V Brendan D II. Details of the navigation system operation are provided in Section 5.1 of the final QA/QC plan (Tetra Tech 1991b). Geographic coordinates for the shore-based water column samples were obtained using a portable Trimble Transpak II GPS receiver. Geographic coordinates and corresponding river mile information for each sampling station are shown in Table 2-1.

The following survey needs were considered in selecting the water column sampling stations (Tetra Tech 1991c):

1. Obtaining broad scale coverage of the entire lower Columbia River.

2. Obtaining data that could be used to develop conceptual models for contaminant transport in the lower river.

3. Estimating pollutant contributions from the major tributaries entering the lower river.

4. Assessing water quality near to, and its potential impacts on, beneficial use areas (i.e., contact recreation and shellfish harvesting areas).

5. Assessing the impacts of point sources and major industrial areas on surrounding water column characteristics.

Based on the above considerations, the 45 water column sampling stations were positioned as follows: (a) one transect station was positioned at the upstream boundary of each identified river segment, including a station just below the Bonneville Dam at the upper end of the study area; (b) one station was located in the river's mouth at RM 0; (c) 11 stations were positioned in or just downstream of the mouths of major tributary rivers; (d) 17 stations were positioned throughout the lower river in beneficial use

TABLE 2-1. STATION LOCATIONS AND TIME OF WATER SAMPLING
FOR THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY
Page 1 of 4

Station Number	River Mile[a]	Latitude/Longitude	Sampling Date/Time	Tide	Water Depth (m)
W1	0	46-14.86N 124-05.776W	10-8-91 0855-0935	Flood	21.0
W2	1.8	46-16-50.1N 124-03-36.8W	10-15-91 1300	Flood	0.5
W3	3	46-18-09.9N 124-02-12.4W	10-15-91 1440	Flood	0.5
W4 (Skipanon River)	11	46-10.805N 123-54.543W	10-10-91 0800-0830	Ebb	6.8
W5 (Lewis and Clark River)	13	46-09.648N 123-51.333W	10-9-91 0835-0855	Flood	4.2
W6 (Transect)	13	46-11.64N 123-51.16W	10-10-91 0920-0950	Flood	16.5
		46-14.60N 123-51.94W	10-10-91 1120-1145	Flood	20.0
		46-13.67N 123-52.06W	10-10-91 1150-1215	Flood	3.0
W7 (Youngs River)	14.5	46-10.106N 123-50.337W	10-9-91 0920-0940	Flood	10.0
W8 (W50 field duplicate) (Transect)	19.5	46-16.30N 123-46.20W	10-10-91 1605-1635	Ebb	19.6
		46-13.24N 123-45.75W	10-10-91 1745-1815	Ebb	15.5
		46-13.94N 123-45.42W	10-10-91 1820-1850	Ebb	6.5
W9	22	46-17.935N 123-43.108W	10-10-91 1500-1530	Ebb	4.8
W10	23	46-10.824N 123-40.384W	10-11-91 1110-1130	Flood	9.2
W11	26	46-13.343N 123-37.256W	10-12-91 1330-1345	Flood	7.2
W12	30.5	46-14.259N 123-31.296W	10-7-91 1400-1420	Ebb	6.5
W13	32.5	46-15.917N 123-28.511W	10-11-91 1740-1800	Ebb	9.0
W14 (Transect)	37.5	46-12.900N 123-25.117W	10-6-91 1530-1550	Ebb	6.5
		46-12.497N 123-25.572W	10-6-91 1600-1620	Ebb	13.5
		46-12-14N 123-26.03W	10-6-91 1630-1650	Ebb	7.5

TABLE 2-1. STATION LOCATIONS AND TIME OF WATER SAMPLING FOR THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

Page 2 of 4

Station Number	River Mile[a]	Latitude/Longitude	Sampling Date/Time	Tide	Water Depth (m)
W15	44	46-10.93N 123-21.14W	10-6-91 1025-1045	Flood	16.0
W16	46.5	46-08-21.2N 123-19-07.4W	10-15-91 1755	Flood	0.5
W17 (Transect)	47.5	46-09.89N 123-17.64W	10-6-91 1125-1145	Flood	6.5
		46-08.68N 123-17.74W	10-6-91 1155-1215	Flood	13.5
		46-08.55N 123-17.75W	10-6-91 1225-1245	Flood	10.5
W18 (Clatskanie River)	50	46-09.235N 123-13.707W	10-5-91 1805-1825	Ebb	4.6
W19 (Transect)	53	46-10.922N 123-11.136W	10-5-91 1000-1030	Flood	18.0
		46-10.99N 123-11.18W	10-5-91 1040-1100	Flood	18.0
		46-11.04N 123-11.13W	10-5-91 1110-1130	Flood	17.0
W20	56	46-11.39N 123-06.91W	10-4-91 1620-1640	Ebb	7.0
W21 (W49 field duplicate)	60	46-10.12N 123-03.04W	10-4-91 1125-1155	Flood	8.0
W22	61.5	46-08.529N 123-01.953W	10-3-91 1450-1520	Ebb	15.0
W23	64	46-07.255N 123-00.287W	10-3-91 1340-1415	Ebb	4.5
W24 (Cowlitz River)	68	46-05.67N 122-55.05W	10-3-91 0945-0955	Flood	1.5
W25	71	46-04.040N 122-52.225W	10-3-91 0900-0930	Flood	5.5
W26 (W52 field duplicate) (Transect)	72	46-02.823N 122-52.948W	10-2-91 1310-1325	Ebb	14.0
		46-02.844N 122-52.817W	10-2-91 1330-1350	Ebb	13.0
		46-02.844N 122-52.691W	10-2-91 1405-1425	Ebb	13.0
W27 (Kalama River)	73	46-02.185N 122-52.554W	10-2-91 1025-1045	Flood/Slack	3.5

TABLE 2-1. STATION LOCATIONS AND TIME OF WATER SAMPLING FOR THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

Page 3 of 4

Station Number	River Mile[a]	Latitude/Longitude	Sampling Date/Time	Tide	Water Depth (m)
W28	75	46-00.553N 122-52.320W	10-1-91 1645-1715	Ebb/Slack	22.0
W29	80	45-56.863N 122-47.206W	10-1-91 1205-1235	Ebb	6.0
W30 (W48 field duplicate)	81	45-56.313N 122-48.278W	10-1-91 1050-1130	Ebb	15.0
W31 (Lewis River)	87	45-51.19N 122-46.89W	9-30-91 1520-1545	Ebb/Slack	3.4
W32 (Multnomah Channel)	87.5	45-50.92N 122-47.86W	9-30-91 1255-1315	Ebb	17.0
W33 (Transect)	88	45-50.878N 122-47.211W	9-30-91 1135-1140	Ebb	12.0
		45-50.91N 122-47.90W	9-30-91 1155-1210	Ebb	15.9
		45-50.91N 122-47.01W	9-30-91 1225-1235	Ebb	16.0
W34 (Lake River)	89.5	45-49.25N 122-45.25W	9-30-91 1435-1455	Ebb	4.5
W35	98	45-42-23.6N 122-46-20.0W	10-16-91 1045	Flood	0.4
W36 (Willamette River)	101.5 (6)[b]	45-36.381N 122-47.047W	9-28-91 1600-1620	Ebb	15.0
W37 (W47 field duplicate) (Transect)	102	45-39.016N 122-45.525W	9-28-91 1250-1315	Ebb	18.2
		45-39.106N 122-45.416W	9-28-91 1330-1355	Ebb	18.1
		45-39.180N 122-45.295W	9-28-91 1400-1420	Ebb	11.3
W38	104	45-38-02.5N 122-44-25.6W	10-16-91 1315	Flood/Slack	0.4
W39	115	45-35.09N 122-30.71W	9-27-91 1000-1020	Ebb	8.5
W40	115	45-33-50.0N 122-30-41.0W	10-16-91 1425	Ebb	0.4
W41 (W51 field duplicate) (Sandy River)	120	45-34.011N 122-24.507W	9-23-91 1310-1420	Ebb	11.0

TABLE 2-1. STATION LOCATIONS AND TIME OF WATER SAMPLING FOR THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY
Page 4 of 4

Station Number	River Mile[a]	Latitude/Longitude	Sampling Date/Time	Tide	Water Depth (m)
W42 (Transect)	123.5	45-33.831N 122-20.890W	9-25-91 1140-1145	Flood	4.1
		45-33.868N 122-20.776W	9-25-91 1200-1210	Flood	6.7
		45-33.920N 122-20.662W	9-25-91 1230-1240	Flood	11.9
W43	128.5	45-32.744N 122-15.574W	9-24-91 1510-1615	Flood	8.8
W44 (W46 field duplicate)	141	45-36.844N 122-01.582W	9-26-91 1110-1130	Ebb	14.0
W45 (Transect)	146	45-38.32N 121-57.40W	9-26-91 0805-0810	Ebb	8.9
		45-38.34N 121-57.47W	9-26-91 0835-0840	Ebb	8.1
		45-38.39N 121-57.49W	9-26-91 0910-0915	Ebb	8.2

[a] Approximate Columbia River Mile (to the nearest half mile) calculated from geographic coordinates.

[b] Willamette River sampled at St. Johns Bridge (Willamette River RM 6) six miles from the confluence with the Columbia River and upriver from the confluence with the Multnomah Channel (Willamette River RM 3.4).

areas, upstream and downstream of point sources, urban and industrial areas, and tributary confluences, and at the former USGS water quality monitoring station at Warrendale; (e) six shore-based sampling stations were located in shallow waters where primary contact recreation and shellfish harvesting occur. More specific details on the rationale for siting each water column station are provided in Section 4.4 and Table 3 of the final sampling plan (Tetra Tech 1991c).

During field operations, five water column sampling stations were relocated a short distance from their originally proposed locations because of navigational difficulties or to sample a more representative area. Details of these relocations are provided in Section 2.2 of the Cruise Report (Tetra Tech 1991a).

2.3 SAMPLING METHODS

With the exception of the six shore-based samples, all water column sampling was conducted concurrently with sediment and benthos sampling during the low-flow period of September 23 to October 12, 1991. Low flow was chosen as the period to assess the water quality of the river because pollutant loading from point and nonpoint sources would have the greatest potential to adversely affect water quality due to the decreased dilution capacity of the river during the low-flow period. The six shore-based samples were collected immediately after the field cruise during October 15 to November 14, 1991. The date and time of sampling at each station, and the tide (ebb or flood tide prediction adjusted to the approximate area of sampling) is provided in Table 2-1.

Vessel-based water samples were collected 1 m below the surface, 1 m above the bottom, and in between these depths using three to five proportionally spaced 2.5-Liter polycarbonate Niskin bottles. The number of bottles used depended on the river's depth at each sampling station. For stations at the upstream boundary of river segments, water samples were collected at three locations along a transect across the width of the river. These locations were at mid-channel and at points halfway between the channel center and each river bank. Water column temperature, conductivity, and dissolved oxygen levels were measured as depth profiles at 1 to 2 m intervals, depending on the depth of the river at each station. The six shore-based water samples were collected close to shore, approximately 40 cm below the surface in water 1 m deep.

All vessel-based water samples collected were composited into a single sample by emptying the contents of all Niskin bottle casts into a large 20-Liter polycarbonate carboy. The contents of the carboy were thoroughly homogenized before decanting subsamples (including samples for volatile organics) into appropriate sample containers. Samples for chemical analyses were stored on ice until delivery to the laboratories. Bacteria samples were collected five times at each of the six sampling stations over a period of 30 days, in compliance with the Oregon water quality regulations [Oregon Administrative Rules (OAR) 1992]. All bacteria samples were collected in 500 mL sterilized glass bottles and stored on ice until delivered to the appropriate laboratory for enumeration of fecal coliform and enterococcus bacteria. Phytoplankton samples were preserved with Lugol's solution and stored in the dark until analysis. Further details of sampling methods and holding times for water column parameters are available in Section 5.2 of the final QA/QC plan (Tetra Tech 1991b) and Sections 4.2 and 4.3 of the final sampling plan (Tetra Tech 1991c).

2.4 LABORATORY METHODS

Water column parameters analyzed included conventionals [i.e., temperature, conductivity, pH, dissolved oxygen (DO), total suspended solids (TSS), turbidity, chloride, fluoride, cyanide, sulfate, and hardness], nutrients [i.e., total Kjeldahl nitrogen (TKN), ammonia, total phosphorous (TP), and nitrate/nitrite], chemicals of concern (metals and organic compounds identified in Table 1-1), indicator bacteria (fecal coliforms and enterococci), phytoplankton, and total organic carbon (TOC). The stations where each parameter was analyzed are identified in Table 2-2.

Conductivity and temperature were measured using a conductivity-temperature-depth (CTD) recorder. DO was measured by lowering a probe attached to a YSI Model 51B DO meter. Temperature-corrected pH and turbidity were measured on aliquots from the composited sample using a portable pH meter (Orion SA250) and a Hach 16800 portable turbidimeter, respectively. Salinity and Sigma-t [Sigma-t=(water density-1)x1,000] were calculated from the measured temperature and conductivity profiles determined at the vessel-based water quality stations using the method of Perkin and Walker (1972). Sigma-t is a surrogate measure of water density, which is a function of temperature and salinity.

TABLE 2-2. STATIONS AT WHICH WATER COLUMN PARAMETERS WERE MEASURED

Station	Total Recoverable Metals	Conventionals	Nutrients	Chemicals of Concern	AOX	TOC	Indicator Bacteria	Phytoplankton
W1	X	X	X					X
W2	X	X	X				X	
W3	X	X	X				X	
W4	X	X	X					
W5	X	X	X		X			X
W6	X	X	X	X	X	X		X
W7	X	X	X					
W8	X	X	X					X
W9	X	X	X					X
W10	X	X	X					X
W11	X	X	X		X			
W12	X	X	X		X			X
W13	X	X	X		X			X
W14	X	X	X	X	X	X		X
W15	X	X	X					
W16	X	X	X				X	
W17	X	X	X		X			X
W18	X	X	X					X
W19	X	X	X					
W20	X	X	X		X			X
W21	X	X	X					
W22	X	X	X		X			X
W23	X	X	X					
W24	X	X	X		X			
W25	X	X	X					X
W26	X	X	X	X	X	X		
W27	X	X	X					
W28	X	X	X					X
W29	X	X	X					X
W30	X	X	X		X			
W31	X	X	X					
W32	X	X	X					
W33	X	X	X		X			X
W34	X	X	X					
W35	X	X	X		X		X	
W36	X	X	X		X			X
W37	X	X	X	X	X	X		X
W38	X	X	X				X	
W39	X	X	X		X			X
W40	X	X	X				X	
W41	X	X	X					
W42	X	X	X		X			
W43	X	X	X					X
W44	X	X	X					
W45	X	X	X	X	X	X		X

Chemicals of concern, nutrients, and conventional parameters were analyzed according to approved U.S. EPA methods listed in Table 5 of the final QA/QC plan (Tetra Tech 1991b). The only exceptions were fluoride and nitrate/nitrite, which were determined by anion chromatography, and adsorbable organic halogens (AOX), which was determined by a modification of the microcoulometric method (SM 506) outlined by the American Public Health Association (APHA 1985). There are currently no EPA-approved methods for the determination of AOX. Dioxin and furan compounds were not sampled due to the relatively great expense of these analyses and the expectation that ambient water concentrations of these compounds would be below the detection limits that could be achieved for these analyses. A typical detection limit for 2,3,7,8-TCDD (the most potent form of dioxin) is 10 pg/L, while the predicted water column concentration is likely below 0.06 pg/L (U.S. EPA 1991c, LTI and Tetra Tech 1991).

Bacteria samples were analyzed in duplicate within 24 hours of sample collection. All fecal coliform bacterial densities (with one exception) were determined using the membrane filtration method (SM 9222D) outlined by the American Public Health Association (APHA 1989). The single exception involved samples collected on November 1 and 2, 1991, which were enumerated using the most probable number (MPN) method (SM 9221C) due to laboratory technical oversight. Both methods are approved for the enumeration of fecal coliform bacteria and should provide consistent results (APHA 1989). Enterococcus bacteria were enumerated using the membrane filtration method (SM 9230C) outlined in APHA (1989). Phytoplankton biomass and species composition were determined by Jim Sweet of Aquatic Analysts in Portland, Oregon using microscope slides prepared by filtering an appropriate volume of sample through a 0.45 μm membrane filter (Guillard and Kilham 1977). Species identification, enumeration, and biovolume estimates were made using a Zeiss standard microscope (1,000x, phase contrast).

Total recoverable metals, conventional parameters, and nutrients were measured in unfiltered, whole-water samples from all 45 stations (Table 2-2). The metal extraction procedure involved heating the sample with nitric acid according to EPA method 3005 (U.S. EPA 1986b). Adsorbable organic halogens (AOX) is a measure of the adsorbable halogenated organic matter in a water sample; it includes iodated, brominated, and chlorinated organic compounds. The test measures the total molar amount of halogenated organic compounds, but does not yield information on the individual halogenated compounds present. Adsorbable organic halogens were reported as chloride (i.e., μg Cl^-/L) in samples collected at 19 stations. Chemicals of concern (excluding AOX) and TOC were measured in composite samples from five stations. Indicator bacteria were enumerated in grab samples from six stations located near beneficial use areas (i.e., contact recreation and shell fishing areas). Phytoplankton biomass and species composition were measured in composite samples from 22 stations. Specific stations where the above measurements were taken are shown in Table 2-2.

All laboratory analytical procedures for water samples were performed by contract laboratories approved by WDOE. Conventional parameters, nutrients, and metals were analyzed by Precision Analytics Incorporated of Pullman, Washington. Chemicals of concern (with the exception of metals and AOX) were analyzed by Alden Laboratories of Seattle, Washington. AOX was analyzed by Weyerhaeuser Technology Center Analytical Laboratories of Tacoma, Washington, under subcontract to Alden Laboratories. Bacteriological analyses were conducted by Coffey Laboratories, Inc., and phytoplankton samples were analyzed by Aquatic Analysts, both of Portland, Oregon.

An extensive QA/QC review of the analytical data was performed according to the data validation guidance provided in U.S. EPA (1988a,b). QA/QC reviews of the water column chemistry data included assessments of sample holding times, initial and continuing calibration, blank results, detection limits, accuracy (matrix spike, matrix spike duplicate, and surrogate recoveries, when applicable), and precision (using blind laboratory and field replicates). Complete results of the QA/QC reviews are provided in the QA memoranda in Appendix A. A brief summary of the QA/QC reviews is provided with the results in the following sections.

2.5 APPLICATION OF WATER QUALITY CRITERIA

The lower Columbia River has been designated by the state of Washington (WAC 173-201 1988, WAC 173-201A 1992) as a freshwater Class A waterbody to the mouth of the river. Therefore, the Washington State freshwater criteria apply (Butkus, S., 22 July 1992, personal communication). [Note: The state of Washington water quality standards were revised after the reconnaissance survey was conducted (adopted November 25, 1992). The most significant revisions covered the application of the metals criteria for fresh and marine waters. In this document, the 1988 water quality standards will be applied, but relevant differences between the 1988 and 1992 standards will be identified in the text and tables of the report.] The state of Oregon has promulgated specific standards for the North Coast-

Lower Columbia Basin in which freshwater, marine, and estuarine state criteria apply depending on the definition given in OAR 340-41-006 (1990) where estuarine waters are defined as "all mixed fresh and oceanic waters in estuaries of bays from the point of oceanic water intrusion inland to a line connecting the outermost points of the headlands or protective jetties." For the purposes of this report, freshwater chronic criteria will be applied to the data collected at all stations above station W8 off Tongue Point. Chronic criteria are more restrictive than acute criteria (short-term elevated levels) and were developed to protect aquatic organisms from harm due to long-term exposure to low levels of toxicants. Although conductivity measurements made at station W9 in Grays Bay also showed evidence of the influence of marine waters, this station and stations W10 and W11 just upriver of station W8, are within the Tidal Fluvial Zone defined in the Columbia River Estuary Data Development Program (CREDDP), and are strongly influenced by freshwater river inputs (Simenstad et al. 1990).

An estuary is a dynamic place where the mixing of marine and freshwater occur. Due to fluctuations in tidal heights and changes in the flow of the river, the furthest point of intrusion of marine waters varies over a period of as little as a few hours. Specific water quality criteria have been developed only for the protection of strictly marine and freshwater organisms, due to the distinct physical and chemical characters of marine and freshwater and the adaptations of the organisms that live in these environments. However, an estuary is a location where these two distinct environments overlap; a place where temporally, marine, freshwater, and estuarine organisms exist. Since criteria have not been developed for estuarine waters, and due to the transitory nature of an estuary, it is difficult to apply either marine or freshwater criteria to an estuary. Oregon considers part of the Columbia River to be an estuary; to ensure that organisms inhabiting the estuarine portion of the Columbia River are protected, the most stringent of the freshwater or marine criteria will be applied to stations W8 to W1. The only exception is for DO for which the state of Washington provides a general consideration that the marine water quality criterion shall apply when salinity is one part per thousand or greater (WAC 173-201-035, 1988). Stations W8 to W1 also fall within the Estuarine Mixing Zone defined by CREDDP (Simenstad et al. 1990).

2.6 RESULTS

This section describes the water column sampling results of the reconnaissance survey. Raw water column data are provided under separate cover in Appendices B-1 through B-20.

2.6.1 Field Parameters

All field collected data and water quality profiles are provided in Appendices B-1, B-2, and B-3. Total Suspended solids (TSS) will also be discussed in this section to facilitate comparison with field measured turbidity. TSS data are provided in Appendix B-4.

2.6.1.1 Summary of Quality Assurance/Quality Control. Field protocols, including instrument calibrations, were performed at the frequency specified in the QA/QC plan (Tetra Tech 1991b). No turbidity data were reported for two stations (W33 and W42) due to loss of power in the portable field unit. All data were acceptable for their intended use in this report.

2.6.1.2 Spatial Trends. Fifty-nine depth profiles of temperature, DO, and conductivity were determined at 39 stations. Ten of these were transect stations at which three separate depth profiles were determined. Several typical depth profiles from the survey are presented in Figures 2-1 through 2-4. Horizontal trends in field parameter values throughout the study area are also presented using the mean values determined from the depth profile data. All the water quality profiles determined during the reconnaissance survey are provided under separate cover in Appendix B-1. Raw profile data are provided in Appendix B-2.

Vertical Profiles. In general, the river above the estuarine portion is well mixed showing no density stratification due to temperature. For example, at transect station W33 (sampled on an ebb tide) below the Portland/Vancouver area, all three stations have similar temperature, Sigma-t, and DO concentration profiles with depth (see Figure 2-1). Dissolved oxygen was 9 mg/L or greater at all depths at all three stations. Measurement of DO did not always extend to the bottom due to the limited recorder cable length; it extended only to about 12 m. Temperature was approximately 19° C throughout the river at this transect.

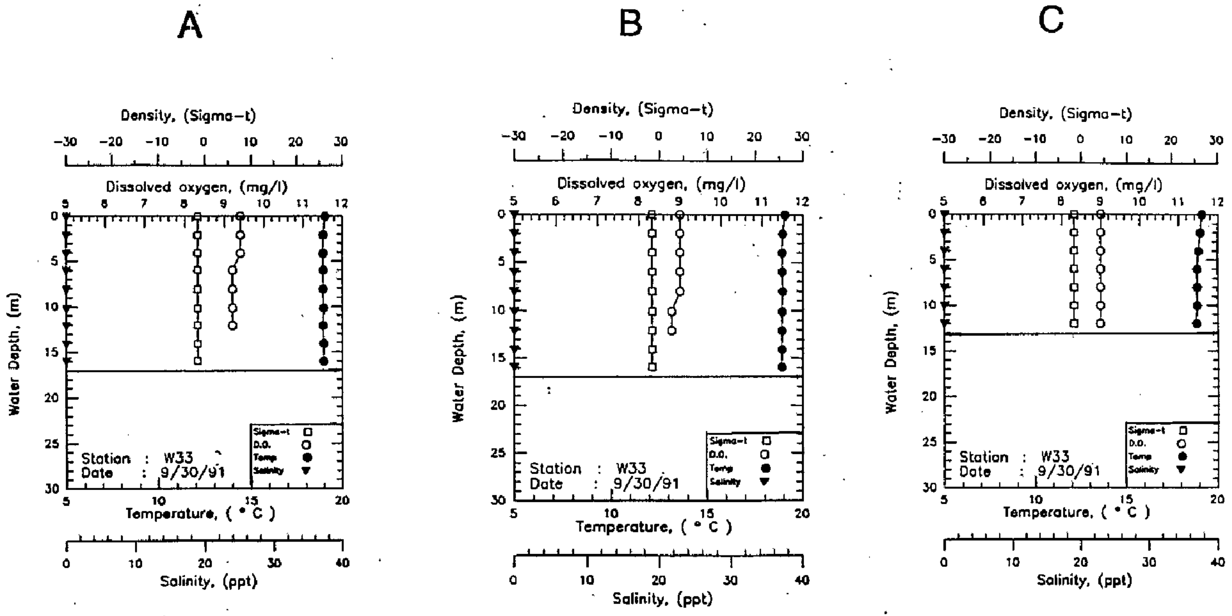


Figure 2-1. Water Column Profiles of Salinity, Sigma-t, Temperature, and Dissolved Oxygen (DO) at the Transect Station W33 (RM 88, ebb tide).
A: Washington Side; B: Mid-Channel; C: Oregon Side

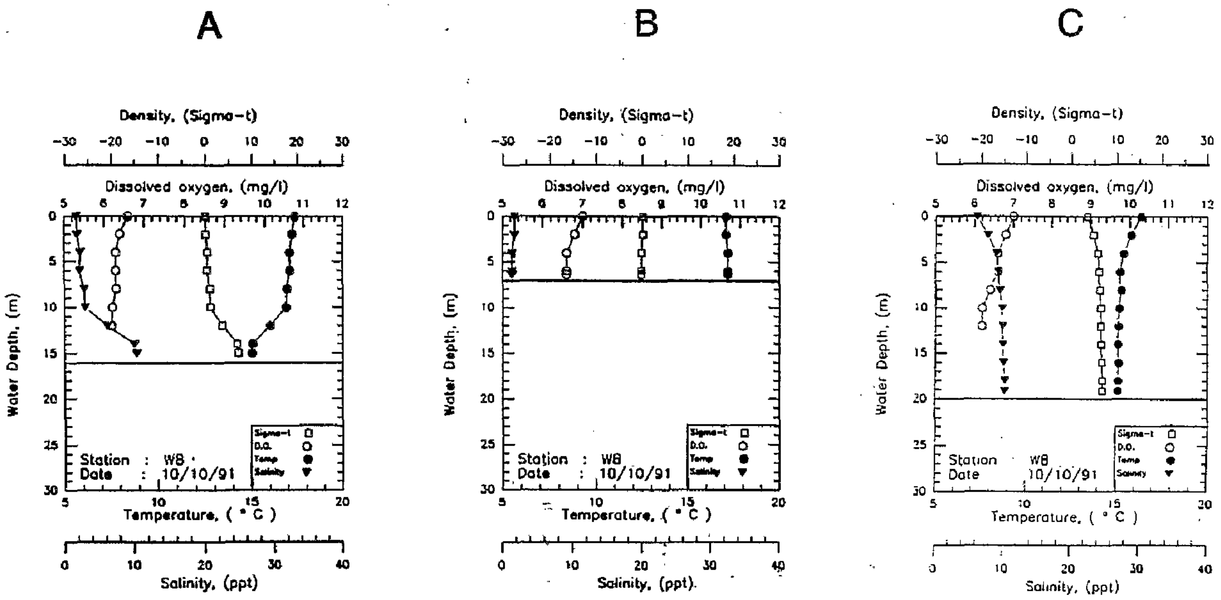


Figure 2-2. Water Column Profiles of Salinity, Sigma-t, Temperature, and Dissolved Oxygen (DO) at the Transect Station W8 (RM 19.5, ebb tide).
A: Washington Side; B: Mid-Channel; C: Oregon Side

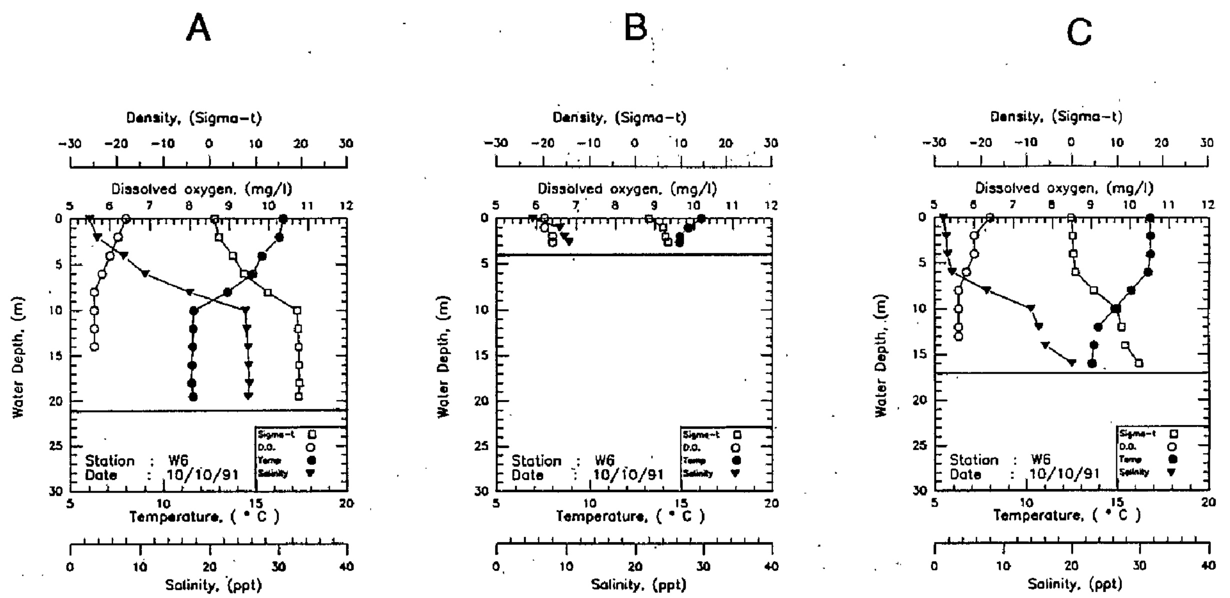


Figure 2-3. Water Column Profiles of Salinity, Sigma-t, Temperature, and Dissolved Oxygen (DO) at the Transect Station W6 (RM 13, flood tide).

A: Washington Side; B: Mid-Channel; C: Oregon Side

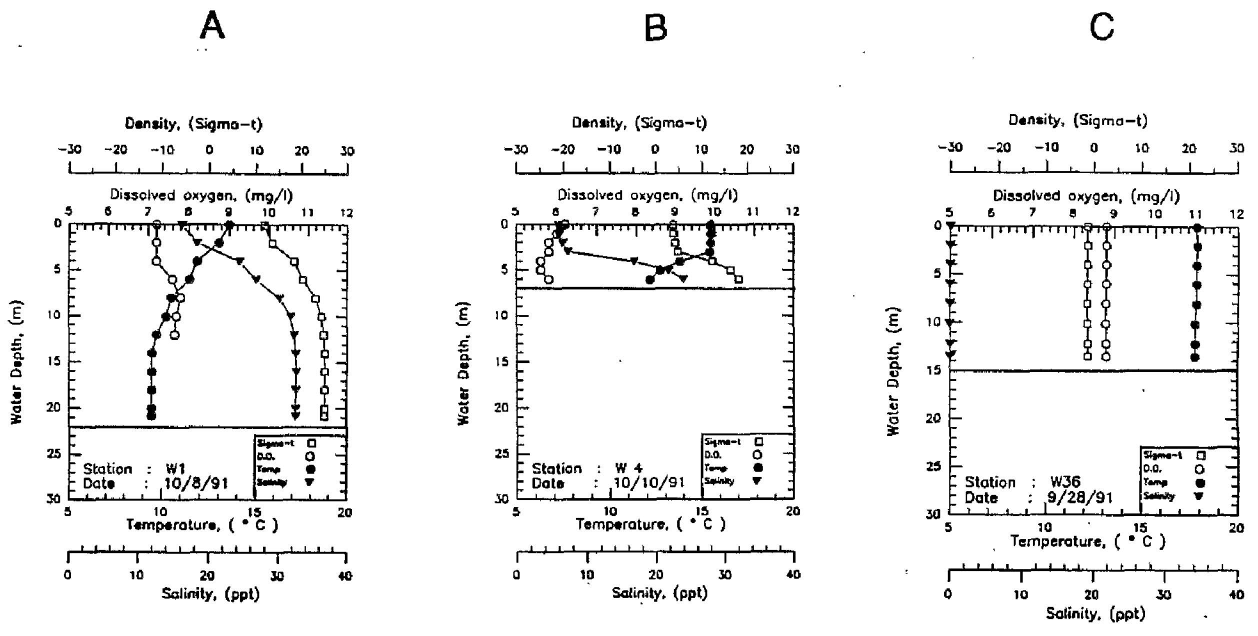


Figure 2-4. Water Column Profiles of Salinity, Sigma-t, Temperature, and Dissolved Oxygen (DO) at:
A: River Mouth Station W1 (RM 0.0, flood tide); B: Skipanon River Station W4 (RM 11, ebb tide); and C: Willamette River Station W36 (RM 101.5, ebb tide)

Evidence of salinity intrusion was observed as far upriver as transect station W8 off Tongue Point (sampled on an ebb tide). Surface water salinity ranged from 1 to 6 ppt at the surface and increased with depth to about 10 ppt at the two deeper stations on either side of the river, indicating that although some mixing of river and marine water occurred, higher salinity water was overlain by a mixture of river water and seawater (see Figure 2-2). The gradual increase of Sigma-t with depth indicated slight density stratification in the main navigational channel on the Oregon side and on the Washington side (Figures 2-2A and 2-2C). The mid-channel profile, taken in an area of extensive sand shallows (depth=7 m) showed no stratification (Figure 2-2B).

Surface DO was 6.5 to 7.0 mg/L and decreased with depth at the two deeper profiles. This decrease was most pronounced at the profile in the navigational channel off Tongue Point, where DO decreased to 6.2 mg/L at 12 m depth (see Figure 2-2C). Temperature ranged from approximately 17° C at the surface to 15° C near the bottom due to the influence of colder oceanic water.

More pronounced stratification was evident at transect station W6 (sampled on a flood tide). Surface salinity ranged from 5.5 to almost 6 ppt and increased with depth at all transect stations (Figure 2-3). Salinity and density increased with depth at all transect stations, with bottom salinities ranging from 10 to 26 ppt. Strong density stratification was noted at the transect station in the navigation channel on the Oregon side off Astoria (Figure 2-3C). DO ranged from 6.4 mg/L at the surface and decreased slightly with depth to 5.6 mg/L in the navigation channel on the Oregon side. DO increased slightly with depth at the shallower mid-channel station from 6.2 mg/L at the surface to 6.4 mg/L near the bottom. Water temperature was over 16° C at the surface and decreased to about 12° C in the deeper channel on the Washington side due to the intrusion of and mixing with colder oceanic water.

At station W1 (sampled on a flood tide) at the river mouth, a single profile was determined (Figure 2-4A). Salinity at the surface was 16 ppt, indicating the presence of river water mixed with seawater. Salinity and Sigma-t increased with depth, indicating stratification. Salinity of the bottom water was over 30 ppt indicating the influence of mostly oceanic water. DO increased gradually from 7.2 mg/L at the surface to 7.7 mg/L at 12 m. Temperature at the surface was 13.5° C and decreased to almost 9.5° C at the bottom of the profile due to the colder oceanic water.

Because of shallow water at the mouths of the various tributaries to be sampled, vessel-based sampling was only possible upstream of the mouth in the Skipanon (station W4), Lewis and Clark (W5), Youngs (W7), Clatskanie (W18), Cowlitz (W24), Lewis (W31), Lake (W34), and Willamette (W36) rivers and in the Multnomah Channel (W32). Vessel-based sampling above the mouths in the Sandy and Kalama tributaries was not possible; therefore, sampling was performed as near to the mouth as possible. The influence of estuarine waters was evident in all of the rivers sampled in the estuary (i.e., Skipanon, Lewis and Clark, and Youngs rivers). The tributaries that were sampled above the estuarine portion of the river were generally unstratified. The profiles from the Skipanon and Willamette rivers were selected as typical examples of tributary profiles in the estuary and upriver, respectively.

The Skipanon River (located in the estuary and sampled on an ebb tide) depth profile indicates the intrusion of saline water into the river (Figure 2-4B). Surface water salinity was about 6 ppt indicating some mixing of Skipanon river water with the estuary water. Temperature of the surface water was 15.5° C, decreasing with depth to about 12.1° C. DO was 6.2 mg/L at the surface and decreased slightly to 5.4 mg/L at 6 m depth.

No density stratification (sampled on an ebb tide) was apparent in the Willamette River (Figure 2-4C). Dissolved oxygen was 8.8 mg/L, and temperature was 17.9 to 17.8° C throughout the water column.

Horizontal Trends. Horizontal salinity trends across the length of the lower Columbia River are shown in Figure 2-5A. Salinity intrusion into the estuarine portion of the river was evident up to station W8 (sampled on an ebb tide) where the average salinity was 13 ppt (Figure 2-5). The average salinity in the estuary ranged from slightly less than 28.5 ppt at station W1 at the river mouth to about 6 ppt at station W5 in the Lewis and Clark River mouth (sampled on a flood tide) and at station W7 in the Youngs River mouth (sampled on a flood tide).

Above station W8, conductivity was used as a more sensitive measure of the total amount of ionic substances dissolved in the water column. Although the salinity of the water sampled at station W9 in Grays Bay (sampled on an ebb tide) was less than 1 ppt, the high conductivity measured (0.37 mMhos/cm) indicates the influence of estuarine waters at this station. The conductivity of the water in the main channel of the Columbia River was about 0.08 to 0.09 mMhos/cm, with large variations at a number of stations due to the influence of tributaries and poorly mixed waters in channels along the river (Figure 2-5B).

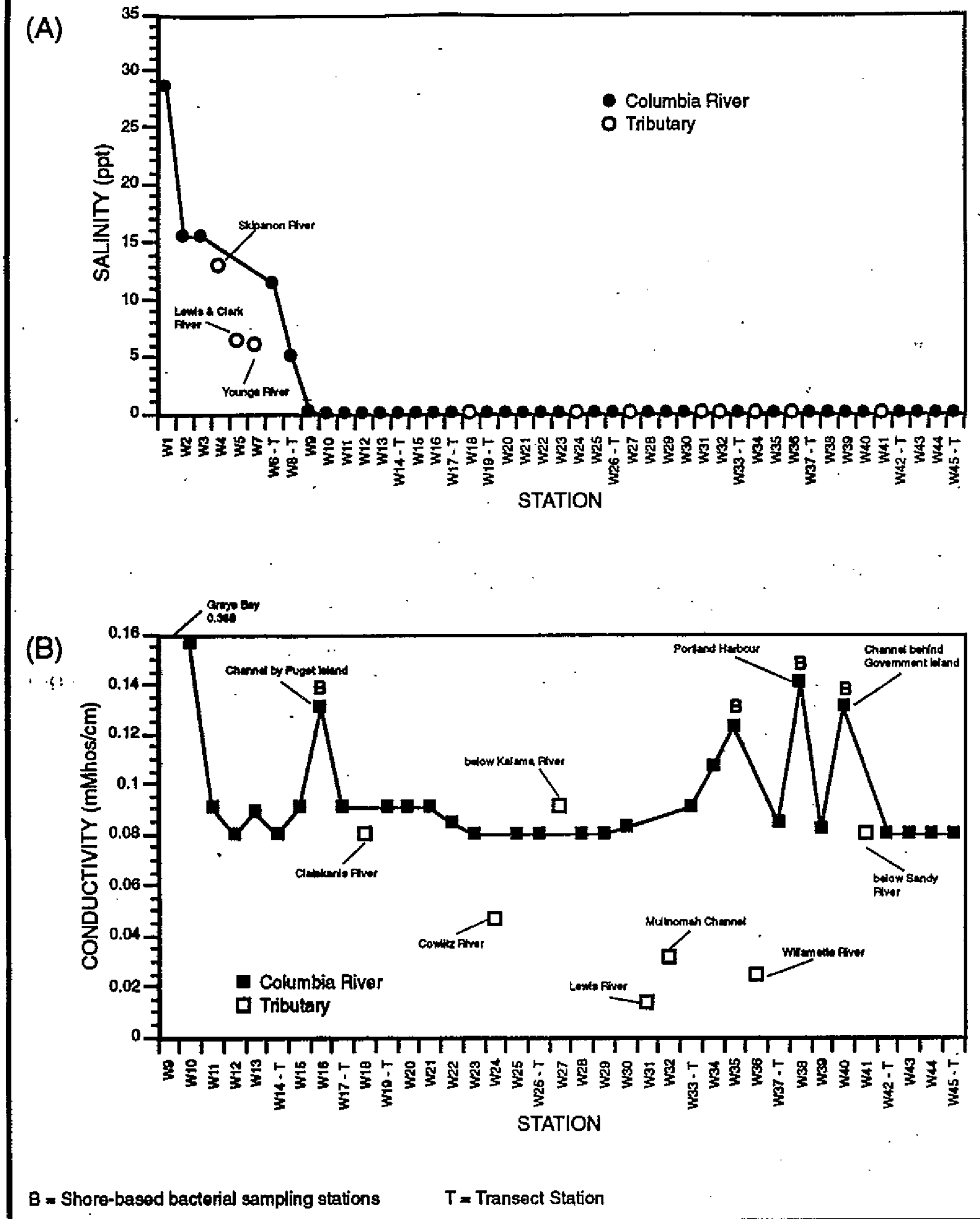


Figure 2-5. Trends in A: Salinity, and B: Conductivity in the Lower Columbia River, September - October 1991

Four peaks in conductivity were measured at the shore-based bacterial sampling stations across from Government Island (station W40), in Portland Harbor (W38), off Sauvie Island (W35), and near Puget Island (station W16). The lower conductivity of the Willamette River, Multnomah Channel, the Cowlitz River, and Clatskanie River suggest that during the sampling period, these rivers were delivering lower concentrations of dissolved ions than were to be found in the Columbia River. Rivers that likely contained higher levels of dissolved ions included Lake River (W34), and the Kalama River (W27).

Measured pH varied considerably, especially in the upper reach of the river, but with no obvious spatial trend along the length of the lower river (Figure 2-6A). The range in pH was between 7.2 to 8.4. The mean of all the measurements was 8.1 and the median was 7.7.

Turbidity is a measure of the scattering of light by suspended particles in the water. These particles are clay, silt, fine organic matter, phytoplankton, and other small organisms. Turbidity measurements ranged from as low as 1 Nephelometric turbidity unit (NTU) at station W12 to almost 35 NTU in Lake River (station W34) (Figure 2-6B). Higher turbidity was also evident in the Lewis River, which had a turbidity of 16 NTU. Higher turbidities were measured in the estuary from station W2 to station W9, ranging from over 6 to 20 NTU. The mean of all turbidity measurements was 7 NTU; the median was 6 NTU. With the exception of the two turbidity peaks in the Lake and Lewis rivers, and the higher turbidity in the estuary, turbidity in the river during the survey was generally below 10 NTU.

The concentration of total suspended solids (TSS) was highly variable. Most of the variation was possibly due to the influence of rivers, shore-based sampling points prone to sediment resuspension, and samples collected in the estuary, which generally contained more suspended sediment than that in the upper river (Figure 2-6C). The higher TSS levels in the estuary may be due to resuspension of sediments as a result of the more vigorous tidal mixing and currents. Higher TSS concentrations were measured at three of the six shore-based bacteria sampling stations. These include station W3 (60 mg/L), W16 (46 mg/L), and W40 (18 mg/L) indicating that shallow areas along the shore typically have higher TSS concentrations. Elevated TSS concentrations were also noted at station W21 in the channel behind Fisher Island (14 mg/L) and at the Lake River station W34 (29 mg/L). The concentration of TSS in the Willamette River (W36, 9 mg/L) was similar, but slightly higher than that at station W37 upriver from the confluence with the Columbia River (7.8 mg/L). Lower concentrations of TSS were noted at station W31 in the Lewis River (1.3 mg/L) and at station W20 in Coal Creek Slough (0.5 mg/L).

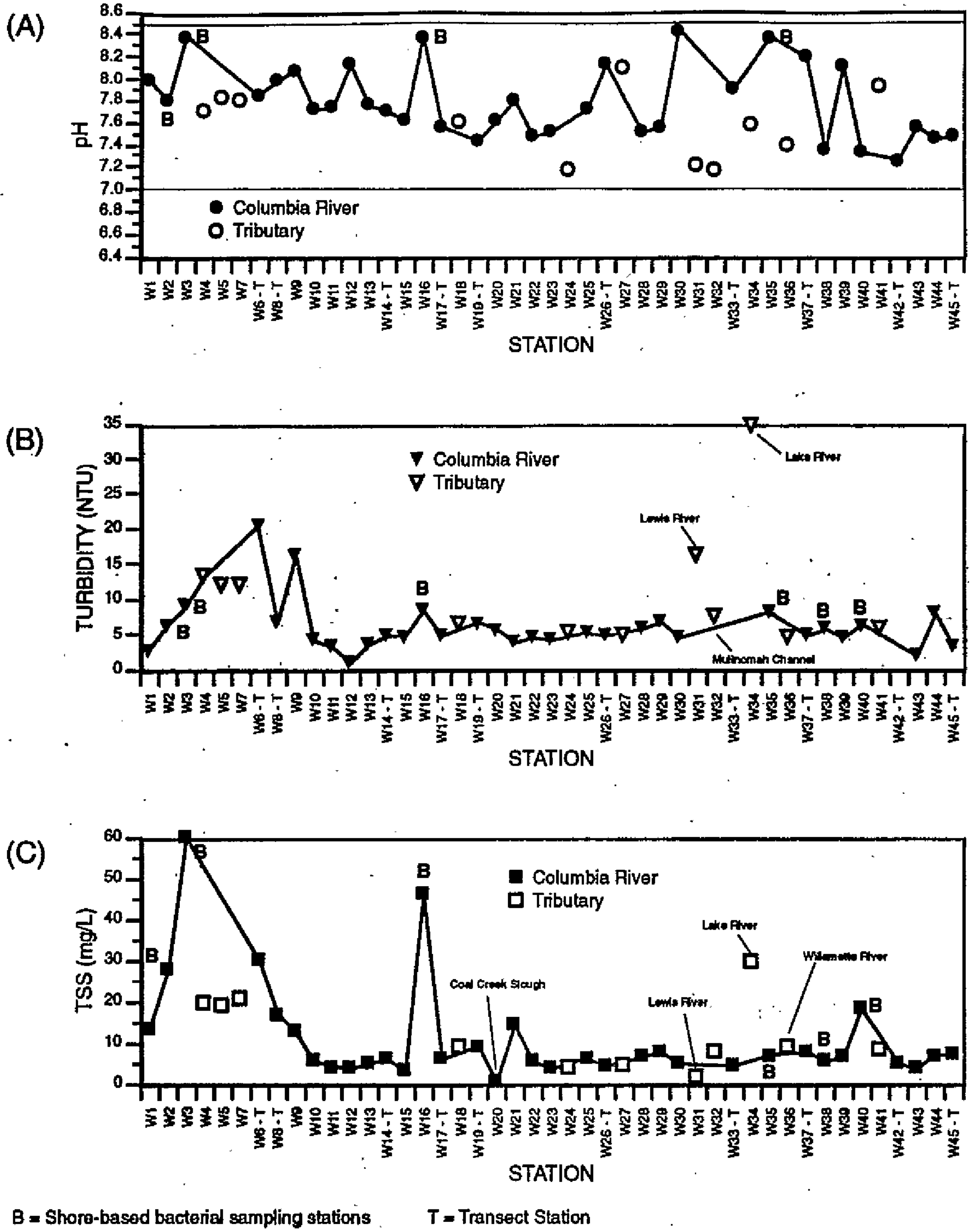


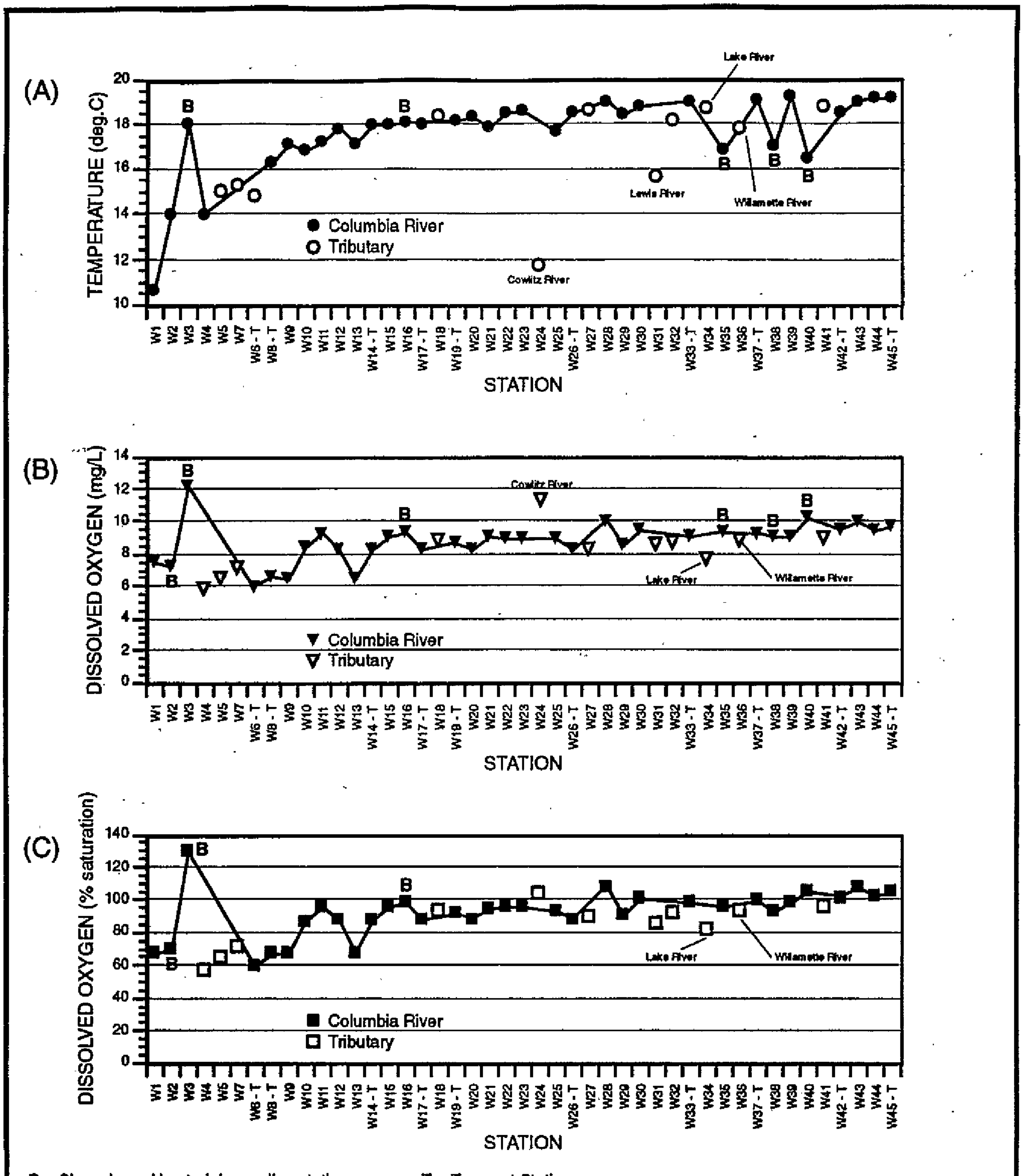
Figure 2-6. Trends in A: Ph, B: Turbidity and C: Total Suspended Solids (TSS) in the Lower Columbia River, September - October 1991

Comparing TSS concentrations with turbidity shows that elevated turbidity and TSS did not always coincide (see Figures 2-6B and 2-6C). This finding is not unusual given that the size and refractive characteristics of suspended material do not always correlate significantly with the weight concentration of the suspended matter. Peaks in turbidity and TSS coincided at three stations (W40, W34, and W16), but a turbidity peak in the Lewis River (W31) occurred when the TSS concentration was low. In the estuary, both TSS and turbidity were generally higher than upriver concentrations, but the extremely high TSS concentration at station W3 (Ilwaco) was not reflected in the measurement of turbidity.

The station temperatures ranged from 19.1° C in the upper reaches of the study area below Bonneville Dam to 10.6° C at the mouth (Figure 2-7A). The mean and median of all temperature measurements were 18.1° and 18.0° C, respectively. Temperature generally decreased from stations in the upper reach of the study area below Bonneville Dam to the mouth, except for one elevated temperature (18° C) measured at the shore-based station in Ilwaco (W3). This overall trend was likely due to the warming of the river in the numerous impoundments above Bonneville Dam, the influence of cooler water from tributaries such as the Cowlitz (11.7° C) and the Willamette (17.8° C) rivers, and the intrusion of the cooler ocean water in the estuary.

The DO content of the river and its tributaries ranged from 5.8 mg/L at station W4 in the Skipanon River to over 12 mg/L at station W3, the shore-based station in Ilwaco (Figure 2-7B). Most of the lower values of DO were recorded in the estuary, except for low DO measured at the mid-channel station W13 (6.5 mg/L). The general trend in the DO data was for a gradual decrease from the upper river to the lower river. The mean and median DO were 9.0 and 8.8 mg/L, respectively.

Because the solubility of DO depends on water temperature, comparing results among stations is facilitated by calculating the percent saturation of DO. At cooler water temperatures, more oxygen is expected to dissolve in the water, while at higher temperatures the solubility of oxygen is decreased. Thus estimating DO percent saturation allows an assessment of whether the DO concentration is lower than would be expected based on water temperature. DO percent saturation ranged from 56 percent at station W4 in the estuary to 129 percent at the shore-based station W3 in Ilwaco (Figure 2-7C). The mean and median DO percent saturation were 94 and 93 percent, respectively. DO percent saturation in the estuary, with the exception of Ilwaco (W3), was generally below 100 percent (56-70 percent). This low DO in the estuary reflects the lowered DO content of intruding ocean water (Haertel and Osterberg



B = Shore-based bacterial sampling stations T = Transect Station

Figure 2-7. Trends in A: Temperature, B: Dissolved Oxygen (DO) and C: Percent DO Saturation in the Lower Columbia River, September - October 1991

1967; Conomos 1972; Neal 1972) and the biological respiration within the estuary (Park et al., 1972). Low DO percent saturation was also noted at the mid-channel station W13 (67 percent). The DO percent saturation in the rest of the stations above the estuary—including estimates from tributaries—ranged from 81 percent in Lake River (W34) to 108 percent in the channel behind Sandy Island (28). DO was supersaturated just below Bonneville Dam (101-107 percent).

2.6.1.3 Comparison with Water Quality Criteria. Parameters such as pH, turbidity, TSS, temperature, and DO have a significant effect on biota in the river, especially coldwater anadromous fish. The pH may directly affect organisms, and pH indirectly affects the toxicity of dissolved substances in the water. Elevated turbidity and TSS may reduce the light available for photosynthetic organisms, reducing primary production which may in turn affect biota higher up on the food chain. Sediments may also affect bottom-dwelling organisms when excessive amounts of sediment are deposited on the river bottom. These sediments may also adversely affect the spawning areas of anadromous fish. Water temperature affects the metabolic rate of organisms, and colder temperatures are required for the maintenance of anadromous coldwater fish. DO is an essential requirement for all animals: adequate levels are necessary for the protection of aquatic organisms. Anadromous coldwater fish are particularly sensitive to reductions in the DO content of marine and freshwaters.

Although water quality criteria have been established for salinity, turbidity, and TSS, the criteria for these parameters are narrative in form and generally apply only to the evaluation of the impacts caused by specific point or nonpoint source discharges. Due to the broad-scale design of the reconnaissance survey, it was not possible to assess whether or not exceedances of the narrative criteria for salinity, turbidity, and TSS occurred during the survey period. However, concentrations of these parameters were not unusual at any station, suggesting that large-scale alterations of these parameters due to anthropogenic influences did not occur during the survey.

Specific numerical water quality criteria are available to determine exceedances of pH, temperature, and DO. The freshwater and marine standards for pH are the same for Oregon (OAR 1990) and Washington (WAC 1988, 1992). The freshwater standard states that water column pH should not exceed the range of 6.5 to 8.5. The marine standard states that the range of pH should not exceed the range of 7.0 to 8.5. Although the pH at a few stations reached 8.4, all pH measurements ranged within the more restrictive marine standard of 7.0 to 8.5 (see Figure 2-6A).

Although Oregon has established temperature criteria, the criteria apply only to relative temperature changes above and below specific point and nonpoint source discharges. The Washington regulations provide both general temperature criteria for Class A waters as well as specific criteria for the lower Columbia River. The Class A waters criteria require that the freshwater temperature not exceed 18° C and the marine water temperature not exceed 16° C. However, regulations promulgated specifically for the lower Columbia River establish a freshwater temperature criterion not to exceed 20° C. During the reconnaissance survey, water temperatures at the freshwater stations were frequently above 18° C. Several stations in the upper segment of the study area exceeded 19° C (see Figure 2-7A). No measurements, however, exceeded 19.1° C in the study area. In the estuary at stations W1 to W8, the marine temperature criterion of 16° C was exceeded at the shore-based station W3 (Ilwaco marina) (18° C) and at station W8 off Tongue Point (16.3° C). Because the Trojan Nuclear Power Plant was not operating during this survey, the possible effect of heated discharge from this facility could not be assessed. However, historical instream monitoring of the effluent mixing zone in the Columbia River did not indicate a significant (greater than 0.1° C) effect on river temperature beyond the defined mixing zone (monitoring data reported to ODEQ; Carter, L., 13 January 1993, personal communication).

Both Oregon and Washington have numerical criteria for DO. The Oregon freshwater criterion for DO states that DO shall not be less than 90 percent saturation (OAR 340-41-205, 1990). The Oregon marine/estuarine criterion states that DO shall not be less than 6 mg/L, except within zones of upwelled marine waters naturally deficient in DO. The class A freshwater criterion for the state of Washington states that DO shall exceed 8 mg/L (WAC 173-201-45, 1988). The Washington Class A marine criterion states that DO shall exceed 6.0 mg/L (WAC 173-201-45,1988) and should apply when salinity is greater than 1 ppt (WAC 173-201-035, 1988). DO above station W8 fell below 8 mg/L at three stations—station W9 in Grays Bay (6.4 mg/L), station W13 near Skamokawa Creek (6.5 mg/L), and station W34 in Lake River (7.6 mg/L) (see Figure 2-11B). In the estuary, DO fell below 6 mg/L at station W4 in the Skipanon River (5.8 mg/L). DO percent saturation was below 90 percent at 10 stations above the estuary: transect station W9 (67 percent), W10 (86 percent), W12 (87 percent), W13 (67 percent), W14 (87 percent), W17 (87 percent), W20 (88 percent), W26 (88 percent), W27 (89 percent), and W34 (81 percent) (Figure 2-11C). DO percent saturation in the estuary was generally greater than 60 percent, but lower than 90 percent, with the exception of station W4 in the Skipanon River (56 percent), and the shore-based station W3 in Ilwaco (129 percent).

2.6.2 Nutrients and Miscellaneous Water Column Parameters

Nutrients and miscellaneous water column parameters include the nutrients nitrate plus nitrite nitrogen, ammonia nitrogen, total Kjeldahl nitrogen (TKN), and total phosphorus (TP); and the miscellaneous parameters fluoride, chloride, sulfate, hardness, total suspended solids (TSS), and total organic carbon (TOC). All nutrient and miscellaneous data are provided under separate cover in Appendix B-4. Median values presented below for nutrients and miscellaneous parameters are based on values reported as detected above the DL and one-half the DL for values reported as undetected.

2.6.2.1 Summary of Quality Assurance/Quality Control. Nutrients and miscellaneous parameters, with the exception of TOC, were measured at all water quality sampling stations. TOC was measured at five stations (stations W6, W14, W26, W37, and W45). When sample concentrations were below the DL they were qualified as "U" (sample concentration below the detection limit). All nutrient data were qualified as unusable (these data are qualified as "R" in the appendix) due to the reporting of unacceptably high detection limits by the analytical laboratory. Three hardness values (stations W3, W6, and W8) were qualified as unusable due to the use of more titrant than recommended in the analytical method employed.

Method blanks were reported for TSS, TOC, fluoride, chloride, sulfate, and nitrate/nitrite. Method blank contamination was reported for chloride, but the level of contamination was less than the reported DL of 0.5 mg/L. Chloride data were not blank corrected. Blank contamination was reported for TOC and the data were blank corrected.

Laboratory duplicates were reported for all compounds. However, the large number of undetected levels precluded an assessment of laboratory variability, with the exception of TSS, TOC, hardness, fluoride, chloride, sulfate, and nitrate/nitrite. Field duplicates for all parameters, except TOC, were analyzed for samples collected from five stations. The coefficient of variation of the field replicated samples indicated that variability associated with field sampling and laboratory analysis was generally not greater than 20 percent (Table 2-3). The high variability associated with the W21/W49 and W30/W48 samples for TSS may indicate poor homogenization of the field sample prior to dispensing into the field sample containers.

TABLE 2-3. MEAN AND COEFFICIENT OF VARIATION OF FIELD-REPLICATED NUTRIENT AND MISCELLANEOUS PARAMETERS FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

Parameter	Station				
	W8	W21	W26	W30	W44
	Mean (mg/L) ± %CV, n = 2				
TKN	0.2U, 0.2U	0.2U, 0.2U	0.2U, 0.2U	0.2U, 0.2U	0.3, 0.2U
Ammonia	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1, 0.1U
Chloride	2,800 ± 11	5.2, 0.5U	3.6 ± 2	3.5 ± 0.0	2.0 ± 4
Sulfate	388 ± 2	11 ± 20	10 ± 0.0	10 ± 0.0	8.7 ± 2
Hardness	987 ± 0.3	57 ± 0.0	62 ± 10	55 ± 5	55 ± 5
TSS	16.6 ± 2	9.2 ± 80	3.8 ± 0.7	3.8 ± 19	6.8 ± 0.0

U = Undetected. Number is the detection limit.

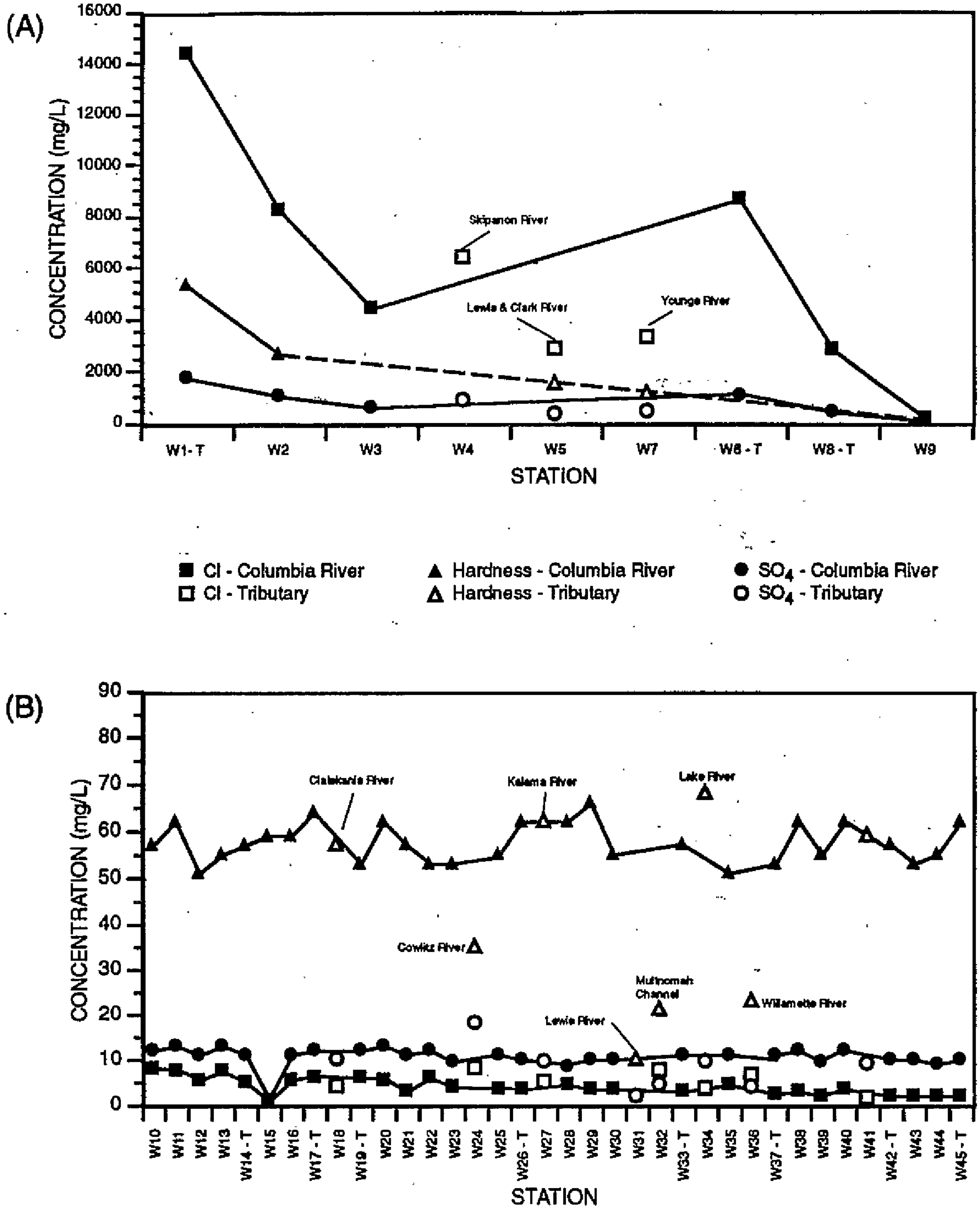
The reported DLs were generally above the target DLs specified in the QA/QC plan (Tetra Tech 1991b), with the exception of cyanide. The reported DL for fluoride (0.5 mg/L) was five times greater than that specified in the QA/QC plan (0.1 mg/L). The reported DLs for the nutrients were all greater than those specified in the QA/QC plan. The reported DLs were 0.5 mg/L for nitrate/nitrite, 0.2 mg/L for TP, 0.2 mg/L for TKN, and 0.1 mg/L for ammonia nitrogen. Since nutrients are typically detected at much lower concentrations than the DLs reported for this project, and the generally lower nutrient concentrations associated with indications of eutrophic conditions, these data were qualified as unusable (these data have been qualified with an "R" in the appendix) and will not be discussed in the text below. The DLs specified in the QA/QC plan for these compounds were 0.05 mg/L for nitrate/nitrite, 0.1 mg/L for TP, 0.03 mg/L for TKN, and 0.03 mg/L for ammonia. The reported DLs for TOC and fluoride were also greater than those specified in the QA/QC plan (2.4 vs. 1.0 mg/L and 0.5 vs. 0.1 mg/L, respectively).

Results and summary statistics of blind laboratory and field replicate samples [e.g., mean and relative percent differences (RPDs)] for those data are presented under separate cover in the QA memorandum, Appendix A-1.

2.6.2.2 Spatial Trends. TOC was not detected above the DL of 2.4 mg/L at stations W45, W26, or W14. TOC was detected at a concentration of 0.7 mg/L at the transect station W6 in the estuary.

Fluoride was not detected above the reported DL of 0.5 mg/L.

Chloride was detected above the DL of 0.5 mg/L at all but one station—station W21 in the channel behind Fisher Island (Figure 2-8). Since chloride is more concentrated in seawater, the concentration of chloride closely reflects salinity and the extent of saline water penetration into the estuarine portion of the river. In the estuary, the concentration of chloride was greatest at station W1 at the mouth of the river (14,380 mg/L), and decreased to 129 mg/L at station W9 in Grays Bay (Figure 2-8A). Chloride content of the river above station W9 was fairly constant and averaged 4.2 mg/L. Chloride concentration in the freshwater portion of the lower Columbia River ranged from 1.6 to 2.0 mg/L measured below the Bonneville Dam. These concentrations gradually increased to 7.8 mg/L (W10), with higher concentrations recorded in the Willamette River, Multnomah Channel, and Cowlitz River (see Figure 2-8B). Those higher chloride concentrations were 6.3, 7.4, and 7.7 mg/L, respectively.



T = Transect Station

Figure 2-8. Trends in Chloride, Sulfate and Hardness in the Lower Columbia River, September - October 1991

Sulfate was detected at all sampling stations. It ranged from 1,780 mg/L at station W1 at the mouth of the Columbia River to 2 mg/L in the Lewis River (W31) (see Figure 2-8). Like chloride, sulfate typically concentrates more in seawater, and therefore highly elevated sulfate concentrations reflect the influence of saltwater intrusion in the estuary. Sulfate concentrations above station W9 were fairly constant, averaging 10 mg/L. However, the concentration of sulfate in the Cowlitz River was slightly higher (18 mg/L); the concentrations in the Lewis River, Multnomah Channel, and the Willamette River were somewhat lower, at 2.0, 4.6, and 4.1 mg/L, respectively. A low concentration of 1.5 mg/L was also noted at station W15.

Hardness, a measure of the polyvalent metal ion content of the water, significantly affects the potential toxicity of metals. In freshwater, hardness is primarily due to the content of calcium and magnesium ions. Elevated hardness (i.e., higher concentrations of calcium and magnesium and associated metallic carbonates and hydroxides) reduces the toxicity of metals due to the antagonistic effects of the principal cations contributing to hardness and/or to the complexation/precipitation of toxic trace metals with metal hydroxides and carbonates (U.S. EPA 1986a). The elevated hardness of the water in the estuarine portion of the river is due to the higher calcium and magnesium content of the intruding oceanic water. In the estuary, hardness ranged from 989 mg/L (W8) to 5,292 mg/L (W1) at the mouth of the river (Figure 2-8). Hardness was generally much lower above the estuary and ranged from 92 mg/L (W9) (in the transition area between estuarine and freshwater) to 10 mg/L in the Lewis River (Figure 2-12B). Lower hardness was evident in a number of other rivers including the Cowlitz (35 mg/L), Multnomah Channel (21 mg/L), and the Willamette (23 mg/L). The median hardness of the river above the estuary was 57 mg/L.

2.6.3.3 Comparison with Water Quality Criteria. There are no water quality criteria established for hardness, sulfate, or TOC. The chronic freshwater criterion for chloride (230 mg/L) (U.S. EPA 1986a) was not exceeded at any of the freshwater stations. No criteria have been established for nutrients, with the exception of a 10 mg/L drinking water standard for nitrate, and a pH-dependent criterion for un-ionized ammonia (U.S. EPA 1986a). The freshwater chronic criterion for un-ionized ammonia is dependent on pH and temperature. For pH of 8.5 and a water temperature of 20° C (the most conservative estimate for the conditions encountered during the survey), the criterion for un-ionized ammonia is equivalent to total ammonia (which was measured in this survey) of 0.32 mg/L. Although the laboratory detection limit for ammonia achieved in this study was higher than the DL specified in the QA plan, the reported detection limit (0.1 mg/L) was adequate for evaluation of the un-ionized ammonia criterion. This criterion was not exceeded in any sample collected during this survey. The marine criterion (pH and temperature dependent) of 2.2 mg/L (pH=8.5, temperature=20° C) was not exceeded in the samples collected in the estuary. The highest level of ammonia nitrogen measured in the survey was 0.2 mg/L (Appendix B-4).

2.6.3 Phytoplankton

The results of the analysis of phytoplankton samples are described below. Complete raw data are provided under separate cover in Appendix B-5.

2.6.3.1 Summary of Quality Assurance/Quality Control. Phytoplankton were identified to species, where possible, by a qualified planktologist (Jim Sweet of Aquatic Analysts, Portland, Oregon) using acceptable methods. One field duplicate from station W8 (sample W50) was also analyzed and was comparable to the original sample. Species identifications were not independently verified and samples were not independently recounted. However, mounted slide preparations have been archived in Tetra Tech files.

The variability associated with sampling and analysis was assessed using one blind field duplicate sample. Comparison of the dominant taxa in the two samples indicates that some variability was associated with estimates of relative density and biovolume. Most variation was associated with estimates of relative density. This was not unusual and was primarily due to the low concentration of phytoplankton in the water and the larger number of small-celled taxa. *Thalassiosira* sp. was the most abundant taxon in sample W8 (14 percent) while *Stephanodiscus hantzchii* was most abundant in sample W50 (18 percent) (Table 2-4). Less variability was associated with relative biovolume. *Fragilaria crotonensis* was the dominant species in both samples, although the relative biovolume of the second most dominant species varied between the two samples (Table 2-4). The coefficient of variation was generally not greater than 20 percent for the number of taxa identified, and relative numbers, and the relative biovolume of each major taxa group (Table 2-4). However, more variability was associated with the density and biovolume of the less abundant groups of chlorophyte and cryptophyte algae (Table 2-4). Although there appears to be some variability associated with field sampling and laboratory analysis, comparison of the relative

TABLE 2-4. COMPARISON OF THE FIELD-REPLICATED PHYTOPLANKTON SAMPLES FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

Sample	Dominant Four Taxa			
	By Density	Relative Percent	By Biovolume	Relative Percent
W8	*Thalassiosira* sp.	14	*Fragilaria crotonensis*	18
	Melosira granulata	8	*Stephanodiscus astraea*	17
	Nitzchia seriata	6	*Nitzchia seriata*	15
	Stephanodiscus subsalsus	5	*Thalassiosira* sp.	12
	Cryptomonas erosa	5		
	Rhodomas minuta	5		
W50	*Stephanodiscus hantzchii*	18	*Fragilaria crotonensis*	49
	Melosira granulata	10	*Melosira granulata*	10
	Fragilaria crotonensis	6	*Nitzchia seriata*	8
	Stephanodiscus astraea minutula	6	*Thalassiosira* sp.	6

Sample	Number of Taxa Identified			
	Total	of Diatoms	of Greens	of Cryptophytes
W8	33	25	6	2
W50	36	27	6	3
Mean±%CV	34.5 ± 6.1	26.0 ± 5.4	6 ± 0.0	2.5 ± 2.7

Sample	Density (#/mL) and Biovolume (um^3/mL x 10^3) of Taxa Identified							
	Total		of Diatoms		of Greens		of Cryptophytes	
	Density	Biovolume	Density	Biovolume	Density	Biovolume	Density	Biovolume
W8	518	303.6	406	280.6	60	8.9	52	14.1
W50	405	304.6	336	290.1	46	6.4	23	8.1
Mean±%CV	462±17	304.1±0.2	371±13	285.4±2	53±19	7.7±23	38±55	11.1±38

abundance of major groups of taxa and the dominant species among stations should be appropriate for this report.

2.6.3.2 Spatial Trends. During the reconnaissance survey, 122 taxa of phytoplankton were identified. Most of these were identified to species. Of these, 91 taxa belonged to the Class Bacillariophyceae (diatoms), 22 belonged to the Division Chlorophyta (i.e., green algae), four belonged to the Division Chrysophyta (excluding diatoms), three belonged to the Division Cryptophyta, one belonged to the Division Cyanophyta (blue-green algae or cyanobacteria), and one was an unidentified alga from the Division Pyrhophyta (dinoflagellates) (Table 2-5). The phytoplankton sampled were dominated by diatoms, both in density and biovolume (Figures 2-9 and 2-10; Table 2-6). The total number of taxa in each water sample ranged from 10 to 36; the lowest number occurred at the three upper stations (W45, W43, and W39) and the river mouth (see Table 2-6). Phytoplankton abundance ranged from 1,852 cells/mL just below the Bonneville Dam (W45) to 518 cells/mL in the estuary (W8). Phytoplankton biovolume ranged from 2.0x10^6 μm^3/mL (W45) to 0.1x10^6 μm^3/mL in Grays Bay (W9). Because phytoplankton species vary greatly in size, a small-celled species may dominate phytoplankton density, while another large-celled species may dominate the total biovolume. In nearly all samples in which one small-celled taxon had the highest density (e.g., *Stephanodiscus astrea minutula* at station W13), a larger celled species (*Fragilaria crotonensis*) comprised the largest portion of the biovolume (see Table 2-6). Marine phytoplankton taxa dominated the phytoplankton in the Columbia River estuary from Astoria (W6) to the mouth (W1). Station W8 was transitional, with the marine diatom *Thalassiosira* sp. dominating phytoplankton numbers, but the freshwater diatom *Fragilaria crotonensis* dominated phytoplankton biovolume. Freshwater taxa dominated both density and biovolume at all stations above the estuary.

Small cryptophyte algae were abundant at a few stations (see Figure 2-9; Table 2-6). The phytoplankton density at station W28 was dominated by the small, motile cryptophyte *Rhodomonas minuta*. However, the large-celled diatom *Melosira granulata* dominated the total biovolume. At station W14, the dominant taxa were the diatom *Stephanodiscus astraea minutula* (21 percent) and *Rhodomonas minuta* and *Melosira granulata* (11 percent each). At station W13 the dominant taxa were *Stephanodiscus hantzchii* (21 percent) and *Rhodomonas minuta* (15 percent). One sample, collected from the Willamette River (W36) had one of the highest cell densities measured (1732 cells/mL), but it also had the lowest total biovolume (502,181 μm^3/mL) due to the relatively abundant, but small-celled taxa identified. The cell density in this sample was dominated by the diatom *Cyclotella atomus*, which dominated the phytoplankton density

TABLE 2-5. LIST OF PHYTOPLANKTON TAXA IDENTIFIED FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

(Page 1 of 4)

Code	Taxa	Authority
B	*Aphanizomenon flos-aquae*	(Linn.) Ralfs.
D	*Achnanthes clevei*	Grun.
D	*Achnanthes exiqua*	Grun.
D	*Achnanthes hauckiana*	Grun.
D	*Achnanthes lanceolata*	(Breb.) Grun.
D	*Achnanthes lewisiana*	Patr.
D	*Achnanthes linearis*	(W.Sm.) Grun.
D	*Achnanthes minutissima*	Kutz.
D	*Achnanthes peragalli*	Brun & Herib.
D	*Achnanthes* sp.	Bory
D	*Amphora coffeiformis*	(Ag.) Kutz.
D	*Amphora ovalis*	Kutz.
D	*Amphora perpusilla*	(Grun.) Grun.
D	*Asterionella formosa*	Hass.
D	*Chaetoceros* sp.	
D	*Cocconeis klamathensis*	Sov.
D	*Cocconeis placentula*	Ehr.
D	*Coscinodiscus* sp.	Ehr.
D	*Cyclotella atomus*	Hust.
D	*Cyclotella meneghiniana*	Kutz.
D	*Cyclotella ocellata*	Pantocsek
D	*Cyclotella pseudostelligera*	Hust.
D	*Cyclotella stelligera*	Cl. u. Grun.
D	*Cymatopleura solea*	(Breb.) W. Sm.
D	*Cymbella affinis*	Kutz.
D	*Cymbella minuta*	Hilse ex Rabh.
D	*Cymbella sinuata*	Greg.
D	*Diatoma hiemale mesodon*	(Ehr.) Grun.
D	*Diatoma tenue elongatum*	Lyngb.
D	*Diatoma vulgare*	Bory
D	*Diploneis puella*	(Schum.) Cl.
D	*Diploneis smithii*	(Breb. ex W.Sm.) Cl.

TABLE 2-5. LIST OF PHYTOPLANKTON TAXA IDENTIFIED FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

(Page 2 of 4)

Code	Taxa	Authority
D	*Fragilaria bicapitata*	A. Mayer
D	*Fragilaria capucina mesolepta*	Rabh.
D	*Fragilaria construens*	(Ehr.) Grun.
D	*Fragilaria construens venter*	(Ehr.) Grun.
D	*Fragilaria crotonensis*	Kitton
D	*Fragilaria leptostauron*	(Ehr.) Hust.
D	*Fragilaria pinnata*	Ehr.
D	*Fragilaria vaucheriae*	(Kutz.) Peters.
D	*Gomphonema angustatum*	(Kutz.) Rabh.
D	*Gomphonema clevei*	Fricke
D	*Gomphonema olivaceum*	(Lyngb.) Kutz.
D	*Gomphonema ventricosum*	Greg.
D	*Hannaea arcus*	(Ehr.) Patr.
D	*Melosira ambiqua*	(Grun.) O. Mull.
D	*Melosira distans*	(Ehr.) Kutz.
D	*Melosira granulata*	(Ehr.) Ralfs.
D	*Melosira granulata angustissima*	Muller
D	*Melosira italica*	(Ehr.) Kutz.
D	*Navicula biconica*	Patr.
D	*Navicula capitata*	Ehr.
D	*Navicula contenta biceps*	(Arn.) V.H.
D	*Navicula cryptocephala*	Kutz.
D	*Navicula cryptocephala veneta*	(Kutz.) Rabh.
D	*Navicula decussis*	Ostr.
D	*Navicula gregaria*	Donk.
D	*Navicula menisculus upsaliensis*	(Grun.) Grun.
D	*Navicula minima*	Grun.
D	*Navicula minuscula*	Grun.
D	*Navicula mutica*	Kutz.
D	*Navicula pseudoscutiformis*	Hust.
D	*Navicula pupula*	Kutz.
D	*Navicula radiosa*	Kutz.

TABLE 2-5. LIST OF PHYTOPLANKTON TAXA IDENTIFIED FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY
(Page 3 of 4)

Code	Taxa	Authority
D	*Navicula* sp.	Bory
D	*Navicula tripunctata*	(O.Mull.) Bory
D	*Neidium* sp.	
D	*Nitzschia acicularis*	W. Sm.
D	*Nitzschia amphibia*	Grun.
D	*Nitzschia capitellata*	Hust.
D	*Nitzschia dissipata*	(Kutz.) Grun.
D	*Nitzschia frustulum*	(Kutz.) Grun.
D	*Nitzschia holsatica*	Hust.
D	*Nitzschia hungarica*	Grun.
D	*Nitzschia palea*	(Kutz.) W. Sm.
D	*Nitzschia paleacea*	Grun.
D	*Nitzschia seriata*	
D	*Nitzschia sigmoidea*	(Ehr.) W. Sm.
D	*Nitzschia* sp.	Hassall
D	*Pinnularia* sp.	Ehr.
D	*Rhoicosphenia curvata*	(Kutz.)Grun. ex Rabh.
D	*Stephanodiscus astraea*	(Ehr.) Grun.
D	*Stephanodiscus astraea minutula*	(Kutz.) Grun.
D	*Stephanodiscus hantzschii*	Grun.
D	*Stephanodiscus subsalsus*	(A. Cl.) Hust.
D	*Synedra delicatissima*	W. Sm.
D	*Synedra radians*	Kutz.
D	*Synedra rumpens*	Kutz.
D	*Synedra ulna*	(Nitz.) Ehr.
D	*Thalassiosira* sp.	
D	Unident. centric diatom	
D	Unident. pennate diatom	
F	Unident. dinoflagellate	
G	*Ankistrodesmus falcatus*	(Corda) Ralfs
G	*Chlamydomonas* sp.	Ehr.
G	*Chlorella* sp.	Beyerinck

TABLE 2-5. LIST OF PHYTOPLANKTON TAXA IDENTIFIED FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY
(Page 4 of 4)

Code	Taxa	Authority
G	*Chodatella quadriseta*	
G	*Chodatella wratislawiensis*	(Schroed.) Ley.
G	*Crucigenia quadrata*	Morren
G	*Crucigenia tetrapedia*	(Kirch.) West & West
G	*Micractinium pusillum*	Fresenius
G	*Mougeotia* sp.	(C.A.Ag.) Wittrock
G	*Nephrocytium* sp.	Naeg.
G	*Oocystis pusilla*	Hansg.
G	*Pediastrum duplex*	Meyen.
G	*Planktosphaeria gelatinosa*	G.M. Smith
G	*Scenedesmus abundans*	(Kirch.) Chodat.
G	*Scenedesmus bijuga*	(Turpin) Lag.
G	*Scenedesmus quadricauda*	(Turpin) Kutz.
G	*Selenastrum minutum*	(Naeg.) Collins
G	*Sphaerocystis schroeteri*	Chodat.
G	*Tetraedron minimum*	(A. Braun) Hansg.
G	*Ulothrix* sp.	Kutz.
G	Unident. desmid	
G	Unident. green alga	
K	*Chrysococcus rufescens*	Klebs.
K	*Dinobryon* sp.	Ehr.
K	*Kephyrion* sp	Pascher
K	*Ochromonas* sp.	Wystozki
Y	*Cryptomonas erosa*	Ehr.
Y	*Cryptomonas* sp.	
Y	*Rhodomonas minuta*	Skuja

B = Cyanophyta (blue-green algae).
D = Bacillariophycea (diatoms).
F = Pyrrhophyta (dinoflagellates).
G = Chlorophyta (green algae).
K = Chrysophta.
Y = Cryptophyta.

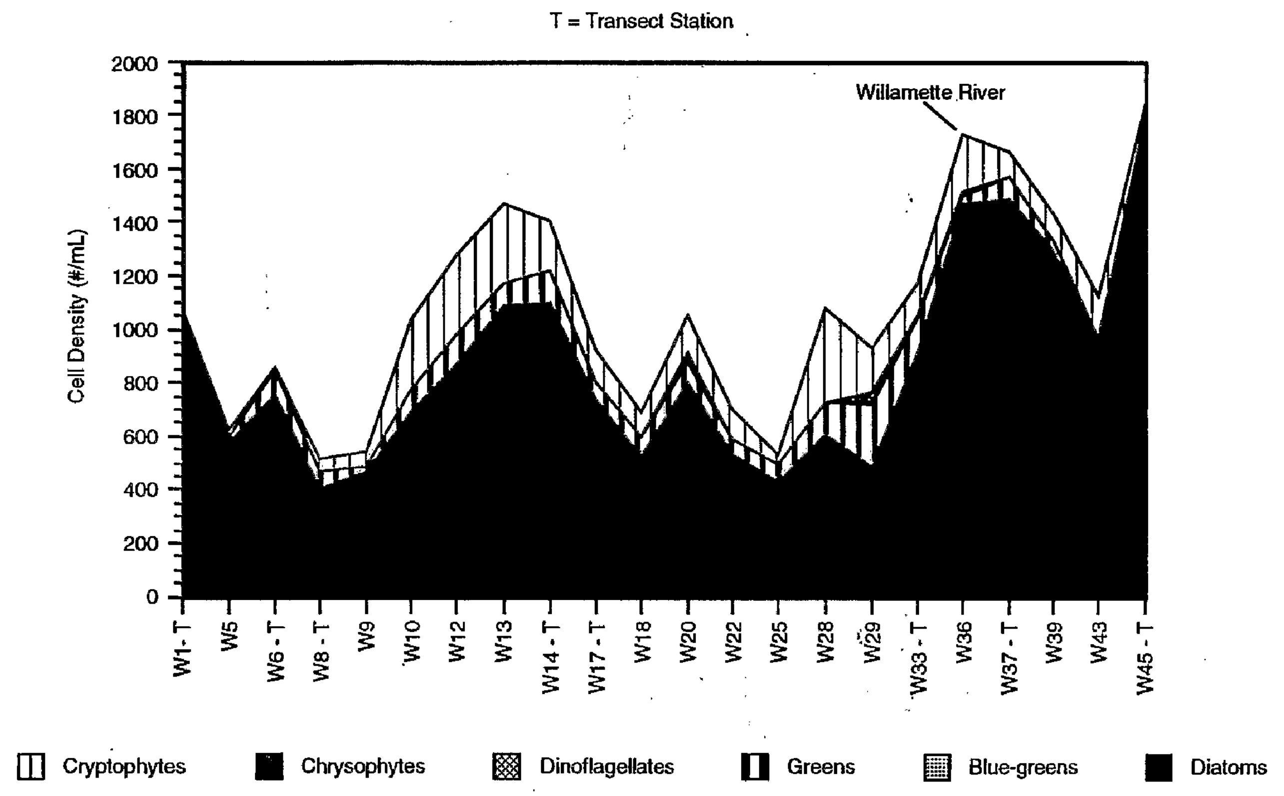


Figure 2-9. Trends in Phytoplankton Density in the Lower Columbia River, September-October 1991

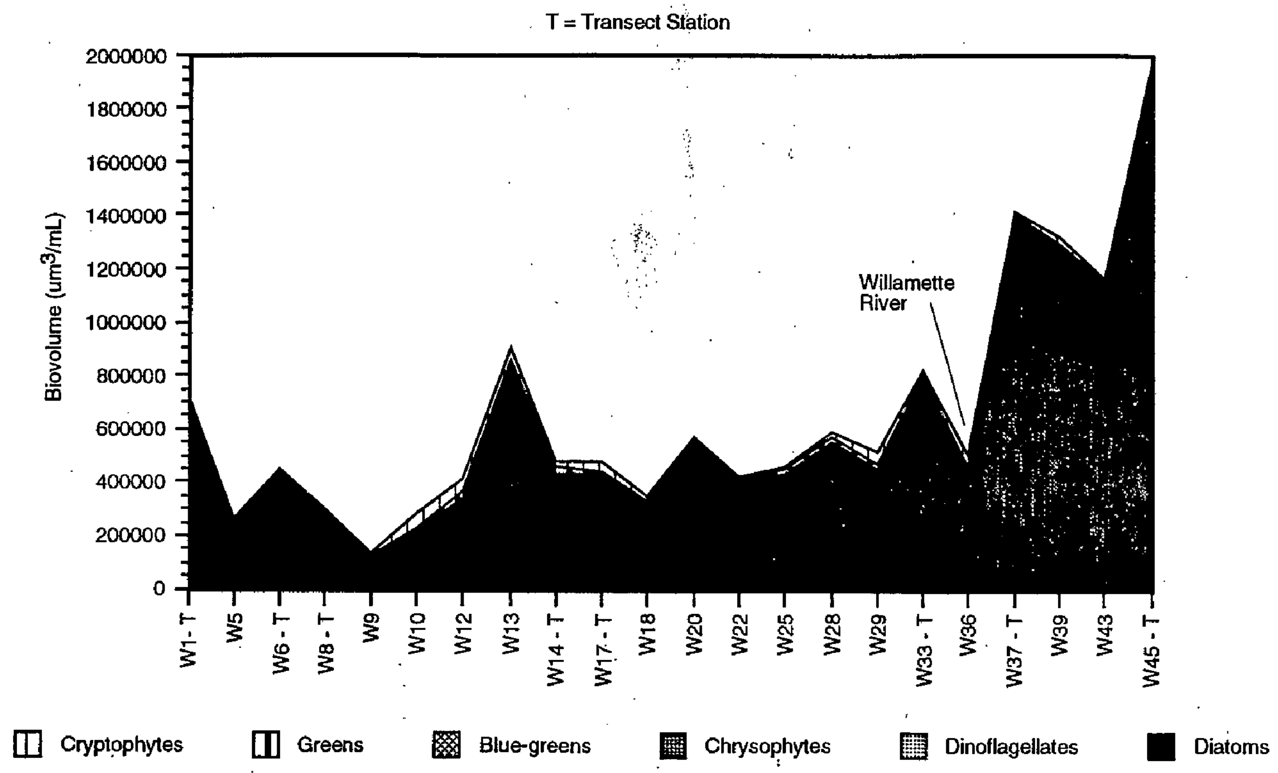


Figure 2-10. Trends in Phytoplankton Biovolume in the Lower Columbia River, September-October 1991

TABLE 2-6. DOMINANT PHYTOPLANKTON TAXA AT EACH STATION FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

Station	Dominant Taxa				
	By Density	Relative Percent	By Biovolume	Relative Percent	Total Number of Taxa
W1	*Thalassiosira* sp.	46	*Nitzschia seriata*	47	11
W5	*Thalassiosira* sp.	23	*Thalassiosira* sp.	26	36
W6	*Thalassiosira* sp.	21	*Nitzchia seriata*	43	35
W8	*Thalassiosira* sp.	14	*Fragilaria crotonensis*	18	33
W9	*Cyclotella atomus*	39	*Melosira italica*	14	25
W10	*Stephanodiscus hantzchii*[a]	22	*Melosira ambigua*	16	24
W12	*Cyclotella atomus*	17	*Fragilaria crotonensis*	29	29
W13	*Stephanodiscus hantzchii*[a]	21	*Fragilaria crotonensis*	58	25
W14	*Stephanodiscus astrea minutula*	21	*Melosira granulata*	33	23
W17	*Melosira granulata*	28	*Melosira granulata*	59	28
W18	*Stephanodiscus hantzchii*[b]	18	*Fragilaria crotensis*	38	29
W20	*Melosira granulata*	15	*Cymatopleura solea*[c]	29	31
W22	*Melosira granulata*[a]	29	*Melosira granulata*	38	28
W25	*Melosira granulata*	44	*Fragilaria crotonensis*	27	23
W28	*Rhodomonas minuta*[c]	30	*Melosira granulata*	47	25
W29	*Melosira granulata*	16	*Melosira granulata*	38	32
W33	*Melosira granulata*	55	*Melosira granulata*	71	23
W36 (Willamette River)	*Cyclotella atomus*[a]	30	*Stephanodiscus astrea*	25	29
W37	*Melosira granulata*	76	*Melosira granulata*	80	14
W39	*Melosira granulata*[d]	81	*Melosira granulata*[d]	82	10
W43	*Melosira granulata*[a]	78	*Melosira granulata*	81	10
W45	*Melosira granulata*[d]	87	*Melosira granulata*[d]	82	10
W50[e]	*Stephanodiscus hantzchii*	18	*Fragilaria crotonensis*	49	36

[a] The cryptophyte *Rhodomonas minuta* was also abundant.
[b] The diatom *Stephanodiscus subsalsus* was also abundant.
[c] The diatom *Melosira granulata* was also abundant.
[d] The blue-green alga *Aphanizomenon flos-aquae* present, but not abundant.
[e] W50 is the field replicate sample for W8.

in only one other sample (W12) (see Table 2-6). The phytoplankton biovolume was dominated by *Stephanodiscus astraea*. That species did not dominate any other sample, but did appear at low densities throughout the lower Columbia River above and below the confluence with the Willamette River.

Only one species of cyanobacteria (blue-green algae), *Aphanizomenon flos-aquae*, was noted (stations W39 and W45) (see Table 2-6). Density and biovolume of this species was 1 percent or less at both stations (Appendix B-5).

2.6.3.3 Comparison with Water Quality Criteria. To date, no water quality criteria have been established for either phytoplankton biovolume or density, although the state of Oregon has established a criterion of 15 μg/L of chlorophyll *a* (an additional surrogate measure of phytoplankton biomass) for the identification of rivers and estuaries in which the water body's recognized beneficial uses may be impaired (OAR 1990). In general, the low phytoplankton numbers (less than 1,853 cells/mL) and biovolume (less than 2.0×10^6 mm^3/mL), as well as the taxa identified, indicate no nuisance algal problems due to eutrophication of the river. The maximum biovolume reported in this study, less than 2×10^6 μm^3/mL, may be compared to the maximum biomass reported for 1981 in eutrophic Green Lake in Seattle,WA (25×10^6 μm^3/mL) (Bolstridge 1982), a maximum less than 6×10^6 μm^3/mL reported for mesotrophic Lake Washington during a period following diversion of direct treated-sewage discharges to the lake in the mid-1960s (1973-1979) (Edmondson and Litt 1982), and a maximum biomass of 0.2×10^6 μm^3/mL reported for 1987 in oligotrophic Crater Lake, OR (Debacon and McIntire 1991).

2.6.4 Bacteria

Bacterial concentrations were measured at six stations on five separate occasions over a 30-day period during the survey. Complete bacteria data are provided under separate cover in Appendix B-6.

2.6.4.1 Summary of Quality Assurance/Quality Control. Fecal coliform and enterococcus bacteria were analyzed on five samples, each collected from six stations (stations W2, W3, W16, W35, and W40). Although the multiple tube fermentation technique was used for the determination of fecal coliform densities in samples collected on November 1 and 2, 1991, this is an acceptable method approved by the American Public Health Association for use in enumeration of fecal coliform bacteria and should provide results that are consistent with the membrane filtration method (APHA 1989). None of the bacteria data were qualified, and they are considered acceptable for their intended use in this report.

2.6.4.2 Spatial and Temporal Trends. Fecal coliform and enterococcus bacterial counts for each station during the five sampling events are shown in Table 2-7. Geometric means of counts at each station over the 30-day sampling period are summarized in Figure 2-11 and 2-12. The highest fecal coliform counts were noted at station W3 near the Ilwaco marina (geometric mean=36 colonies per 100 mL), station W16 near Puget Island (geometric mean=32 colonies per 100 mL), station W35 off Sauvie Island (geometric mean=28 colonies per 100 mL), and station W38 in Portland Harbor (geometric mean=31 colonies per 100 mL). Much lower counts were noted at station W2 off the Ilwaco spit (geometric mean=4 colonies per 100 mL), and at station W40 near Government Island (geometric mean=10 colonies per 100 mL), which is upriver from the Portland/Vancouver area but downstream of the municipal wastewater discharge of the city of Gresham (see Figure 1-4). The density of enterococcus bacteria was consistently higher than the fecal coliform density, and the spatial pattern was somewhat different. Relatively higher geometric mean enterococcus densities were noted at stations W3, W16, W35, W38, and W40; 113, 82, 96, 113, and 99 colonies per 100 mL, respectively. Relatively lower enterococcus densities were noted at station W2 (geometric mean=44 colonies per 100 mL).

The temporal variability characteristic of bacterial distributions is evident in the considerable variation in fecal coliform and enterococcus bacterial densities found at each station during the five sampling events (Table 2-7). Generally, higher concentrations were noted on the first, second, and fifth sampling events at each station although this pattern did not hold true for every sampling station or sampling date (Table 2-6). Bacterial sampling was initiated on October 15 and 16, 1991 prior to the passage of a storm system that brought rainfall throughout the study area shortly thereafter on October 17 and 18 (see Figure 1-7). Sampling that was performed after the initial sampling effort was conducted under conditions of intermittent rainfall. Peaks in rainfall intensity evident in Figure 1-7 did not appear to coincide with peaks in measured fecal coliform or enterococcus densities.

2.6.4.3 Comparison with Water Quality Criteria. Both Oregon and Washington have established fecal coliform criteria for marine, fresh, and shellfish growing waters (WAC 1988,1992; OAR 1990). The Oregon standards include a specification of the sampling frequency for the application of the criteria. The criteria are based on the collection of a minimum of five samples collected over a 30-day period. For the freshwater portion of the lower Columbia River, the geometric mean of the samples collected should not exceed 200 colonies per 100 mL, and no more than 10 percent of the samples collected should have fecal coliform concentrations exceeding 400 colonies per 100 mL. For marine and shellfish growing

TABLE 2-7. SUMMARY BACTERIA DATA FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

Station	Sampling Date	Fecal Coliform Counts (Colonies per 100 mL)	Geometric Mean[a] (n=5)	Enterococcus Counts (Colonies per 100 mL)	Geometric Mean (n=5)
W2	10/15/91	5, 5	4	175, 145	44
	10/22/91	ND, ND		95, 120	
	11/1/91	3, 5		8, 8	
	11/7/91	7, 8		63, 68	
	11/13/91	3, 5		15, 20	
W3	10/15/91	265, 305	36	400, 600	113
	10/22/9	35, 25		170, 125	
	11/1/91	30, 23		37, 35	
	11/7/91	12, 10		32, 33	
	11/13/91	26, 23		210, 220	
W16	10/15/91	50, 60	32	1300, 700	82
	10/22/91	85, 80		375, 355	
	11/1/91	15, 19		30, 34	
	11/7/91	17, 12		16, 9	
	11/13/91	28, 32		23, 27	
W35	10/16/91	ND, ND	28	93, 101	96
	10/23/91	30, 35		415, 385	
	11/1/91	21, 25		31, 31	
	11/7/91	97, 106		21, 24	
	11/14/91	214, 227		285, 310	
W38	10/16/91	3, ND	31	180, 200	113
	10/23/91	205, 195		220, 250	
	11/2/91	40, 35		65, 70	
	11/8/91	22, 17		19, 16	
	11/14/91	99, 109		325, 360	
W40	10/16/91	3, 4	10	160, 180	99
	10/23/91	71, 79		265, 330	
	11/2/91	ND, ND		85, 95	
	11/8/91	11, 16		27, 22	
	11/14/91	36, 31		75, 95	

ND = No colonies detected.

[a] Geometric means for fecal coliforms were calculated using ND = 1 (i.e., the detection limit).

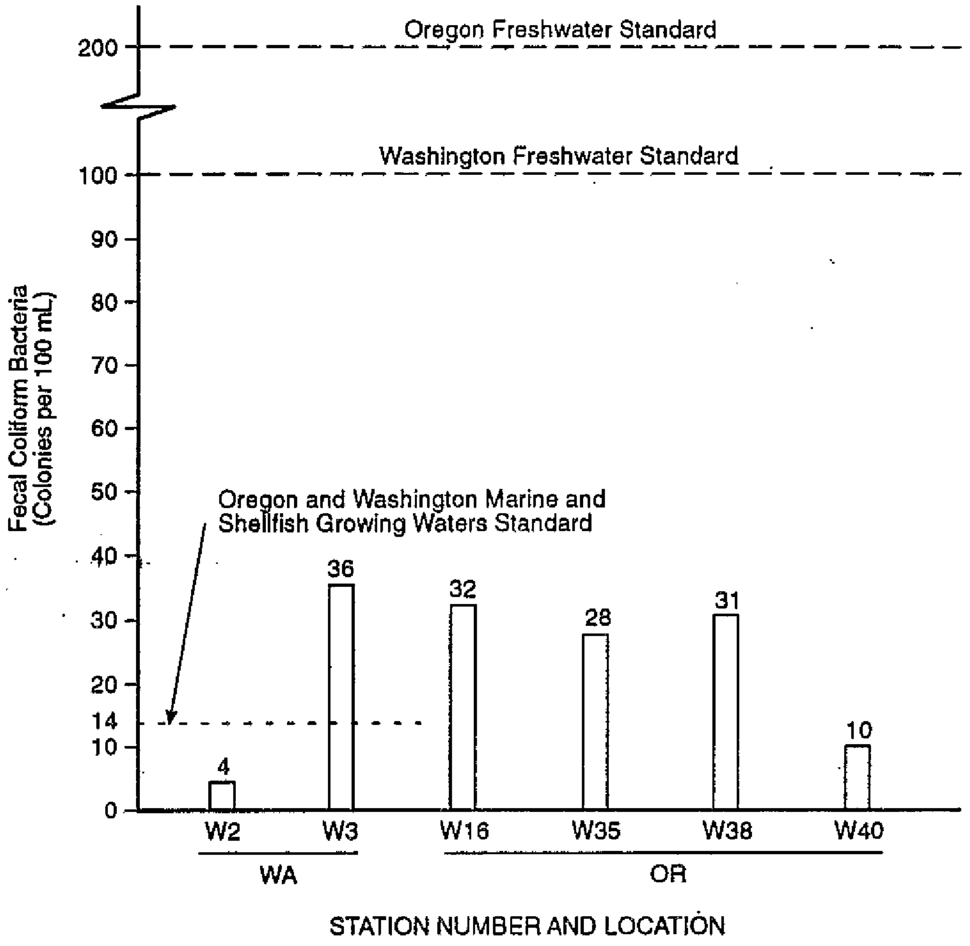


Figure 2-11. Geometric Mean Fecal Coliform Densities at Six Stations in the Lower Columbia River, October-November 1991

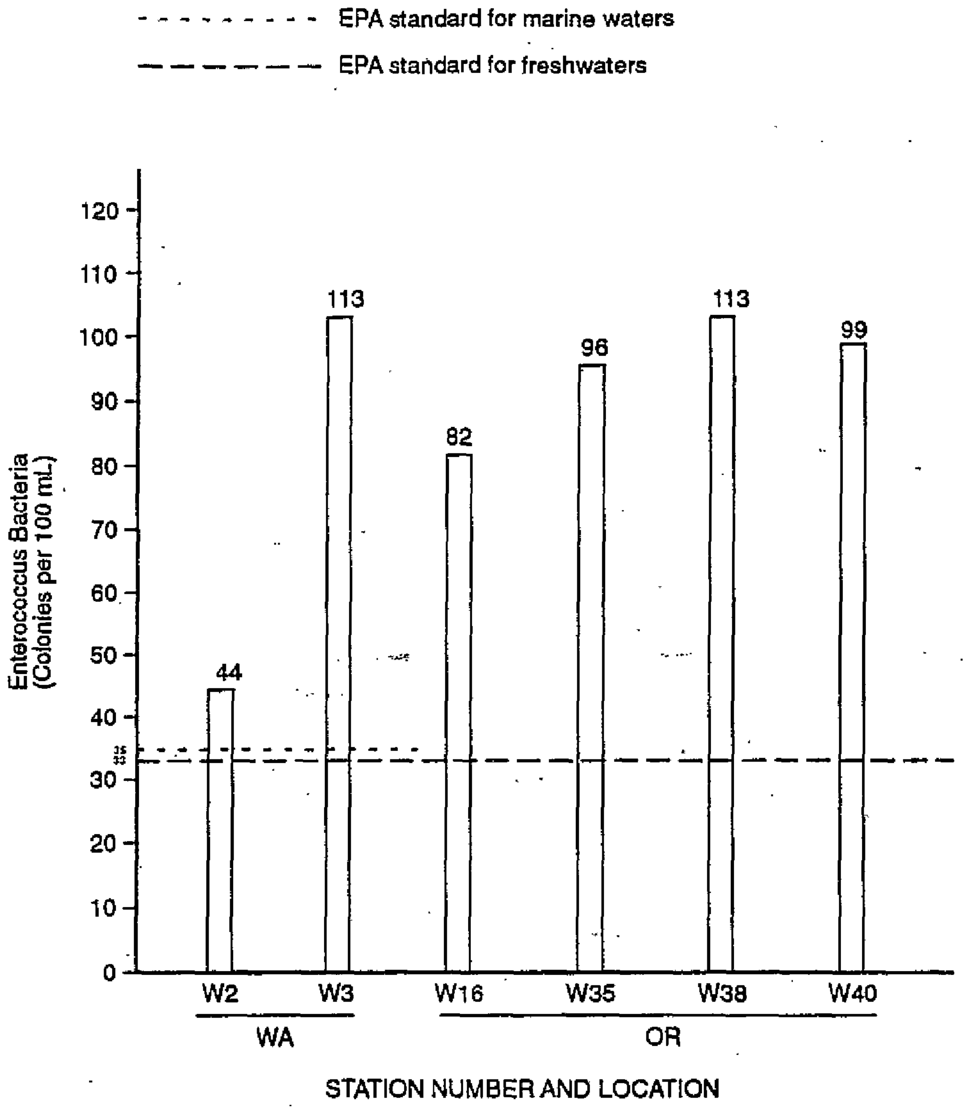


Figure 2-12. *Enterococcus* Densities at Six Stations in the Lower Columbia River, October-November 1991

waters, the median concentration of 14 colonies per 100 mL should not be exceeded, and no more than 10 percent of the samples should exceed 43 colonies per 100 mL. For estuarine waters other than shellfish growing waters, the standard is the same as that for freshwaters. The Washington standards do not specify the sampling frequency needed for application of the criteria. For freshwater the geometric mean of 100 colonies per 100 mL should not be exceeded, and no more than 10 percent of the samples collected should exceed 200 colonies per 100 mL. For marine waters, the Washington standard is similar to that of Oregon for marine and shellfish growing waters—the geometric mean of 14 colonies per 100 mL should not be exceeded, with not more than 10 percent of the samples exceeding 43 colonies per 100 mL. Stations W2 and W3 were located in Washington in the estuarine waters around the Port of Ilwaco. Because shellfish may be harvested in these waters, the Washington marine water standard of 14 fecal coliform colonies per 100 mL has been used to determine sanitary quality at these stations.

There are currently no state-promulgated standards for enterococcus bacterial densities. (Note: the proposed Oregon standard was not adopted into law). The U.S. EPA (1986a) standards for enterococcus bacteria in fresh and marine bathing waters are 33 and 35 colonies per 100 mL, respectively.

Geometric mean fecal coliform standards exceeded the marine standard at the estuarine station W3 in the area of Ilwaco (Figure 2-11). The geometric mean of the freshwater stations did not exceed the Washington criterion of 100 colonies per 100 mL (Figure 2-11). However, 10 percent of the samples at the marine station W3 exceeded the 43 colonies per 100 mL standard and 10 percent of the samples at stations W35 and W38 exceeded the freshwater Washington criterion of 200 colonies per mL (see Table 2-7).

Geometric mean enterococcus bacterial densities exceeded the U.S. EPA standards for enterococcus bacteria at all of the stations sampled (Figure 2-12).

2.6.5 Metals and Cyanide

Metals were detected in a number of samples collected during the survey. The median values presented below for the metals data are based on reported values above the detection limit and one-half the DL for values reported as not detected. Complete metals data are provided under separate cover in Appendix B-7. Cyanide was not detected in the survey nor did the DL exceed the freshwater criteria for this chemical. Cyanide data are included with the nutrient and miscellaneous water quality data in Appendix B-4.

2.6.5.1 Summary of Quality Assurance/Quality Control. Field samples for metals analyses were collected from all water quality stations. A field duplicate was collected at stations W8, W21, W26, W30, and W44 (identified as samples W50, W49, W52, W48, and W46, respectively). The metals data were considered acceptable for the use in this report, although many of these data have been qualified as estimates due to poor recovery and precision of MS and MSDs (i.e., those metals with MS/MSDs outside of the range of 60-145 percent and RPDs greater than 35 percent) (Appendix A-3). These include samples W7, W18, and W52 for iron; samples W18 and W52 for antimony, and samples W43 and W52 for selenium and arsenic, respectively. All of the metals data have also been qualified as estimates (using the qualifier "E"), with the exception of cadmium and lead, due to the lack of supporting quality assurance information on quality control check standards and calibration data. However, the cadmium and lead data were qualified as estimates as well, due to the inconsistency of the water metals results when compared to recent measurements made using ultra-clean sampling and analysis techniques. These data will be discussed in detail in Section 2.7.4. Most of the data were qualified with a "U" for values at or below the DL. However, some of the DLs reported were not within those established in the QA/QC Plan, specifically those reported for antimony (15-150 vs. 19 μg/L), cadmium (0.5-5.0 vs. 0.5 μg/L), selenium (5-100 vs. 5 μg/L), and silver (2 vs. 1 μg/L) (Tetra Tech 1991b). Elevated detection limits were due to dilution of the sample to correct for matrix interferences. Method blank analyses indicated concentrations of aluminum and iron above the DL at concentrations of 86 and 110 μg/L, respectively. The iron and aluminum data have not been blank corrected, although this level of possible contamination may indicate an overestimation of actual sample concentrations of aluminum and iron. The concentrations of iron and aluminum that were less than 5 times the reported blank concentrations were qualified as undetected (qualifier "U") as directed in the U.S. EPA Contract Laboratory Guidelines for the evaluation of inorganics analyses (U.S. EPA 1988a). The concentrations of iron and aluminum that were greater than 5 times the blank concentration were qualified as estimates using the data qualifier "E." Field blanks were not reported for the metals data; therefore, an assessment of possible contamination of the samples in the field cannot be made.

Comparison of the field replicate data for metals indicates that variability associated with field sampling and laboratory analysis is generally not greater than 20 percent, although a few replicates had coefficients of variation much greater than 20 percent (Table 2-8). These included barium at station W21 (44 percent), lead at station W26 (64 percent), and copper at station W30 (44 percent). Much of this uncertainty may be associated with laboratory variability for samples with concentrations very near the DL.

TABLE 2-8. MEAN AND COEFFICIENT OF VARIATION OF FIELD-REPLICATED METAL SAMPLES FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

Parameter	Station				
	W8	W21	W26	W30	W44
	Mean (ug/L) ± %CV, n=2				
Alumimum	370 ± 11	225 ± 3	200 ± 7	215 ± 3	235 ± 9
Barium	26 ± 8	18 ± 44	30 ± 0.0	35 ± 3	28 ± 4
Copper	5U, 5U	10 ± 10	7, 5U	9 ± 44	5U, 5U
Iron	435 ± 5	260 ± 22	505 ± 13	565 ± 14	310 ± 5
Lead	1U, 1U	3.5 ± 17	7.5 ± 28	5.0 ± 2	1.0, 1U
Selenium	100U, 100U	5U, 5U	22 ± 64	5.8 ± 3	5U, 5U
Zinc	20U, 20U	20U, 20U	20U, 20U	20U, 20U	33.0, 20U

U = Undetected. Number is the detection limit.

Results and summary statistics of blind laboratory and field replicate samples (e.g., mean and relative percent difference) are presented under separate cover in the QA memorandum in Appendix A-3.

2.6.5.2 Spatial Trends. The concentration of aluminum and iron was highly variable with no trend apparent in the river (Figure 2-13). Concentrations of iron and aluminum that were reported as undetected due to the presence of iron and aluminum in the method blank are also presented here to illustrate river trends of these metals. Extremely high peaks of both aluminum and iron were measured at stations W42 and W43 in the upper river (1100 and 1300 µg/L of aluminum and 1300 and 1800 µg/L of iron, respectively). Peaks were also noted at the shore-based bacteria sampling stations W3 (1,300 µg/L of aluminum and 1800 µg/L of iron) and W16 (1100 µg/L of aluminum and 1300 µg/L of iron). Because aluminum and iron are primarily associated with sediments, the aluminum and iron data were compared to the TSS and turbidity data (see Figure 2-13). The peaks at the shore-based stations W3 and W16 coincide with peaks in TSS and, to a lesser extent, to turbidity. The peaks in aluminum and iron at stations W42 and W43 did not, however, correspond to peaks in either TSS or turbidity.

Several trace metals (antimony, arsenic, beryllium, mercury, silver, and thallium) and cyanide were not detected in any of the water samples at concentrations above the DL (Table 2-9). However, the DLs for a few of these samples were very high due to laboratory dilution of the estuarine samples to control interferences from the high concentration of additional ions present in seawater. Therefore, sample dilution resulted in two DLs for those samples. For example, the DLs for samples collected in the estuary for antimony and thallium were 150 and 360 µg/L, respectively.

Barium, cadmium, chromium, copper, lead, nickel, selenium, and zinc were detected above their respective DLs at several stations. Barium was detected above the DL of 10 µg/L at 44 of the 45 water quality stations, with a median concentration of 26 µg/L (Table 2-9). The concentration of barium was fairly constant throughout the river and ranged from undetected (DL=10 µg/L) to a maximum of 42 µg/L at station W5 at the mouth of the Lewis and Clark River (Figure 2-14). Copper was detected above the DL of 5 µg/L less frequently (10 of 45 stations) with a median concentration of 2.5 µg/L (Table 2-9). The detected concentrations of copper were variable, with the highest concentrations occurring at station W28

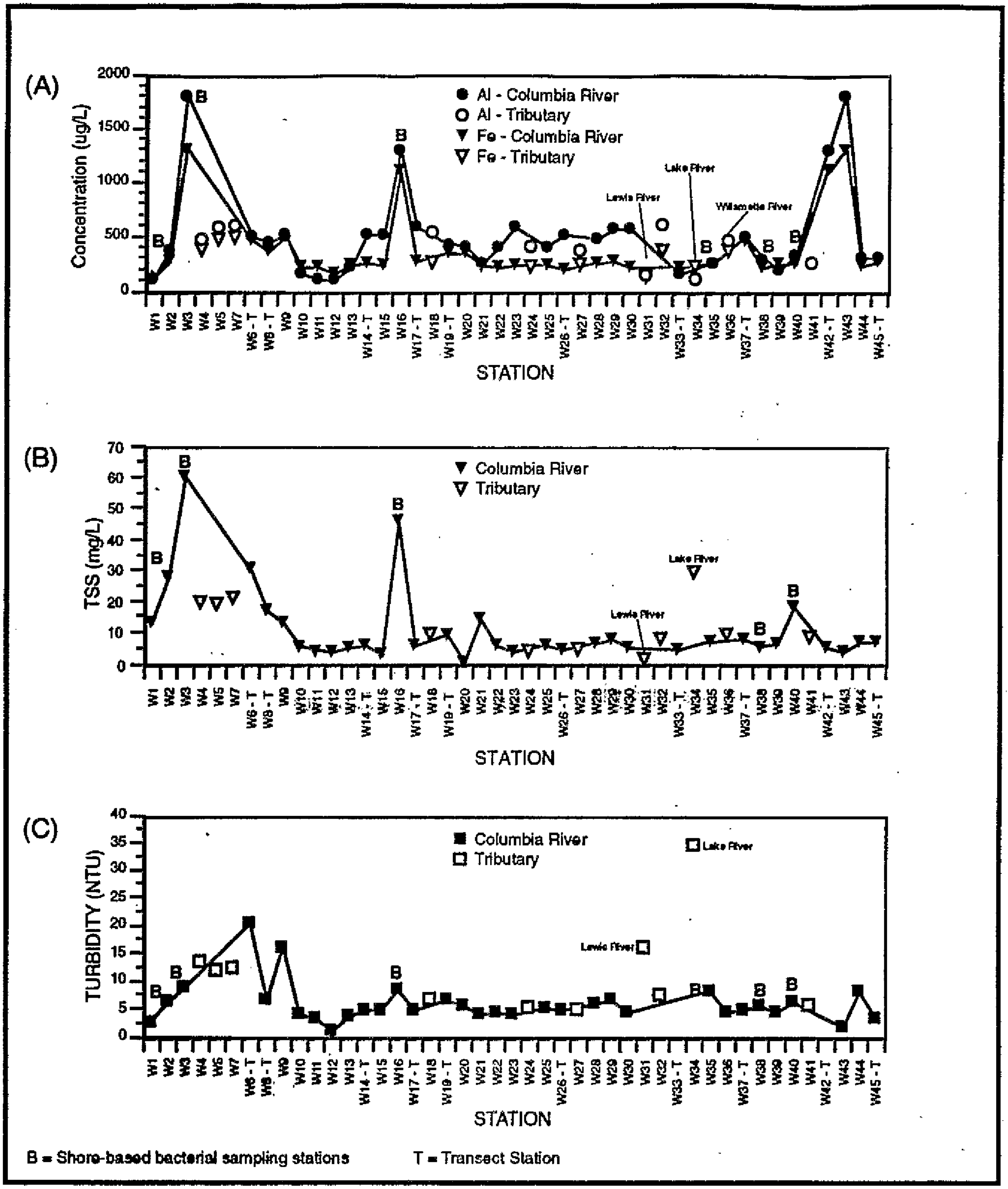


Figure 2-13. Trends in A: Aluminum and Iron and Comparison with B: Total Suspended Solids (TSS) and C: Turbidity, in the Lower Columbia River, September - October 1991

TABLE 2-9. SUMMARY OF WATER COLUMN METALS AND CYANIDE DATA FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY[a,b]

(Page 1 of 2)

Parameter	Frequency of Detection	Detection Limit(s)	Units in ug/L		Chronic Water Quality Criteria		Water Quality Criteria for Fish Consumption[d]
			Range	Median[c]	Freshwater	Marine	
Aluminum	45/45	--	120-1300	250	87	--	--
Antimony	0/45	15, 150[e]	15U-150U	7.5U	1,600[f]	--	45,000
Arsenic[g]	0/45	5	5U	2.5U	48 (190)[f,h]	13 (36)[f,h]	0.0175[i]
Barium	44/45	10	10U-42	26	--	--	--
Beryllium	0/45	5	5U	2.5U	5.3[f]	--	0.117[i]
Cadmium[j]	3/45	0.5, 5[b]	0.5U-3.5	0.25	0.7[k,l]	9.3 (8.0)[j]	--
Chromium[g]	3/45	5	5U-5.5	2.5	11[m]	50[m]	3.433 x 10^6 [n]
Copper[j]	10/45	5	5U-54	2.5	7.3[k,o]	--	--
Iron[j]	43/45	100	100U-1800	430	1,000	--	--
Lead[j]	25/45	1, 20[b]	1U-8	2.1	1.6[k,p]	5.6 (5.8)[j]	--
Mercury[g]	0/45	0.5	0.5U	0.25U	0.012	0.025	0.146
Nickel[j]	0/45	40	40U	20	98[k,q]	8.3 (7.9)[j]	100
Selenium[g]	3/45	5, 100[b]	5U-22	2.5	5.0	71	--
Silver[j]	0/45	2	2U	1U	0.12	--	--
Thallium	0/45	36, 360[b]	36U-360U	18U	40[f]	--	48
Zinc[j]	12/45	20	20U-84	10	66[k,r]	86 (76.6)[j]	--
Cyanide	0/45	2	2U	1U	5.2	--	200

TABLE 2-9. SUMMARY OF WATER COLUMN METALS AND CYANIDE DATA FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY[a,b]

(Page 2 of 2)

U = Undetected.

-- = Not available.

[a] Criterion is the same for Oregon, Washington, and U.S. EPA for the protection of aquatic organisms, except where noted.
[b] All metals data have been qualified as estimated. See text for details.
[c] Median based on detected concentrations and half the detection limit for undetected concentrations.
[d] Human health water quality criteria for ingestion of fish and shellfish. These criteria are based on the predicted water concentration of a particular contaminant that would not result in an adverse human health effect for a non-carcinogen, and for carcinogens, a lifetime incremental increase in cancer risk of one additional cancer in populations ranging from 10 million to 100,000 people.
[e] The higher detection limit was due to dilution of the sample before analysis.
[f] No criteria established. Value is the lowest observed effects level (LOEL).
[g] Updated Washington criterion based on measurement of total recoverable metal concentration (WAC 1992).
[h] Least observed effects level (LOEL) for pentavalent arsenic. Chronic criterion for trivalent arsenic in parentheses.
[i] The metal is a carcinogen. Human health criteria reported for three risk levels. Value presented is the incremental risk of one cancer in a population of one million people.
[j] Updated Washington criterion based on measurement of dissolved metal concentration (WAC 1992).
[k] Criterion is hardness dependent. The median freshwater hardness from this study (57mg/L) was used.
[l] Formula for calculating criterion for cadmium is $e^{(0.7852\ [\ln\ (\text{hardness})]\ -\ 3.490)}$. The result is multiplied by 0.865 for application of the Washington updated dissolved criterion (WAC 1992).
[m] Criterion for hexavalet chromium.
[n] Criterion for trivalent chromium.
[o] Formula for calculating criterion for copper is $e^{(0.8545\ [\ln\ (\text{hardness})]\ -\ 1.465)}$. The result is multiplied by 0.862 for application of the Washington updated dissolved criterion (WAC 1992).
[p] Formula for calculating criterion for lead is $e^{(1.273\ [\ln\ (\text{hardness})]\ -\ 4.705)}$. The result is multiplied by 0.687 for application of the Washington updated dissolved criterion (WAC 1992).
[q] Formula for calculating criterion for nickel is $e^{(0.8460\ [\ln\ (\text{hardness})]\ +\ 1.1645)}$. The result is multiplied by 0.950 for application of the updated Washington criterion (WAC 1992).
[r] Formula for calculating criterion for zinc is $e^{(0.8473\ [\ln\ (\text{hardness})]\ +\ 0.7614)}$. The result is multiplied by 0.891 for application of the updated Washington criterion (WAC 1992).

Source: OAR (1990), WAC (1988, 1992), U.S. EPA (1986a).

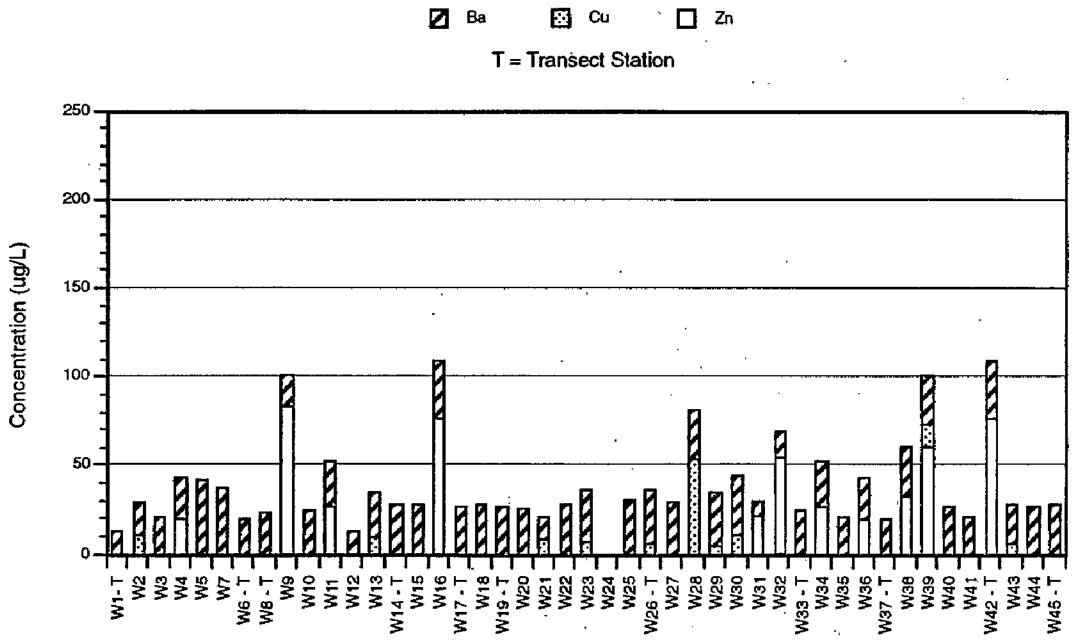


Figure 2-14. Trends in Barium, Copper, and Zinc, in the Lower Columbia River, September-October 1991.

behind Sandy Island (54 μg/L) (Figure 2-14). Zinc was also detected above the DL of 20 μg/L at 12 of 45 stations with a median concentration of 10 μg/L (Table 2-9). The highest concentration measured was at station W9 in Grays Bay (84 μg/L) (Figure 2-14). Concentrations above 50 μg/L were measured at stations W16 (the shore-based bacteria sampling station near Puget Island), W32 (Multnomah Channel) W39 (in the main channel between Camas and Vancouver), and W42 (above Camas).

Lead was detected above the DL of 1 to 20 μg/L at 25 of the 45 stations with a median concentration of 2.1 μg/L (Table 2-9). The higher DL was reported at only four of the stations located in the estuary, where lead was not detected at stations with the lower 1 μg/L DL. Lead was detected in varying concentrations at a number of stations in the upper portion of the study area below Bonneville Dam. It was also detected at all stations from W34 (Lake River) below the Portland/Vancouver area to station W14 at RM 37.5, the transect station below Cathlamet and Wauna. This station is also just above the point where the river widens, river velocity decreases, and sedimentation of particulate matter increases (Tetra Tech 1992b). Highest concentrations were noted at stations W23 in the channel behind Lord Island (8.8 μg/L) and the transect station W26 in the main channel below Kalama.

Of the other metals detected, chromium was above the DL of 5 μg/L at 3 of the 45 stations with a median concentration of 2.5 μg/L (see Table 2-9). The highest concentration of chromium (5.5 μg/L) was measured at two stations, station W6 off Tongue Point and station W37 in the Portland/Vancouver area (Figure 2-15). Selenium was detected above the DLs of 5 and 100 μg/L at 3 of the 45 stations with a median concentration of 2.5 μg/L (Table 2-9). The higher DLs were reported for several stations in the estuary. Very high concentrations of selenium were reported for two stations. These stations were W23 in the channel behind Lord Island (16 μg/L) and the transect station W26 below Kalama (32 μg/L), although selenium was also detected at the transect station W30 (6 μg/L) (Figure 2-15). Cadmium was detected above the DL of 0.5 and 5 μg/L at 3 of the 45 stations with a median concentration of 0.25 μg/L (Table 2-9). The higher DLs were reported for several stations in the estuary. However, cadmium was not detected at the few estuarine stations with the lower DL of 0.5 μg/L. Cadmium was detected at stations W22 (1.2 μg/L), W28 (2.9 μg/L), and W37 (3.5 μg/L).

Of the metals analyzed, only iron, barium, and zinc were detected at the Willamette River station (W36), but other trace metals were not detected including cadmium, chromium, copper, lead, nickel, and selenium. The aluminum concentration was qualified as undetected at a concentration of 370 μg/L.

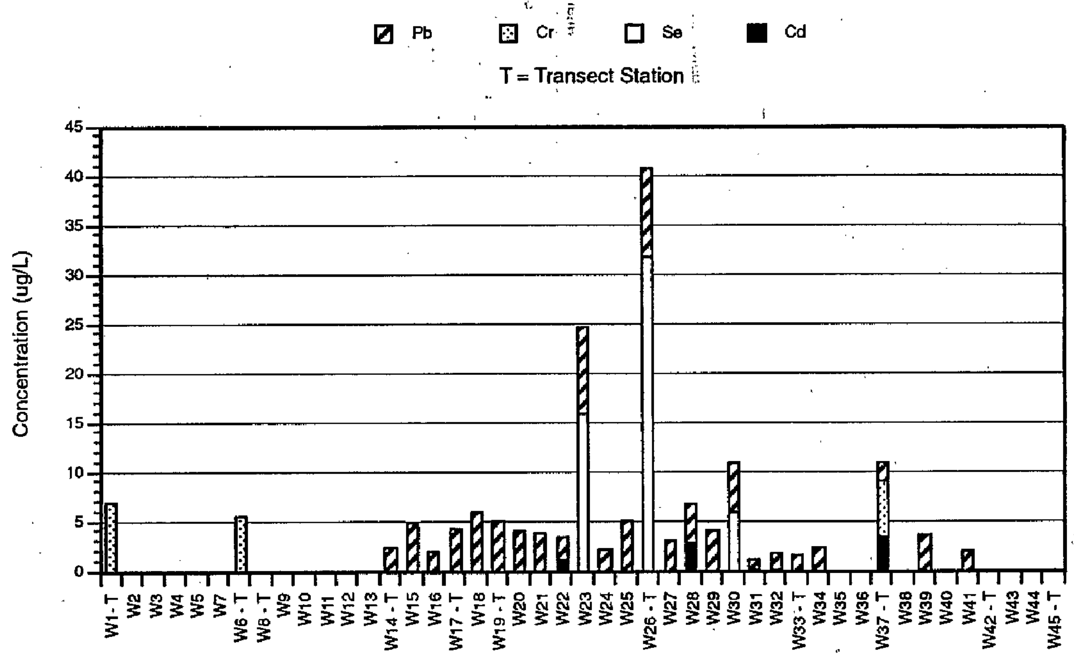


Figure 2-15. Trends in Lead, Chromium, Selenium, and Cadmium in the Lower Columbia River, September-October 1991.

2.6.5.3 Comparison with Water Quality Criteria. U.S. EPA freshwater chronic water quality criteria are available for cyanide and most of the metals measured in the reconnaissance survey, except barium (see Table 2-9). Oregon and Washington have adopted the EPA (U.S. EPA 1986a) metals criteria (WAC 1988; OAR 1990). The recently revised water quality standards for Washington waters have also adopted the use of dissolved and total recoverable metal concentration limits for specific metals (WAC 173-201A 1992) (see Table 2-9). Marine chronic criteria have been established for eight of the metals measured. Generally, the marine criteria are less restrictive than those for freshwater, with the exception of the criteria for nickel and arsenic. Freshwater criteria for several of the metals depend on the hardness of the water tested. These metals are cadmium, copper, lead, nickel, and zinc. To assess possible exceedances of these hardness-based criteria in the non-estuarine portion of the river, the median hardness of 57 mg/L was used to calculate the criteria for these metals.

Historically, EPA has recommended the measurement of total recoverable or acid-soluble concentrations of metals for comparison with the established water quality criteria for metals in ambient waters (U.S. EPA 1986a). The use of the total recoverable method is still recommended for evaluation of effluent quality (U.S. EPA 1992). However, EPA has recently (since the reconnaissance survey was conducted) re-evaluated the use of these methods for the assessment of water quality compliance for metals in ambient waters (U.S. EPA 1992). This guidance supersedes past criteria document statements expressing criteria in terms of an acid soluble or total recoverable method. In general, the EPA has stated that although use of the total recoverable measurement provides greater safety than does the dissolved method, the total recoverable method may result in overestimation of metal toxicity. The EPA has further stated that while adjustment of the criteria to dissolved metal may be small for some metals (e.g., copper), other metals may require larger adjustments to account for the much lower percentage of dissolved to particulate metal present during toxicity testing (e.g., aluminum) (U.S. EPA 1992). Three approaches have been recommended by EPA for applying the metals criteria (U.S. EPA 1992):

- Continue to use the total recoverable method for water quality standard assessment.

- Measure dissolved metal concentration and compare these concentrations to criteria appropriate for dissolved metal.

- Use case-by-case assessment of the "water-effect ratio" in the receiving water to determine a site-specific value of the criteria.

Although the first recommendation has been applied in this study, the other approaches should be considered in future studies of the lower Columbia River. The use of dissolved metal measurements and criteria has been recently adopted by the state of Washington for several metals (i.e., cadmium, copper, iron, lead, nickel, silver, and zinc; see Table 2-9) (WAC-201A, 1992).

Although the state of Washington designates the Columbia River to the mouth as freshwater, the state of Oregon provides for the application of marine criteria in the estuarine portion of the river (Mullane, N., 22 July 1992, personal communication). Therefore, to ensure adequate assessment of potential effects on aquatic organisms, the lowest of the marine or freshwater criteria will be used for the identification of water quality problems in the estuary.

Water quality criteria for the consumption of fish have also been compared (see Table 2-9). The water quality criteria for fish consumption are water-column concentrations that would not result in an adverse health effect for a non-carcinogen, and for carcinogens, a concentration that would result in a lifetime incremental increase in cancer risk of one additional cancer in human populations ranging from 10 million to 100,000 people. These criteria are presently available for cyanide and seven metals measured in the reconnaissance survey. They include antimony, arsenic, beryllium, chromium, mercury, nickel, and thallium. The fish consumption criteria for arsenic, beryllium, and chromium are even more restrictive than the freshwater and marine criteria, while the criteria for antimony, mercury, nickel, thallium, and cyanide are less restrictive.

Detection limits were higher than the water concentration criteria for fish consumption for arsenic and mercury, which prevents an assessment of potential effects on human health due to the consumption of fish (see Table 2-9). Detected water metal concentrations did not exceed available metal water concentration criteria for fish consumption for antimony, beryllium, chromium, nickel, thallium, or cyanide.

The available chronic freshwater quality criteria were never exceeded for antimony, beryllium, chromium, nickel, thallium, or cyanide. In some cases, the exceedances of water quality criteria could not be assessed because the DLs were higher than the available criteria. This was true for the freshwater chronic criteria for lead, mercury, selenium, and silver and for the marine chronic criteria for lead, mercury, nickel, and selenium. The concentrations of aluminum that were qualified as undetected due to possible laboratory contamination also exceeded the freshwater quality chronic criterion for aluminum.

Exceedances of the freshwater chronic criteria due to detected concentrations occurred for these metals: aluminum, cadmium, copper, iron, lead, and zinc. The exceedances of the chronic freshwater criterion for aluminum (87 μg/L) occurred at all stations where aluminum was not qualified as undetected (Figure 2-16). The lowest concentration reported as undetected (120 μg/L) was over 30 μg/L higher than the chronic freshwater criterion. The freshwater criterion for cadmium (0.7 μg/L) was exceeded at stations W22 (1.2 μg/L), W28 (2.9 μg/L), and W37 (3.5 μg/L) (Figure 2-17). The higher cadmium DL of 5 μg/L for six stations in the estuary, and station W9 above the estuary, exceeded the freshwater chronic criterion of 0.7 μg/L. However, the DL of 5 μg/L is lower than the marine chronic criterion of 9.3 μg/L. Exceedances of the freshwater criterion for copper (7.3 μg/L) occurred at 8 stations [W2 (11 μg/L), W13 (10 μg/L), W21 (9 μg/L), W23 (8 μg/L), W28 (54 μg/L), W30 (11 μg/L), W31 (47 μg/L), W32 (47 μg/L), W39 (13 μg/L)] (Figure 2-17).

Exceedances of the freshwater criterion for iron (1,000 μg/L) occurred at four stations: at the shore-based stations W3 in Ilwaco and W16 near Puget Island (1300 μg/L), and stations W42 near the mouth of the Sandy River (1300 μg/L) and W43 (1800 μg/L) in the upper reach of the study area below Bonneville Dam (Figure 2-17). No marine criterion for iron is currently available for comparison with the data collected from the estuarine stations. Exceedances of the freshwater criterion for lead (1.6 μg/L), based on detected concentrations, occurred at 22 stations (see Figure 2-18). The DL reported for four of the estuary stations (20 μg/L) was higher than the freshwater criterion of 1.6 μg/L; lead was not detected at other estuarine stations with the lower DL of 1 μg/L. The 20 μg/L detection limit was also greater than the marine chronic criterion of 5.6 μg/L. All three of the detected concentrations of selenium exceeded the chronic freshwater criterion of 5 μg/L (Figure 2-18). Samples from eleven stations exceeded the freshwater criterion for selenium based on the DL of 100 μg/L reported for samples collected at those stations. Although the DL for selenium at all but one station in the estuary was greater than the chronic marine criterion of 71 μg/L, at station W4 selenium was not detected above the DL of 5 μg/L. Exceedances of the freshwater criterion for zinc (66 μg/L) occurred at four stations (W9, W16, W32, W42) (see Figure 2-18). No exceedances of the marine criterion for zinc (86 μg/L) were noted in the estuary.

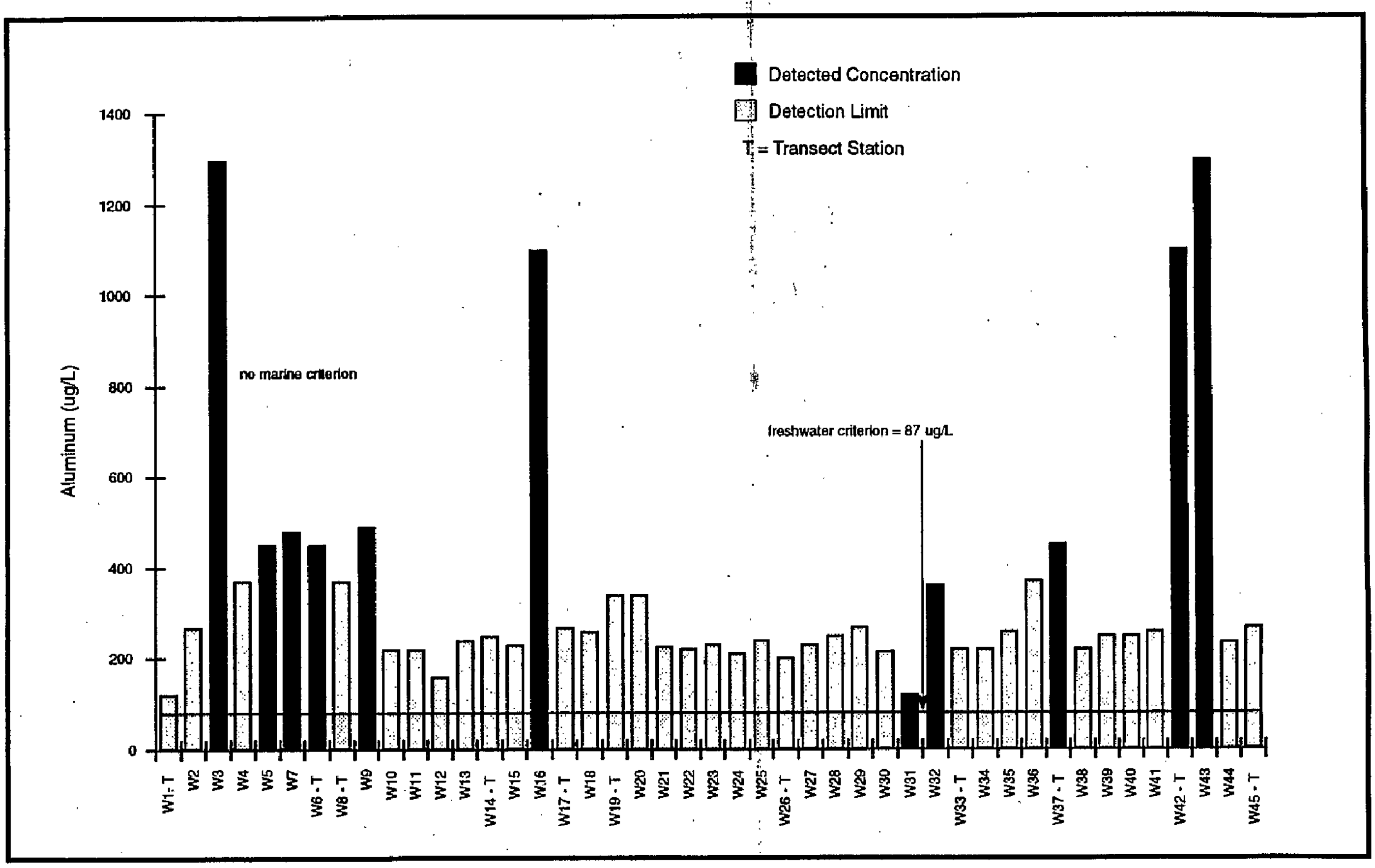


Figure 2-16. Comparison with Chronic Criteria for Aluminum in the Lower Columbia River, September-October 1991.

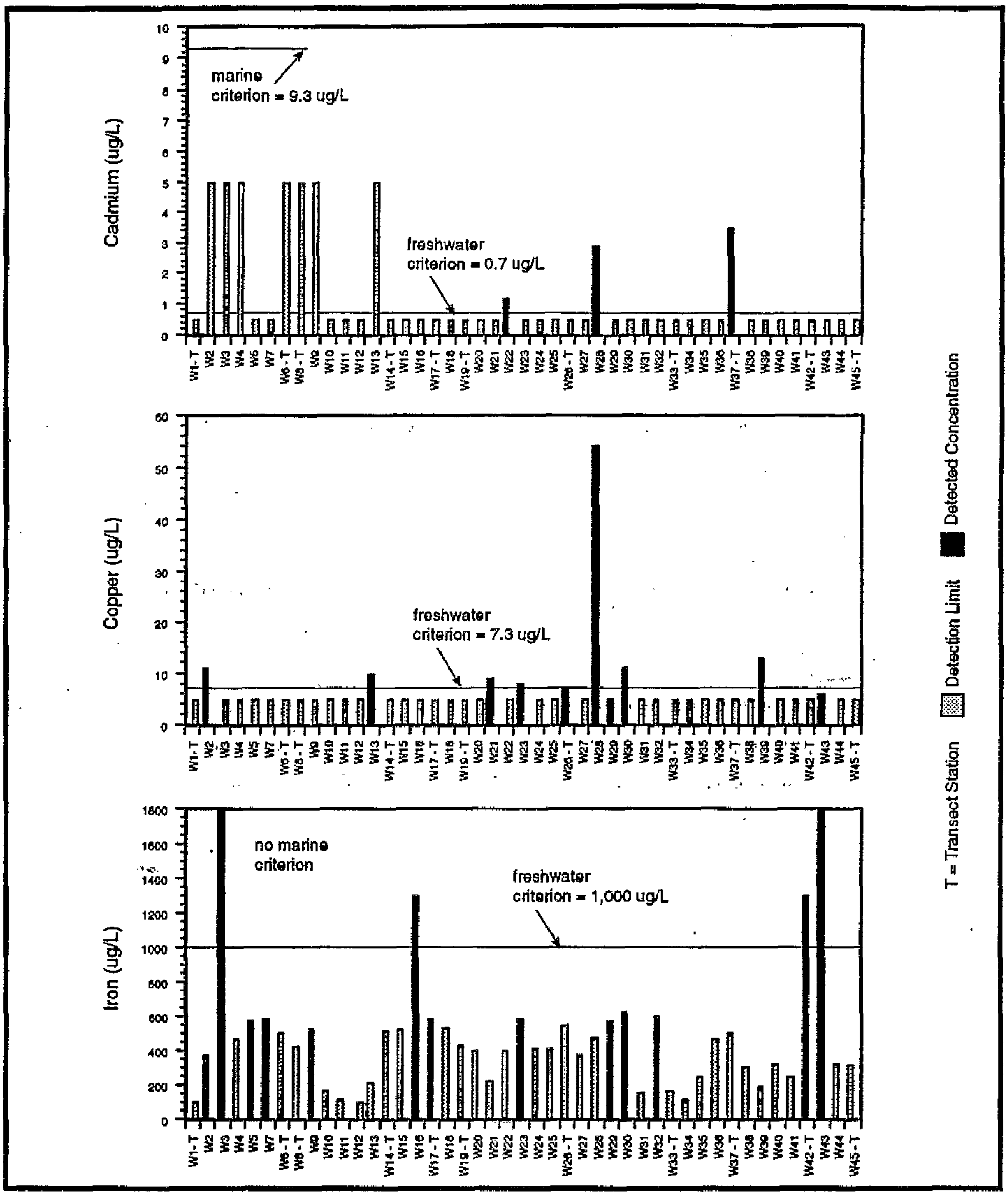


Figure 2-17. Comparison with Chronic Criteria For Cadmium, Copper and Iron in the Lower Columbia River, September-October 1991

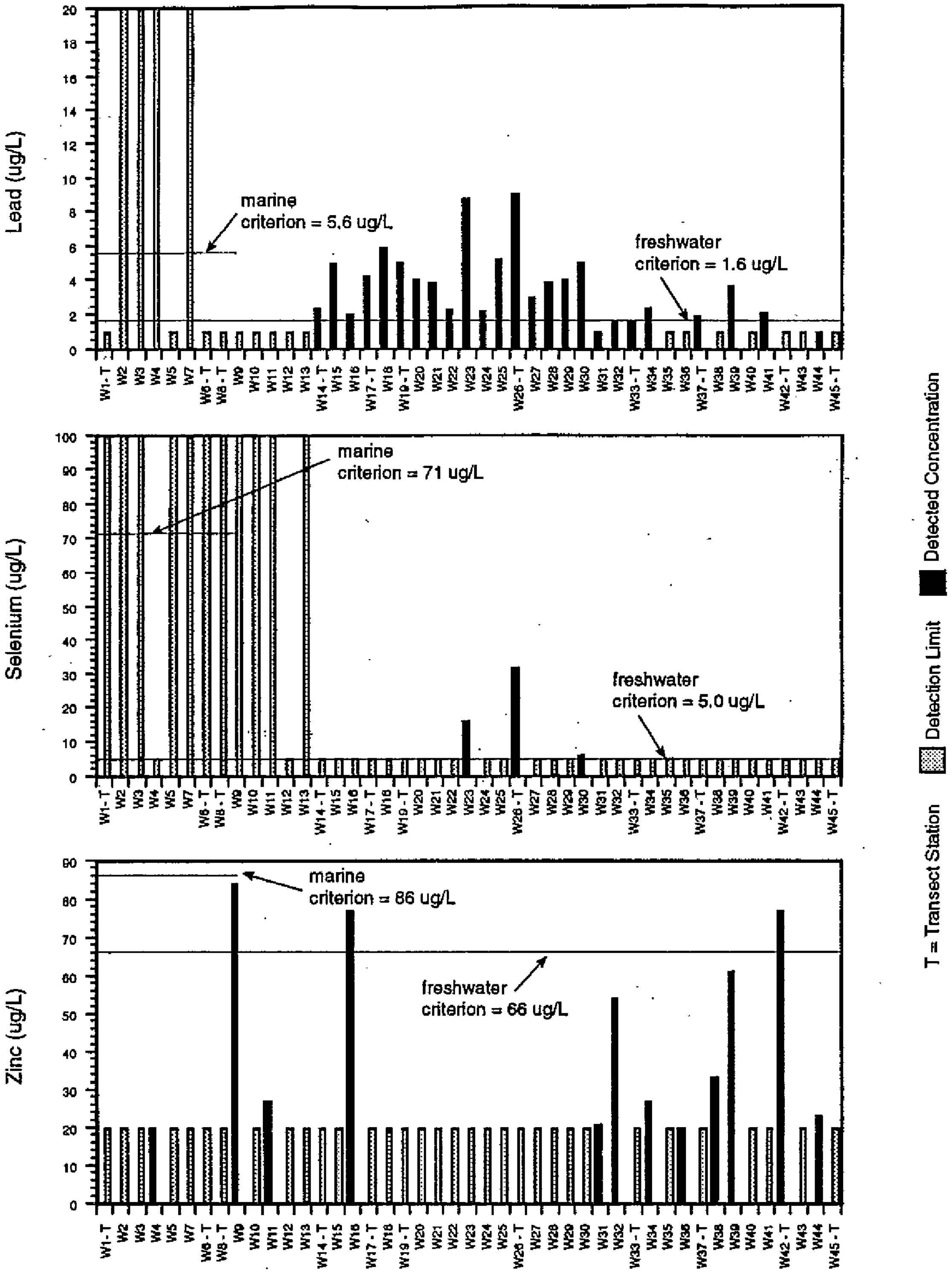


Figure 2-18. Comparison of Chronic Criteria with Lead, Selenium, and Zinc in the Lower Columbia River, September-October 1991

2.6.6 Organic Compounds

The discussion of the organic compound data is divided into separate sections on priority pollutant organic compounds and pesticides and a section on adsorbable organic halogens (AOX), due to the distinct nature of these compounds and the rationale for their inclusion in the reconnaissance survey. Priority organic pollutants are considered toxic when in sufficient concentration; they may derive from a variety of point and nonpoint sources. AOX on the other hand are discharged in relatively high concentrations in bleached kraft pulp and paper mill wastewater. They are not considered a toxic pollutant, although specific halogenated organic compounds measured indirectly as AOX are highly toxic. Complete raw data for semivolatile organic compounds, volatile organic compounds, pesticides and PCBs, and AOX are provided under separate cover in Appendices B-6, B-7, B-8, and B-9, respectively.

2.6.6.1 Summary of Quality Assurance/Quality Control

Semivolatile Organic Compounds. Field samples for semivolatile organic compounds were collected from stations W6, W14, W26, W37, and W45. A field duplicate was analyzed from station W26 (identified as sample W52), and two carboy blanks were analyzed from stations W37 and W41 (identified as samples W47 and W51, respectively). The semivolatile organic compound data were considered acceptable for use in this report, with the exception of the data for station W6. All of the data for station W6 were qualified as unusable (qualifier code "R") due to unacceptably low surrogate spike recoveries. In addition, method blank analyses indicated possible contamination of the station W6 sample with the common laboratory contaminant bis(2-ethylhexyl)phthalate. The reported concentration of this compound in sample W6 was above the DL, but below the value detected in the blank. Because the semivolatile data for station W6 have been qualified as unusable, they will not be discussed further in the report. Most of the semivolatile organics data were qualified with a "U" for values at or below the DL. The DLs (2-40 μg/L) were within those established in the QA/QC plan (Tetra Tech 1991b).

Results and summary statistics of blind laboratory and field replicate samples (e.g., mean and relative percent difference) are presented under separate cover in the QA memorandum in Appendix A-4.

Volatile Organic Compounds. Field samples for volatile organic compounds were collected from stations W6, W14, W26, W37, and W45. A field duplicate was analyzed from station W26 (identified as sample W52) and two carboy blanks were analyzed from stations W37 and W41 (identified as samples W47 and W51, respectively). The volatile organic compound data were considered acceptable for use in this report. Most of the data were qualified with a "U" for values at or below the DL. The DLs (1-10 µg/L) were within those established in the QA/QC plan (Tetra Tech 1991b). Method blank analyses did not indicate contamination of any samples; therefore, no data were qualified based on method blank results.

Results and summary statistics of blind laboratory and field replicate samples (e.g., mean and relative percent difference) are presented under separate cover in the QA memorandum in Appendix A-5.

Pesticides and PCBs. Field samples for pesticides and PCBs were collected from stations W6, W14, W26, W37, and W45. A field duplicate was analyzed from station W26 (identified as sample W52) and two carboy blanks were analyzed from stations W37 and W41 (identified as samples W47 and W51, respectively). The pesticide and PCB data were considered acceptable for use in this report. One compound, nonachlor, specified in the sampling plan was not reported (Tetra Tech 1991c) due to lack of a suitable standard for this compound. All of the data were qualified with a "U" (undetected) for values at or below the DL. The reported concentrations of endosulfan sulfate and methoxychlor in two samples from station W26 (W26 and the field duplicate W52) were qualified with an "E" (estimated value) as a result of the laboratory continuing calibration falling outside QC criteria. However, these values were also qualified as undetected at the DL and will be treated as undetected values below. The reported concentrations of dieldrin and endrin aldehyde at station W6 were qualified with a "U" and an "E" due to unacceptably high matrix spike and matrix spike duplicate recoveries reported for this sample, even though the reported concentrations (0.06 µg/L and 0.07 µg/L for dieldrin and endrin aldehyde, respectively) were slightly greater than the reported DL of 0.05 µg/L. These two compounds will be treated as undetected in the sample from station W6. The DLs (0.05-5.0 µg/L) were within those established in the QA/QC plan (Tetra Tech 1991b), except for the DL reported for dicofol (0.5 vs. 0.05 µg/L).

Results and summary statistics of blind laboratory and field replicate samples (e.g., mean and relative percent difference) are presented under separate cover in the QA memorandum in Appendix A-6.

AOX. Field samples for AOX were collected from 19 stations. A field duplicate was analyzed from station W26 (identified as sample W52). No carboy blanks were analyzed; therefore, an assessment of possible field contamination cannot be made. Blanks reported by the laboratory indicated methodological contamination of the samples. Blank-corrected data were indicated by the "Z" qualifier code. The DL reported by the laboratory of 5 μg/L was less than the method DL of 10 μg/L specified in the QA/QC plan (Tetra Tech 1991b). The laboratory reported the concentration of AOX to the nearest 5 μg/L. These data were qualified as blank-corrected and as undetected when the blank correction resulted in a concentration below the DL. These data were considered acceptable for use in this report.

Results and summary statistics of blind laboratory and field replicate samples (e.g, relative percent difference) are presented under separate cover in the QA memorandum in Appendix A-1.

2.6.6.2 Semivolatile and Volatile Organic Compounds, Pesticides and PCBs. Only one priority pollutant organic compound was detected in the water column at a concentration above the DL at two stations. The bis(2-ethylhexyl)phthalate concentrations at station W26 below Kalama (9 and 15 μg/L) and W37 in the Portland/Vancouver area (18 μg/L) violated both the freshwater and marine water quality criteria of 3 and 3.4 μg/L, respectively, for phthalate esters (Table 2-10).

The rest of the compounds have been reported as undetected at the DL. However, in several instances the reported DL for a specific compound exceeded established chronic freshwater and marine water quality criteria (Table 2-10). These compounds include pentachlorophenol, hexachlorocyclopentadiene, forms of DDT and their metabolites, heptachlor, alpha-chlordane, aldrin, dieldrin, mirex, parathion, toxaphene, endrin, methoxychlor, and PCBs. These DLs exceed the criteria because of the difficulty in achieving DLs below these criteria using conventional analytical methods. It is possible that several of these compounds are present, but at undetectable concentrations using conventional methods. In the case where the DL exceeds the water quality criteria, it is not possible to assess whether or not levels greater than the criteria were present in the river during the reconnaissance survey.

In general, the DLs achieved in this study for toxic organic compounds were less than the water concentration criteria for fish consumption (see Table 2-10). However, DLs were greater than these criteria for 2,4,6-trichlorophenol, bis(2-chloroethyl)ether, all of the polynuclear aromatic hydrocarbons (PAHs) (except for fluoranthene), hexachlorobenzene, 3,3'-dichlorobenzidine, and the pesticides DDT,

TABLE 2-10. SUMMARY OF WATER COLUMN ORGANIC COMPOUND SAMPLE DETECTION LIMITS AND WATER QUALITY CRITERIA

(Page 1 of 6)

Compound	Reported Detection Limit	Units in ug/L Chronic Water Quality Criteria[a] Freshwater	Marine	Water Quality Fish Consumption Criteria[a]
VOLATILE ORGANIC COMPOUNDS				
Vinyl chloride	1	—	—	525[b]
Methylene chloride	10	—	—	—
1,1-Dichloroethane	1	—	—	—
Chloroform	1	1,240[c]	—	15.7[b]
1,1,1-Trichloroethane	1	—	—	$1.03x10^6$
Bromodichloromethane	1	—	—	—
trans-1,3-Dichloropropene	1	244[c]	—	14,100
Dibromochloromethane	1	—	—	—
Benzene	1	—	700[c]	40[b]
Bromoform	1	—	—	—
Tetrachloroethene	1	840[c]	450[c]	8.85[b]
Chlorobenzene	1	50[c,d]	129[c,d]	—
Total xylenes (o-, m, p-)	1	—	—	—
Chloroethane	1	—	—	—
1,1-Dichloroethene	1	—	—	1.85[b]
trans-1,2-Dichloroethene	1	—	—	1.85[b]
1,2-Dichloroethane	1	20,000[c]	—	243[b]
Carbon tetrachloride	1	—	—	6.94[b]
1,2-Dichloropropane	1	5,700[c]	3,040[c]	—
Trichloroethene	1	2,000[c]	—	80.7[b]
1,1,2-Trichloroethane	1	9,400[c]	—	41.8[b]
cis-1,3-Dichloropropene	1	244[c]	—	14,100
1,1,2,2-Tetrachloroethane	1	2,400[c]	—	10.7[b]
Toluene	1	—	5,000[c]	424,000
Ethylbenzene	1	—	—	3,280
Methyl chloride	1	—	—	—
Methyl bromide	1	—	—	—

TABLE 2-10. SUMMARY OF WATER COLUMN ORGANIC COMPOUND SAMPLE DETECTION LIMITS AND WATER QUALITY CRITERIA

(Page 2 of 6)

Compound	Units in ug/L			
		Chronic Water Quality Criteria[n]		
	Reported Detection Limit	Freshwater	Marine	Water Quality Fish Consumption Criteria[a]
SEMIVOLATILE ACID EXTRACTABLE ORGANIC COMPOUNDS				
Phenolic Compounds				
Phenol	2	2,560	--	--
2-Methylphenol	4	--	--	--
4-Methylphenol	4	--	--	--
2,4-Dimethylphenol	2	--	--	--
Pentachlorophenol	20	6-16[e]	7.9[c]	--
2-Chlorophenol	2	2,000[c]	--	--
2,4-Dichlorophenol	4	365[c]	--	--
2,4-Dinitrophenol	20	--	--	--
2-Nitrophenol	4	150[c,f]	--	--
4-Nitrophenol	20	150[c,f]	--	--
2,4,6-Trichlorophenol	4	970[c]	--	3.6[b]
SEMIVOLATILE BASE/NEUTRAL EXTRACTABLE ORGANIC COMPOUNDS				
Halogenated Ethers (Other than those listed elsewhere)				
bis(2-chloroethyl)ether	2	--	--	1.36[b]
bis(2-chloroethoxy)methane	2	--	--	--
bis(2-chloroisopropyl)ether	2	--	--	4,360
4-Bromophenylphenylether	4	--	--	--
4-Chlorophenylphenylether	2	--	--	--
Nitroaromatics				
2,4-Dinitrotoluene	2	230[c]	370[c,g]	9.1[b]
2,6-Dinitrotoluene	2	--	370[c,g]	--
Nitrobenzene	2	--	--	--
Nitrosamines				
N-nitroso-di-n-propylamine	2	--	--	--
N-nitrosodiphenylamine	2	--	--	16.1[b]

TABLE 2-10. SUMMARY OF WATER COLUMN ORGANIC COMPOUND SAMPLE DETECTION LIMITS AND WATER QUALITY CRITERIA

(Page 3 of 6)

Compound	Units in ug/L			
	Reported Detection Limit	Chronic Water Quality Criteria[n]		Water Quality Fish Consumption Criteria[a]
		Freshwater	Marine	
Chlorinated Naphthalene				
2-Chloronaphthalene	2	--	--	--
Polynuclear Aromatics				
Acenaphthene	2	520[c]	710[c]	0.0311[b,h]
Acenaphthylene	2	--	--	0.0311[b,h]
Anthracene	2	--	--	0.0311[b,h]
Benzo(a)anthracene	2	--	--	0.0311[b,h]
Benzofluoranthenes [(b) and (k)]	4	--	--	0.0311[b,h]
Benzo(a)pyrene	4	--	--	0.0311[b,h]
Benzo(g,h,i)perylene	4	--	--	0.0311[b,h]
Chrysene	2	--	--	0.0311[b,h]
Dibenzo(a,h)anthracene	4	--	--	0.0311[b,h]
Fluoranthene	2	--	16[c]	54[b,h]
Fluorene	2	--	--	0.00311[b,h]
Indeno(1,2,3-cd)pyrene	4	--	--	0.0311[b,h]
Naphthalene	2	620[c]	--	0.0311[b,h]
Phenanthrene	2	--	--	0.0311[b,h]
Pyrene	2	--	--	0.0311[b,h]
Chlorinated Benzenes		50[c]	129[c]	
1,3-Dichlorobenzene	2	763[c,i]	--	2,600
1,2-Dichlorobenzene	2	763[c,i]	--	2,600
1,4-Dichlorobenzene	2	763[c,i]	--	2,600
1,2,4-Trichlorobenzene	4	--	--	--
Hexachlorobenzene	4	--	--	$7.4x10^{-4}$[b]
Hexachlorinated Organic Compounds				
Hexachlorobutadiene	2	9.3[c]	--	50[b]
Hexachloroethane	4	540[c]	--	8.74
Hexachlorocyclopentadiene	10	5.2[c]	--	--

TABLE 2-10. SUMMARY OF WATER COLUMN ORGANIC COMPOUND SAMPLE DETECTION LIMITS AND WATER QUALITY CRITERIA
(Page 4 of 6)

Compound	Units in ug/L			
		Chronic Water Quality Criteria[n]		
	Reported Detection Limit	Freshwater	Marine	Water Quality Fish Consumption Criteria[a]
Benzidines				
3,3'-Dichlorobenzidine	20	--	--	0.02[b]
Phthalate Esters		3[c]	3.4[c]	
Dimethylphthalate	2	--	--	$2\text{x}10^{6}$
Diethylphthalate	4	--	--	$1.8\text{x}10^{6}$
Di-n-butylphthalate	2	--	--	154,000
Butylbenzylphthalate	2	--	--	--
bis-2-(ethylhexyl)phthalate	2	--	--	--
Di-n-octylphthalate	4	--	--	--
PESTICIDES/PCBs				
Pesticides				
o,p'-DDE	0.05	0.001[j]	0.001[j]	--
o,p'-DDD	0.05	0.001[j]	0.001[j]	--
o,p'-DDT	0.05	0.001[j]	0.001[j]	$2.4\text{x}10^{-5}$[b,j]
4,4'-DDT	0.05	0.001[j]	0.001[j]	$2.4\text{x}10^{-5}$[b,j]
4,4'-DDE	0.05	0.001[j]	0.001[j]	--
4,4'-DDD	0.05	0.001[j]	0.001[j]	--
Heptachlor	0.05	0.0038	0.0036[j]	$2.9\text{x}10^{-4}$[b]
Heptachlor epoxide	0.05	--	--	--
Total chlordane	0.05	0.0043[k]	0.004[k]	$4.8\text{x}10^{-4}$[b]
Aldrin	0.05	0.0019[l,o]	0.0019[l,o]	$7.9\text{x}10^{-5}$[b]
Dieldrin	0.05	0.0019[l]	0.0019[l]	$7.6\text{x}10^{-5}$[b]
Mirex (dechlorane)	0.05	0.001	0.001	--
Dacthal	0.05	--	--	--
Dicofol	0.05	--	--	--
Methyl parathion	0.05	--	--	--
Parathion	0.05	0.013	--	--
Malathion	0.05	0.1	0.1	--
Toxaphene	5	0.0002	0.0002	$7.3\text{x}10^{-4}$[b]

TABLE 2-10. SUMMARY OF WATER COLUMN ORGANIC COMPOUND SAMPLE DETECTION LIMITS AND WATER QUALITY CRITERIA

(Page 5 of 6)

	Units in ug/L			
		Chronic Water Quality Criteria[n]		
Compound	Reported Detection Limit	Freshwater	Marine	Water Quality Fish Consumption Criteria[a]
Isophorone[m]	2	--	--	520,000
Endosulfan I	0.05	0.056	0.0087	159
Endosulfan II	0.05	0.056	0.0087	159
Endosulfan sulfate	0.05	--	--	--
Endrin	0.05	0.0023	0.0023	--
Endrin aldehyde	0.05	--	--	--
Methoxychlor	0.05	0.03	0.03	--
alpha-BHC	0.05	--	--	--
beta-BHC	0.05	--	--	--
delta-BHC	0.05	--	--	--
gamma-BHC (Lindane)	0.05	0.08	--	--
PCBs				
Total PCBs	--	0.014	0.03	7.9x10^{-5}[b]
Aroclor 1016	0.5	--	--	--
Aroclor 1221	0.5	--	--	--
Aroclor 1232	0.5	--	--	--
Aroclor 1242	0.5	--	--	--
Aroclor 1248	0.5	--	--	--
Aroclor 1254	0.5	--	--	--
Aroclor 1260	0.5	--	--	--

TABLE 2-10. SUMMARY OF WATER COLUMN ORGANIC COMPOUND SAMPLE DETECTION LIMITS AND WATER QUALITY CRITERIA

(Page 6 of 6)

Source: OAR (1990); WAC (1988, 1992); U.S. EPA (1986a).

[a] Human health water quality criteria for ingestion of fish and shellfish. These criteria are based on the predicted water concentration of a particular contaminant that would not result in an adverse human-health effect for a non-carcinogen, and for carcinogens, a lifetime incremental increase in cancer risk of one additional cancer in populations ranging from 10 million to 100,000 people.

[b] Human health criteria reported for three risk levels. Value presented is the incremental risk of one cancer in a population of 1 million people.

[c] Insufficient data to develop criterion. Value presented is the lowest observed effects level (LOEL).

[d] Criterion for chlorinated benzenes.

[e] pH-dependent criterion. pH range of 7-8 used. Formula is $e^{[1.005\ (ph)\ -\ 5.29]}$.

[f] Criterion for nitrophenols.

[g] Criterion for dinitrotoluene.

[h] Value reported is for general category of PAHs.

[i] Criterion for dichlorobenzenes.

[j] Criterion is for DDT (and metabolites for Washington).

[k] Criterion is for alpha-chlordane.

[l] Aldrin is converted metabolically to dieldrin. Therefore, the sum of the aldrin and dieldrin concentrations is compared to the criterion.

[m] Technically not a pesticide, but analyzed by the same method. Synthesized from acetone, it is a solvent for finishes, laquers, cellulose resins, pesticides, fats, oils, and gums.

[n] Oregon, Washington, and U.S. EPA criterion the same for protection of aquatic organisms, except where noted.

[o] Washington criterion.

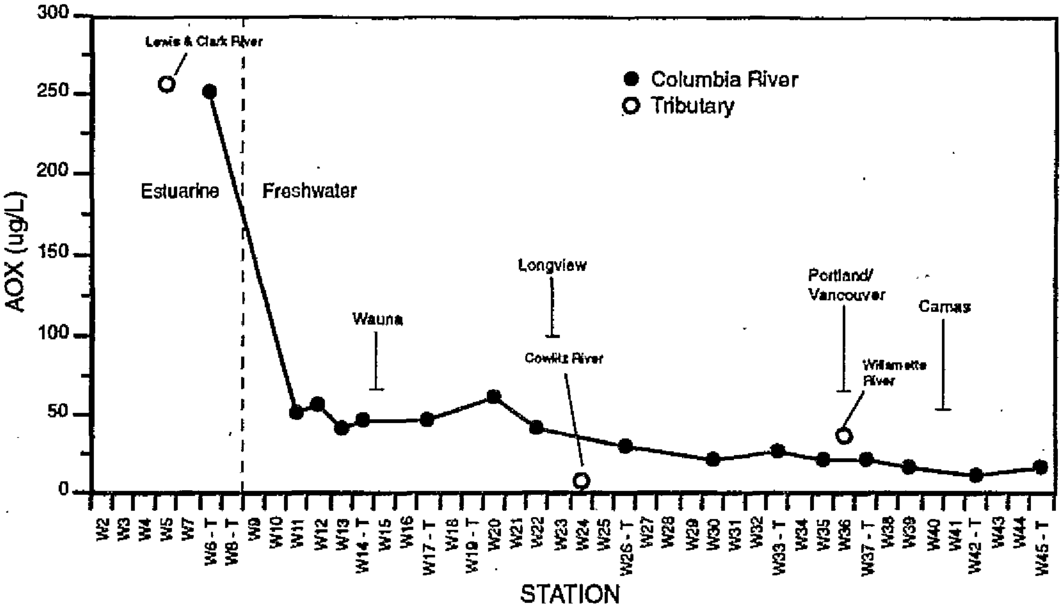
heptachlor, total chlordane, aldrin, dieldrin, toxaphene, and total PCBs; this prevents an assessment of potential effects on human health resulting from fish consumption. The only organic compound detected [i.e., bis(2-ethylhexyl)phthalate] does not currently have a fish consumption criterion for water.

2.6.6.3 AOX. AOX concentrations were measured at 19 stations, including two stations located in the Willamette and Cowlitz rivers (see Table 2-2). Concentrations ranged from 10 μg Cl⁻/L at station W42 in the upper river to over 250 μg Cl⁻/L at station W5 at the mouth of the Lewis and Clark River in the estuary (Figure 2-19). The general trend in AOX was for the concentration to increase from the upper river to the mouth, with the greatest increase evident at stations below Longview. The concentration of AOX in the Willamette River (station W36) was 35 μg Cl⁻/L, a higher concentration than that found at station W37 just above the confluence with the Columbia River (20 μg Cl⁻/L). The concentration of AOX in the Cowlitz River (station W24) was undetected at the reported DL of 5 μg Cl⁻/L. The high levels of AOX (>200 μg Cl⁻/L) measured in the estuary may be due to high concentrations of AOX associated with the higher levels of suspended sediment in the estuary, or they may be due to the interference of ocean-derived halogens with the coulometric method used for analysis of AOX. That is, the high chloride content of the estuarine water (greater than 10 mg/L at both stations sampled in the estuary) could have interfered with the conductivity measurement of AOX.

Because no ambient water quality criteria have been established for AOX, the significance of the levels of AOX in the river can not be assessed.

2.7 DISCUSSION

Sampling at 45 water column stations on the lower Columbia River and several tributaries during low-flow conditions resulted in identification of potential problems that may warrant further study. These problems were indicated by low DO and DO percent saturation at a few stations, elevated temperature in the upper river, and high levels of metals measured at several stations. Of all the organic compounds analyzed, only one was detected at two stations on the river. Phytoplankton biomass (biovolume) at the stations sampled was low, indicating that nutrient conditions in the river had not caused excessive growth of planktonic algae. These results are discussed in more detail below.



T = Transect Station

Figure 2-19. Trends in Adsorbable Organic Halogens (AOX) in the Lower Columbia River, September - October 1991

2.7.1 Field and Miscellaneous Parameters

Field and miscellaneous parameters surveyed include salinity, conductivity, pH, turbidity, TSS, temperature, DO, chloride, sulfate, and TOC. However, because exceedances of water quality criteria were noted only for DO, the discussion below largely focuses on this parameter. However, historical measurements of temperature indicate that the Washington temperature criterion of 20° C is exceeded and these historical data will be discussed as well.

Salinity and conductivity measurements were useful for characterizing the general ionic character of the sampled water column. Depth profiles of salinity, temperature, and Sigma-t indicate that during the sampling period, the estuary was stratified: the upper layer was dominated by river water and the lower layer by the intrusion of colder and denser ocean water. Therefore, the integrated samples collected in the estuary included some fraction of seawater that may be estimated from the average salinity. Average salinity concentrations from 28.5 ppt at the river mouth (station W1) to 5 ppt at station W8 define the limit of extensive intrusion and mixing of ocean water with the fresh river water. However, additional data on conductivity, chloride, and sulfate indicate that the influence of estuarine waters extended as far upriver as the Grays Bay station (W9) at RM 22, although salinity at this station was less than 1 ppt. Conductivity measurements at stations above the estuary serve as a good indicator of the ionic content of the water column. The conductivity of water sampled at shore-based stations was typically higher than that at stations located in the main channel of the river, indicating that these nearshore waters may not be as well flushed as the waters of the main channel. The higher conductivity at these stations may be indicative of nearby pollution sources. The low ionic content of several tributaries sampled during the survey was apparent. These tributaries included the Clatskanie, Cowlitz, Lewis, and Willamette rivers. The relatively higher ionic content of the Kalama and Lake rivers was also apparent. Conductivity is also a useful tool for identifying areas affected by large inputs of high ionic strength wastewaters. Higher conductivity, however, was not observed downstream of major urban and industrial areas.

The pH measured in the field was highly variable, but the freshwater and marine water quality criteria were not exceeded at any station.

Turbidity and TSS were generally lower in the mainstem of the river and somewhat higher at the estuarine stations near the river mouth. TSS was typically higher at several of the shore-based bacterial sampling stations due to resuspension of sediments in these shallow areas. Elevated turbidity and TSS were also noted for the Lewis and Lake rivers, indicating possible point or nonpoint sources of sediments and contaminants entering these rivers from their drainage basins.

TOC was generally not detected during this survey due to the relatively high detection limits achieved by the laboratory. Dahm et al. (1981) report monthly concentrations of TOC in the Columbia River at Kalama and Bonneville Dam for 1973 and 1974. TOC concentrations ranged from approximately 1.5 to 3.3 mg/L with slightly higher concentrations measured at Kalama due to organic pollutant input from the Portland/Vancouver area (Dahm et al. 1981).

Water temperature ranged from 19.1° C in the upper reach of the study area below Bonneville Dam to less than 11° C at the river mouth. Cooler waters were evident in the Cowlitz, Lewis, and Willamette tributaries. Cooler water was also noted at three upstream shore-based bacterial sampling stations, further suggesting differentiation of the waters close to shore from water in the main channel. The higher temperature at the shore-based station in Ilwaco (W3) is likely due to the sampling of warm, poorly mixed intertidal waters. Although the temperatures measured during the survey did not exceed established criteria, historical data identified by Tetra Tech (1992a) indicate that exceedances of the 20° C freshwater criterion established for the lower Columbia have occurred in the upper reach of the Columbia River within the study area below Bonneville Dam. These exceedances may be due, in part, to the impoundment of water behind hydroelectric and navigational dams in the Columbia River system.

Historically, water temperature in the lower Columbia River below Bonneville Dam ranges from minimum monthly average temperatures measured in December, January, and February and maximum monthly average temperatures reported for July, August, and September (Tetra Tech 1976). Water temperature observations made by the USGS at their Warrendale station at RM 141 in 1991 indicate that the Washington 20° C standard was exceeded on 40 days during the months of July, August, and September (Hubbard et al. 1991). A maximum temperature of 22° C was measured on five consecutive days in August (Hubbard et al. 1991). Hubbard et al. (1991) did not present data for July and August of 1992, but the maximum temperature reported in September was 21.5° C. A water quality study conducted by WDOE in 1990 (Johnson, A. and B. Hopkins, 30 April 1991, personal communication) found that temperatures in September 1990 were at the limit of the 20° C temperature standard. Hileman et al. (1975) also noted exceedances of temperature criteria at several lower Columbia River locations. These reports indicate that exceedances of the water temperature standard is a chronic problem in the study area below Bonneville Dam from July through September. Limited temperature data are available from the USGS at the recently re-established (June of 1991) Beaver Army Terminal station at RM 53.8, but the water temperature of 20.0° C reported for August 29, 1991 suggests that temperature standards in lower reaches of the study area may also exceed the standard during August.

A report by the USGS in 1968 (Moore 1968), prior to the establishment of the state standards for water temperature, contains a summary of temperature data for the lower Columbia River from 1938 to 1966. These data indicate that the mean monthly temperature typically exceeded 20° C in August during the period of record. Moore (1968) evaluated the historical data and concluded that the maximum effect of heated effluent discharges during peak plutonium production at Hanford was only as much as 1° F on the temperature of the Columbia River below Hanford during the warmest months. The effect of Hanford heated wastewater discharges in the immediate vicinity of the discharges was probably greater than the effect observed at the downstream temperature monitoring stations. The effects of variation in flow and climate were also considered as possible factors causing the observed increase in water temperature beginning in the mid-1950s, but these causes were ruled out. No temperature effect on the Columbia River due to the development of the reservoir and navigation system of the river was suggested by Moore (1968). However, Moore (1968) also pointed out that water releases from upstream impoundments (primarily the Grand Coulee and Brownlee Reservoir) provided relatively cooler water during the spring and early summer and relatively warmer water during the fall and winter.

Chloride and sulfate data generally reflect the trends already identified for conductivity. Because the Trojan Nuclear Power Plant was not operating during the reconnaissance survey, the effect of its sulfate discharge on the sulfate content of the river cannot be evaluated.

DO conditions in the river during the reconnaissance survey were below the state freshwater quality criteria of 8 mg/L and 90 percent DO saturation at ten freshwater stations below Bonneville Dam. The marine criterion of 6 mg/L of DO was exceeded at one station in the estuary (Skipanon River, W4). However, many of these exceedances were due to DO percent saturation falling slightly below the 90 percent saturation standard. Significant DO standards exceedances, less than 70 percent DO saturation, occurred at stations W4 (Skipanon River), W13 (near Skamokawa), and W34 (Lake River). The generally low DO content of the estuary in the fall has been noted in a previous study and has been attributed to natural excess biological respiration in the estuary during the fall (Park et al. 1972). The intrusion of ocean water with a relatively lower DO content may also be a factor (Haertel and Osterberg 1967). The low DO concentration noted at station W13 in the main navigational channel is more difficult to explain. There are no large point sources of oxygen-demanding wastes in the vicinity of this station. One potential source is nearby Skamokawa Creek. Although the water of this creek was not sampled directly during the reconnaissance survey, sediments with a septic odor were encountered during sediment sampling in the small embayment at the mouth of this creek (Tetra Tech 1991a). The low DO concentrations at this station may have been transitory, but they warrant confirmation of the field results and/or a preliminary investigation of sources of oxygen-demanding wastes near this station. Any further studies should focus on potential sources of oxygen-demanding wastes in the Skamokawa drainage basin.

2.7.2 Nutrients and Phytoplankton

Cultural or anthropogenic eutrophication (the increase in the nutrient supply to a receiving water due to human activities) has been a significant concern for the management of fresh, estuarine, and marine waters, especially for freshwater lakes (e.g., Beeton and Edmondson 1972; Paerl 1988). Under certain conditions this increase in nutrient input to a receiving water may result in increased production and/or biomass of phytoplankton. Conditions favorable for the formation of large standing crops of phytoplankton include adequate light, temperature, pH, nutrient supply, low rates of predation, and relatively long residence times. Any one of these factors may limit phytoplankton biomass or production. Phytoplankton biomass and production are not necessarily correlated, however. Although adequate supplies of nutrients and light may result in high rates of production, predation by zooplankton can keep phytoplankton biomass at relatively low levels. When certain conditions permit, algae, often species of blue-green algae (cyanobacteria), may bloom at levels causing aesthetically displeasing scums on the water surface and unpleasant odors due to rotting. Decaying algae may reduce DO, due to the microbial degradation process. Lowered DO levels may in turn affect other aquatic organisms.

2.7.2.1 Comparison with Historical Data. Nutrients measured in the reconnaissance survey included combined nitrate and nitrite nitrogen (NO_3+NO_2-N), ammonia nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN, the sum of total organic and ammonia nitrogen), and total phosphorus (TP, the sum of dissolved phosphate and particulate forms of phosphorus). However, these data were considered unusable due to the elevated detection limits reported by the analytical laboratory.

Historical information on nutrients in the Columbia River was summarized by Hileman et al. (1975). Based on studies conducted by U.S. EPA in 1971 and 1972, Hileman et al. (1975) concluded that the major proportion of nutrient loading to the mainstem of the Columbia River was attributable to tributary inputs. Their mass balance calculations suggested that the Snake and Willamette Rivers accounted for 57 to 80 percent of the tributary total nitrogen input and 46 to 85 percent of the tributary TP input. Hileman et al. (1975) recommended further studies that would include: (1) investigation of nutrient sources in the Snake and Willamette rivers, (2) design and implementation of a long-term monitoring system, (3) a complete point and non-point source waste inventory that would be updated continuously, and (4) the incorporation of additional parameters such as algal bioassays, phytoplankton productivity studies, and chlorophyll *a* analyses.

Recent nutrient data have been reported by WDOE for three dates in 1990 at two stations on the lower Columbia River at Bradwood (RM 39) and Warrendale (RM 141). These data include measurements of the concentration of nitrite plus nitrate nitrogen, ammonia nitrogen, and both total and soluble reactive phosphorus [soluble reactive phosphorus is the operationally defined soluble phosphorus fraction often incorrectly termed orthophosphate phosphorus (Rigler 1968,1973)]. These data indicate that soluble nitrogen levels range from 0.7 mg/L in May to 0.48 mg/L in January (see Table 2-11). Total phosphorus concentrations ranged from 0.03 to 0.07 mg/L. Soluble reactive phosphorus concentrations were generally lower than total phosphorus concentrations and ranged from below detection (less than 0.01 mg/L) to 0.04 mg/L. Generally, the concentration of total phosphorus associated with eutrophic conditions in lakes is 0.020 mg/L or greater (Welch 1980). Therefore, the concentration of total phosphorus reported by WDOE indicates that phosphorus is present in sufficient quantity to produce elevated concentrations of algal biomass.

Phytoplankton biomass (measured as total cell biovolume) and abundance (density) was relatively low in samples collected during the reconnaissance survey. The dominant taxa were diatoms, with the exception of an abundant cryptophyte (*Rhodomonas minuta*) at station W28. Results of this survey are consistent with the seasonal variation in Columbia River phytoplankton described by Haertel et al. (1969). Haertel et al. (1969) observed a seasonal variation in phytoplankton abundance, with the period of lowest abundance occurring during the low-flow period of September and October. The phytoplankton were always dominated by diatoms. For example, *Melosira italica* dominated phytoplankton abundance in the late winter and spring, and *Fragilaria crotonensis* and *Melosira granulata* dominated phytoplankton

TABLE 2-11. MEAN WATER NUTRIENT CONCENTRATIONS REPORTED BY WDOE FOR BRADWOOD (RM 39) AND WARRENDALE (RM 141) IN 1990.

DATE (1900)	STATION	Ammonia-N	Nitrite plus Nitrate-N	Total Phosphorus	Soluble Reactive Phosphorus
		Mean concentration in mg/L ±1 standard deviation, n = 3[a]			
January 9	Warrendale	0.01±0.00	0.26±0.00	0.05±0.01	0.05±0.01
	Bradwood	0.04±0.00	0.44±0.03	0.07±0.01	0.03±0.01
May 30	Warrendale	0.02±0.01	0.05±0.00	0.03±0.00	<0.01
	Bradwood	0.01±0.00	0.09±0.02	0.04±0.01	0.01±0.01
September 25	Warrendale	0.051±0.01	0.06±0.01	0.03±0.00	0.03±0.02
	Bradwood	0.033±0.01	0.06±0.01	0.04±0.01	0.02±0.00

" < " indicates that the concentration was below the laboratory detection limit. The value reported is the detection limit.

[a] Mean based on three sample results reported for "Left Bank," "Mid Channel," and "Right Bank" locations reported by WDOE.

SOURCE: Johnson, A., and B. Hopkins, 30 April 1991, personal communication to S. Saunders, WDOE.

abundance in summer and late summer. All of the dominant diatom taxa identified in the reconnaissance survey have been identified previously in water column samples from the lower Columbia River (Williams and Scott 1962; Williams 1964, 1972).

The marine diatom species dominated only the samples from the river mouth (station W1) to Tongue Point (station W8). The narrow range of estuarine/marine phytoplankton in the Columbia River estuary has been noted previously (Lara-Lara et al. 1990).

2.7.2.2 Significance and Recommendations. That generalizations about the relationship of nutrients and phytoplankton biomass can be made is not disputed; however, several investigators have emphasized the unique response of individual systems to nutrients and the need for adequate investigations to formulate rational water quality management plans (e.g., Velz 1984, p. 562; Edmondson 1991, p. 115). Although nutrients are likely present at levels sufficient to promote phytoplankton growth during the low-flow period, large masses of nuisance algae were not observed. This phenomenon has been noted in previous studies of the Columbia River (e.g., Hileman et al. 1975, Lara-Lara et al. 1990), and in the Willamette River (Rickert et al. 1977a). In the Columbia River mainstem, algal biomass appears to be controlled by the production and release of these algae from impoundments of the extensive hydroelectric and navigational dam system of the Columbia River (Robeck et al. 1954; Haertel et al. 1969; Dahm et al. 1981). Therefore, peak phytoplankton biomass and abundance in the lower Columbia River occurs mainly as a result of increases in the abundance of diatoms in spring in the upstream reservoirs and their release downriver as spring and early summer water flow increases.

To explain why nuisance growths of planktonic algae had not occurred in the Willamette River, Rickert et al. (1977a) proposed five hypotheses: (1) low temperature limitation, (2) light limitation, (3) trace-nutrient limitation, (4) major nutrient limitation, and (5) detention-time limitation. They concluded that the short detention time in the river was the major factor controlling algal biomass in the Willamette River. The study by Rickert et al. (1977a) also noted, however, that light limitation was a factor controling algal production in relatively turbid reaches with mixing depths greater than the euphotic zone of the river. Lara-Lara et al. (1990) also cite light limitation and detention time as primary factors in controling phytoplankton productivity in the Columbia River estuary. Due to the relatively high flushing rates and the rapid transition from fresh to saline water, freshwater phytoplankton cells are lysed at the freshwater-brackish water boundary. The areal primary productivity in the Columbia River estuary was one of the lowest recorded for a North American estuary due to rapid flushing times, loss of phytoplankton biomass due to cell lysis, and light limitation from elevated turbidity in the estuary (Lara-Lara et al. 1990a,b).

The phytoplankton assemblages observed during the low-flow period are more likely indicative of environmental conditions in upstream impoundments than of conditions in the main stem of the lower river. However, it may be useful to analyze a more limited number of phytoplankton samples on a seasonal basis to assess the present composition and abundance of phytoplankton present during the spring and early summer high-flow periods when phytoplankton abundance would be greatest. Phytoplankton samples should be coupled with additional nutrient sampling data to better quantify nutrient levels in the lower Columbia River. This information would also help in understanding the potential influence of large nutrient discharges on the Columbia River—including municipal and industrial wastewater sources and tributaries.

2.7.3 Bacteria

Fecal contamination of beneficial use waters has long been a concern because of the potential for associated input of pathogenic microorganisms and subsequent risks to public health. To circumvent the difficulties with direct detection of pathogens, other microorganisms such as the coliform and fecal enterococcus groups of bacteria have traditionally been used as surrogates to indicate possible fecal contamination of waters. The assumption underlying the use of such indicators is that these groups of bacteria would be present only if fecal contamination had recently occurred. Recent studies, however, increasingly demonstrate that fecal coliform bacteria also occur in pristine environments, and that their presence is not always well correlated with the occurrence of pathogens (Cabelli et al. 1982; Cabelli 1983a,b; Cabelli et al. 1983; Dufour 1984; O'Shea and Field 1991; Fujioka et al. 1988; Ferley et al. 1989; Geldenhuys and Pretorius 1989; WSDH 1991).

On the other hand, fecal enterococci, although suffering from some of the same limitations as indicators as the fecal coliform group (Toranzos 1991; Cornax et al. 1991), are generally regarded as valuable indicators of the extent of fecal contamination in surface waters (Cabelli et al. 1983; Cabelli 1983b; Dufour 1984; U.S. EPA 1986a; APHA 1989). Several epidemiological studies have indicated an association between defined enterococcus densities and swimming-associated gastrointestinal illnesses (Cabelli et al. 1982; Cabelli 1983a,b; Cabelli et al. 1983; Dufour 1984), leading to the promulgation of federal enterococcus standards for bathing waters (U.S. EPA 1986a). Cabelli et al. (1983) performed a prospective epidemiological study at marine bathing beaches that demonstrated that enterococcus was superior to several other bacteria (including *Escherichia coli*, *Klebsiella* sp., total coliforms, and fecal coliforms) as an indicator of the risk of acute gastroenteritis in swimmers exposed to fecal contaminated marine waters. Dufour (1984) conducted a prospective epidemiological study at freshwater bathing beaches that demonstrated that both *E. coli* and enterococcus bacteria were superior to fecal coliform bacteria as indicators of the risk of acute gastroenteritis in swimmers exposed to fecal-contaminated fresh waters. No state or federal standards have yet been promulgated for maximum enterococcus densities in shellfish harvesting waters. The EPA therefore recommends that standards for fecal coliforms be used in determining sanitary compliance of such waters (U.S. EPA 1986a).

With the exception of station W40 (Port of Portland), all bacterial sampling stations were located in primary contact recreational areas that included seasonal swimming uses. Despite the relatively low fecal coliform densities at these stations, the consistently high enterococcus densities exceeding federal standards suggest an impairment of water quality. The limited bacterial data collected in this survey further suggest that both primary contact recreation and shellfish harvesting in these areas may potentially involve public health risks.

Although the limited bacterial sampling locations and sample sizes for this study do not allow conclusions regarding the overall sanitary conditions in the river, the consistently high fecal enterococcus densities at all the primary contact recreation sites sampled indicate that water quality impairment may pose a health risk problem. It is therefore recommended that future water quality studies give higher priority to investigating bacterial conditions in the river.

2.7.3.1 Comparison with Historical Data and Identification of Potential Sources. Despite the extensive seasonal contact recreation that occurs in the lower Columbia River, assessment of bacterial conditions has received limited historical attention. The USGS has collected long-term bacterial data at their Bradwood monitoring station (RM 39) from 1973-1980, and at their Warrendale station (RM 141) from 1973 to the present. More recently (since 1990), the USGS has also established a monitoring station at the Beaver Army Terminal (RM 53.6).

Historically, fecal coliform densities at the Warrendale station have been consistently low, generally remaining below 30 colonies per 100 mL (Tetra Tech 1992a). In contrast, fecal coliform levels at the Bradwood station have been highly variable, ranging from below 10 to 320 colonies per 100 mL during the 1976-1980 sampling period (Tetra Tech 1992a). Similarly, fecal coliform densities at the Beaver Army Terminal station have also been variable, ranging from zero to 300 colonies per 100 mL since sampling was started there in 1990. These are similar to the results for this study which ranged from not detected to a maximum of 305 fecal coliform colonies per 100 mL.

Since February 1991, ODEQ has been collecting data on fecal coliform and enterococcus densities approximately once per month at a station located at RM 102.5, one mile above the mouth of the Willamette River. Both fecal coliform and enterococcus densities at this station have been consistently low (below 93 and 10 colonies per 100 mL, respectively) since the beginning of sampling, in contrast to the consistently higher densities measured in this study. The ODEQ data also differ in that enterococcus densities were typically lower than fecal coliform densities, in contrast to the data collected during the reconnaissance survey. Fecal coliform data were also reported by WDOE for three dates in 1990 at Bradwood (RM 39) and Warrendale (RM 141) (Johnson, A. and B. Hopkins, 30 April 1991, personal communication). These data indicated that fecal coliform bacteria concentrations were generally low during the period of lowest rainfall (May and September samples), but that during wetter weather (January sample) the concentrations of fecal coliform bacteria increased at the Bradwood station to levels as high as 300 colonies per 100 mL.

Potential sources of the bacteria measured in this survey include point sources (including the effluent from municipal wastewater treatment plants, and the effluent from pulp and paper mills), nonpoint sources which include runoff from urban and agricultural areas which may be contaminated by animal (livestock and domestic animals) fecal material, combined sewer overflows from urban areas, and septic system failures. Vasconcelos et al. (1975) evaluated historical total and fecal coliform data and data collected during a U.S. EPA study (including the identification of specific pathogenic bacteria) to evaluate water quality of the lower Columbia River. Vasconcelos et al. (1975) concluded that although bacterial levels in the river had generally declined since the 1960s, much of the fecal bacteria identified in the river originated from the wood products wastewater of pulp and paper mills which consisted primarily of *Klebsiella* sp. Specific pathogens were detected in Columbia River water (i.e., *Pseudomonas aeruginosa,* *Staphylococcus aureus*, and *Salmonella* spp.), but their numbers were considered to be relatively low and their source or origin could not be confirmed. No recommendations for further study were made.

These findings are consistent with those of Cabelli et al. (1982), Cabelli (1983a,b), Cabelli et al. (1983), and Dufour (1984). These studies demonstrated that the fecal coliform standard was inadequate as an indicator of fecal contamination due to the presence of many bacteria that were identified in the fecal coliform test, but were not of fecal origin (e.g., Dufour 1984). For example, Cabelli et al. (1983) stated that although the thermotolerant *Klebsiella* was commonly detected in the fecal coliform test, this bacterium was infrequently present in human feces, and then generally only as a minor portion of the coliform population. Cabelli et al. (1983) further stated that although *Klebsiella* is known to be an opportunistic pathogen, *Klebsiella* is an opportunistic pathogen of the respiratory and genito-urinary system and not the gastrointestinal tract, and that there are no data showing that *Klebsiella* infections have been obtained by the waterborne route. These statements are corroborated by a National Council of the Paper Industry for Air and Stream Improvement (NCASI) study performed by Dr. T.C. Eickhoff (NCASI 1972) who reviewed the epidemiology of *Klebsiella*. Dr. Eickhoff could identify no association of *Klebsiella* in water-borne outbreaks of disease. However, *Klebsiella* was identified as a well-known causative agent of respiratory and urinary tract infections in hospitals. Infections of this type are generally isolated to hospitalized patients who may be immuno-compromised; such infections are not common outside of the hospital environment. Another NCASI study demonstrated that the strains of *Klebsiella* that had been isolated from pulp and paper effluents were biochemically different than the strains of *Klebsiella* isolated from the hospital environment (NCASI 1975). However, Bagley and Seidler (1977) and Knittel et al. (1977) did demonstrate the possibility that fecal coliform-positive *Klebsiella pneumoniae* isolated from the environment could be of fecal and/or clinical origin and that the environment could serve as reservoir of pathogenic strains of this bacterium (based on studies of various biological media, strains of *Klebsiella*, and mouse pathogenicity studies).

Cabelli (1983a) also hypothesized that swimming-associated gastroenteritis is primarily due to viral pathogens (primarily Norwalk-like and human rotavirus and to a lesser degree hepatitis A virus) specific to human fecal material. Cabelli (1983a) hypothesized that in their studies, the utility of enterococcus bacteria as the best predictor of health effects was due to the close association with, and similar environmental resistance to, the viral agents that caused the observed health effects. With further study and the advancement of microbiological techniques, better indicator organisms or tests would likely be identified. Cabelli (1983b) and Dufour (1984) also stressed that the present enterococcus standards were only developed for, and applicable to, waters polluted by substantial amounts of municipal wastewater; present standards were not adequate or applicable to small water bodies that did not receive steady municipal effluent discharges or to waters that received significant amounts of stormwater pollution. Cabelli (1983a,b) also emphasized the need for sanitary surveys and good public health surveillance in addition to routine surveillance for indicator bacteria.

2.7.3.2 Significance and Recommendations. Although the data are not completely consistent with recent historical data collected by ODEQ, the limited data collected during the reconnaissance survey indicate that bacterial conditions in the lower Columbia River during the survey period exceeded state and federal standards that are designed to protect from fecal contamination both water contact recreationists and shellfish destined for human consumption. These results indicate that there may be concern for the health of contact recreationists and safety concerns about shellfish harvested for human consumption. It is recommended that more intensive sampling be conducted to confirm the results of the bacterial sampling conducted for this study. A sampling program to address these recommendations was initiated by WDOE in September of 1992 and a report of the results of sampling during dry-weather has been completed (Hallock 1993). A draft report on the results of wet-weather sampling has been submitted for review to the Columbia River Bi-State Committee (Ehinger 1993).

Of even greater concern may be the indicator bacteria used to identify water quality problems in general. Recent studies have indicated that fecal coliform bacteria are a poor indication of fecal contamination and potential enteric disease outbreaks due to water recreation (e.g., Cabelli et al. 1983). O'Shea and Field (1991) have also identified the inadequacy of fecal indicator bacteria for the assessment of the potential for non-enteric infections and the distinct character of pathogens in stormwater runoff. These non-enteric infections include eye, ear, nose, throat, and upper respiratory illnesses that are extremely common in recreational water bathers (WSDH 1991). Therefore, enterococcus levels may be a good indication of risk for gastrointestinal illnesses (enteric infections), but may not be suitable for assessing the risk for non-enteric infections. Based on evaluation of several historical studies, the Washington State Department of Health (WSDH) has hesitated to adopt a single water quality standard for public bathing beaches (WSDH 1991). Instead, the WSDH has recommended that bacterial sampling results be coupled with additional information (including sanitary surveys) and actions (including limiting bather densities to avoid contamination of the water by the bathers themselves) to ensure the health of public bathing areas.

Further research, including epidemiological studies, evaluation of additional indicator organisms, and evaluation of new methods for the direct detection of pathogens should be conducted to develop the criteria necessary to ensure the public health of recreational waters.

2.7.4 Metals and Cyanide

In general, the widely spaced collection of samples along the river and the single samples collected, preclude identification of specific sources of the metals detected in this survey. Because metals occur as natural constituents in rocks and sediments, some background level of these elements in the water column is expected. Some portion of the metals will be present in dissolved form, but another portion will be sorbed to the surface of suspended sediment or form part of the crystal lattice of the suspended sediment particles. The total recoverable analytical method used in this project dissolves most metals associated with particles, but it may not remove metals contained within sediment particles resistant to the digestion procedure. The concentration of dissolved, colloidal, sorbed, and particulate forms of metals in a particular sample will depend on a number of physical and chemical factors including the pH, hardness, oxidation-reduction potential, and dissolved oxygen content of the water, the magnitude and duration of metal inputs, and the physical partitioning mechanisms of sedimentation, resuspension, and advection. Without adequate knowledge of these factors, the limited number and frequency of samples collected during the reconnaissance survey do not allow particular point or nonpoint pollution sources to be identified. However, the survey data are suitable for identifying metals concentrations that may result in impairment of designated beneficial uses in particular river segments.

The usefulness of these data is further limited due to the qualification of these data as estimates only. The reliability of historical freshwater trace metal data has also been questioned due to the realization that reported trace metal concentrations of fresh water and marine water samples may have been overestimated due to contamination during sampling and/or analysis (e.g., Shiller and Boyle 1985; Shiller and Boyle 1987; Windom et al. 1991). Historically, both USGS and U.S. EPA water column trace metal sampling results for the Columbia River in the late 1970s were questioned (Velz 1984). Although Velz (1984) conceded that the USGS and U.S. EPA samples were more limited, the results of an intensive survey conducted by a private contractor indicated that trace metals levels were much lower than the data reported by USGS and U.S. EPA and were within federal standards, with the exception of iron. Evaluation of historical freshwater trace metal data collected by the USGS has led to the conclusion that historical results reported for arsenic, boron, beryllium, cadmium, chromium, copper, lead, and zinc were biased due to contamination of the samples by the metallic solenoid-activated, flow-weighting water sampler (Bortleson, G., 3 June 1992, personal communication). Whether or not the published results for aluminum, iron, and manganese were biased due to contamination is not clear (Bortleson, G., 3 June 1992, personal communication). Historical metal and cation data that are not considered to be biased due to contamination are barium, calcium, cobalt, lithium, magnesium, molybdenum, nickel, sodium, silicon, strontium, and vanadium (Bortleson, G., 3 June 1992, personal communication). The USGS is presently evaluating the use of teflon sampling bags for collecting flow-weighted and depth-integrated samples (e.g., Taylor et al. 1990).

Partly in response to concerns about the reliability of the published USGS data for the Columbia River at Bradwood (RM 39) and Warrendale (RM 141) (see Figures 1-2 and 1-4), WDOE initiated water sampling of the lower Columbia River in 1990 using methods that reduce the potential for metal contamination of the samples. The historical USGS data in question indicated exceedances of freshwater chronic metal criteria for lead, copper, mercury, cadmium, and zinc. The results of WDOE sampling indicated that total metal concentrations in whole water samples collected at Bradwood and Warrendale for copper, zinc, lead, cadmium, and mercury were lower than freshwater chronic criteria. Dissolved metal concentrations of these same metals were generally much lower than concentrations reported by USGS at the same stations for 1990. The WDOE results were consistently lower, often by more than an order of magnitude, than those reported by USGS (see Table 2-12). Johnson and Hopkins (30 April 1991, personal communication) concluded that their preliminary investigation did not indicate that water concentrations of cadmium, copper, lead, mercury, or zinc were a present water quality concern in the lower Columbia River.

The results reported for the lower Columbia River reconnaissance survey are generally more similar to the historical USGS results than the more recent WDOE data, although a metallic sampler was not used in this study. In general, it is difficult to compare the USGS dissolved and total metals data, WDOE dissolved and total metals data, and the total recoverable metals data reported here. Sampling by the USGS and WDOE has been conducted at two stations (Warrendale and Bradwood) during a variety of flow regimes. The reconnaissance survey included water sampling at 45 stations along the mainstem of the lower Columbia River below Bonneville Dam and in a number of river tributaries and backwater areas. These stations were sampled only once during low-flow conditions. Although USGS and reconnaissance survey sampling apparatus differed (metallic sampler vs. the polycarbonate Niskin bottles

TABLE 2-12. COMPARISON OF WDOE AND USGS MEASURED WATER COLUMN DISSOLVED METALS CONCENTRATIONS IN THE COLUMBIA RIVER AT WARRENDALE (RM 141) DURING 1990.[a]

DATE (1990)	Copper		Zinc		Lead		Cadmium		Mercury	
	WDOE	USGS	WDOE	USGS	WDOE	USGS	WDOE	USGS	WDOE	USGS
	Mean concentration in ug/L ±1 standard deviation, n = 3[a]									
January 9	0.94± 0.15	--	<0.33	--	0.04±0.031	--	0.014±0.001	--	<0.002	--
March 6	--	3	--	4	--	<1	--	<1	--	<0.1
May 30	0.76±0.26	--	0.26±0.06	--	0.049±0.006	--	0.012±0.002	--	<0.001	--
June 27	--	8	--	5	--	1	--	3	--	<0.1
August 14	--	22	--	4	--	<1	--	<1	--	<0.1
Sept. 25	0.81±0.06	--	0.20±0.03	--	<0.015	--	0.012±0.002	--	<0.001	--

" < " indicates that the concentration was below the laboratory detection limit.
The value reported is the detection limit.

[a] WDOE data are the mean ±1 standard deviation based on triplicate samples.
USGS data are based on single samples.

SOURCE: Johnson, A., and B. Hopkins, 30 April 1991, personal communication to S. Saunders, WDOE.

used in this study), laboratory analytical techniques (i.e., the use of a total recoverable metal acid digestion procedure) were similar. However, the WDOE study used a chemical precipitation procedure to concentrate their samples and the acid digestion procedure used differs from that recommended by EPA for total recoverable metals (Bloom and Crecelius 1983,1984 vs. U.S. EPA 1986b). Although the reconnaissance survey metals data reported here may have been contaminated during sampling and/or analysis, it is presently not possible to dismiss these data as biased (with the exception of aluminum and iron) since matrix spike recoveries were within quality control limits, and laboratory method blanks did not evidence contamination with trace metals, with the exception of aluminum and iron. Therefore, the reconnaissance survey data will be discussed in comparison with historical total metals data reported by the USGS for Bradwood (and summarized by Tetra Tech 1992a) and the total metals data reported by WDOE at Bradwood and Warrendale for 1990 (Johnson, A. and B. Hopkins, 30 April 1991, personal communication to S. Saunders, WDOE) (see Table 2-13). If no historical total metals data are available for comparison, dissolved metals data from the USGS station at Warrendale during the 1990 water year will be used for comparison. Dissolved metals loading data calculated by Tetra Tech (1992c) based on USGS NASQUAN data will be used for comparison only for metals for which significant data quality problems have not been noted (i.e., aluminum and iron).

With the exception of aluminum, barium, iron, and lead, total recoverable metals were detected relatively infrequently in the lower Columbia River and its tributaries during the reconnaissance survey. Cyanide, antimony, arsenic, beryllium, mercury, nickel, silver, and thallium were not detected above DLs in any of the samples collected during the reconnaissance survey.

The following discussion will relate the concentrations of metals measured in the reconnaissance survey to historical data identified in Task 1 (Tetra Tech 1992a), and will discuss potential anthropogenic sources of these metals identified in Task 2 (Tetra Tech 1992c).

2.7.4.1 Comparison with Historical Data and Identification of Potential Sources.

Aluminum. Aluminum was reported as detected at 11 stations at concentrations ranging from undetected (DL of 120 μg/L) to 1300 μg/L. The freshwater criterion for aluminum (87 μg/L) was exceeded at all of the freshwater stations where aluminum was detected. Due to possible laboratory contamination of the aluminum samples, the rest of the aluminum values which also exceeded the

TABLE 2-13. TOTAL WATER COLUMN METAL CONCENTRATIONS REPORTED BY WDOE AT BRADWOOD (RM 39) AND WARRENDALE (RM 141) IN 1990.

DATE (1990)	STATION	Copper	Zinc	Lead	Cadmium	Mercury
		Mean concentration in ug/L ±1 standard deviation, n = 3				
January 9	Warrendale	1.8±0.2	<0.33	0.33±0.04	0.030±0.002	<0.002
	Bradwood	2.2±0.2	0.77±0.07	0.50±0.12	0.028±0.003	<0.002
May 10	Warrendale	1.2±0.2	1.4±0.0	0.35±0.01	0.044±0.001	<0.001
	Bradwood	1.5±0.4	1.7±0.6	0.35±0.06	0.034±0.004	<0.001
September 25	Warrendale	1.3±0.1	1.1±0.2	0.18±0.01	0.025±0.002	<0.001
	Bradwood	1.3±0.3	1.6±0.6	0.20±0.04	0.025±0.002	<0.001

" < " indicates that the concentration was below the laboratory detection limit. The value reported is the detection limit.

SOURCE: Johnson, A., and B. Hopkins, 30 April 1991, personal communication to S. Saunders, WDOE.

freshwater quality criterion were qualified as undetected. It is likely that much of this aluminum occurred in a mineral or adsorbed form unavailable to biota (Horowitz 1991). For example, measurements made on two rivers in Japan indicated that the suspended particulate fraction of aluminum (greater than 0.45 μm diameter particle size) ranged from 55.5 to 99.7 percent of the total river aluminum concentration (Tanizaki et al. 1992). Aluminum is the third most abundant element in the earth's crust (Krauskopf 1979), and therefore its presence in the water column at these levels may not be unusual. However, exceedances of the criterion indicate potential effects on biota and human health due to aluminum.

Typically, aluminum is associated with the suspended sediment in the water column (Horowitz 1991). The fraction of aluminum in dissolved form was not determined in this study. Tetra Tech (1992a) identified only data for dissolved aluminum in the lower Columbia River. Concentrations of dissolved aluminum concentrations measured at Warrendale during the 1990 water year ranged from undetected (DL of 10 μg/L) to 20 μg/L. The WDOE did not measure water aluminum concentrations in 1990 at Bradwood or Warrendale. The higher levels measured in the reconnaissance survey are likely due to the measurement of both dissolved and particulate aluminum measured as total recoverable aluminum. Potential additional sources of aluminum to the lower Columbia include three aluminum smelters located in Longview (RM 63), Vancouver (RM 103), and Troutdale (RM 120). However, any obvious impact of discharges from these industries on the water aluminum content was not evident during this survey. This was due to the high variability in aluminum concentration measured in the river, the limited number of sampling stations, and the relatively small mass of aluminum discharged from these point sources (187 lb/day) relative to the total dissolved aluminum discharge of the river (7,590 lb/d from the Willamette River alone) (Tetra Tech 1992c).

Barium. Barium was detected at all but one station during the reconnaissance survey at concentrations ranging from undetected (DL of 10 μg/L) to 42 μg/L. No chronic water quality criteria were available for assessment of the possible environmental significance of these levels. Only one historical measurement of the water column total barium concentration was identified by Tetra Tech (1992a). This value of 20 μg/L was similar to the median value of 26 μg/L determined from reconnaissance survey data. The WDOE did not report water barium concentrations at Bradwood or Warrendale in 1990. Evidence of the influence of point sources on barium concentrations was not evident during the reconnaissance survey. Two municipal wastewater facilities that discharge directly to the Columbia River

(Portland and Gresham) reported effluent barium concentrations in 1989 and 1990; however, barium was typically undetected in the effluent of these facilities (Tetra Tech 1992c).

Cadmium. Cadmium was detected above the DL at three stations (W22, W28, and W37). The highest detected concentration was 3.5 µg/L. All three detected concentrations exceeded the freshwater criterion of 0.7 µg/L. These exceedances indicate possible effects on biota in the lower Columbia River. All three stations were located in the Columbia River, although station W28 was located in the channel behind Sandy Island. These values are comparable to the concentrations of total cadmium reported from the USGS Bradwood station (RM 39) which ranged from undetected (DL of 2 µg/L) to 37 µg/L (Tetra Tech 1992a). However, the WDOE reported average concentrations of total cadmium at Bradwood and Warrendale during 1990 which ranged from 0.025 to 0.044 µg/L (see Table 2-13).

Sources of cadmium include smelting operations, surface mine drainage, and phosphate fertilizer (May and McKinney 1981). Mining and smelting operations in the upper river basin have been cited as a major source of cadmium to the Columbia River (May and McKinney 1981). Point sources within the lower Columbia River that are required to monitor effluent discharge for cadmium include the municipal wastewater treatment facilities of Portland, Gresham, and St. Helens, Reynolds Metals Co. in Longview, and Kalama Chemical (Tetra Tech 1992c). Tetra Tech (1992c) identified data on effluent cadmium discharge for the municipal facilities in Portland and Gresham only; however, cadmium was typically undetected in the effluent of these sources. Station W22 is downstream of the Reynolds Metals Co. in Longview. No major permitted point sources of cadmium were identified directly upstream of station W28. Station W37 is downstream of the discharges of the cities of Portland and Vancouver as well as the ALCOA aluminum production facility in Vancouver. However, the ALCOA facility is not required to monitor the effluent discharge of cadmium (Tetra Tech 1992c).

Chromium. Chromium was detected above the DL of 5 µg/L at three stations (stations W1, W6, and W37) with concentrations ranging from undetected (DL=5 µg/L) to 7 µg/L. The concentration of chromium did not exceed the freshwater criterion of 11 µg/L. Historically, concentrations of total chromium at Bradwood have been undetected at DLs of 1 to 20 µg/L (Tetra Tech 1992a). The WDOE did not measure water chromium concentration in 1990 at Bradwood or Warrendale.

Facilities that discharge directly to the lower Columbia River that are required to monitor chromium include Kalama Chemical, Pendleton Woolen Mills, ALCOA (Vancouver), and the municipal wastewater treatment facilities in St. Helens, Portland, and Gresham. Tetra Tech (1992c) reviewed effluent data for the Portland, Gresham, ALCOA, and Pendleton Woolen Mills facilities. Portland and Gresham typically reported undetected levels of chromium in their effluent. Pendleton reported an average chromium discharge of 0.46 lb/day in 1989 and 0.32 lb/day in 1990 (Tetra Tech 1992c). ALCOA reported a discharge of 0.08 lb/day in 1989 and 0.04 lb/day in 1990 (Tetra Tech 1992c). Potential point sources of chromium did not appear to contribute to elevated levels of this metal, although station W37 with a detected concentration of 5.5 μg/L is downstream of ALCOA. There may, however, be additional unidentified point and nonpoint sources that contribute to chromium levels measured in the lower river.

Copper. Copper was detected at 10 of the 45 stations monitored, at concentrations ranging from undetected (DL of 5 μg/L) to 54 μg/L. Exceedance of the freshwater criterion for copper (7.3 μg/L) occurred at seven stations in the river. The highest level of copper was noted at station W28 (54 μg/L). Exceedances of the criteria indicate potential for effects to biota in the Columbia River. The copper values measured were within the range of total copper concentrations reported for the USGS Bradwood station (Tetra Tech 1992a), which ranged from 1 to 49 μg/L. However, the WDOE reported average total copper concentrations in 1990 at Bradwood and Warrendale which ranged from 1.2 to 2.2 μg/L (see Table 2-13).

Facilities discharging directly to the Columbia River required to monitor effluent copper concentrations include the Portland General Electric power plant in Clatskanie, OR, Weyerhaueser Paper Co. (Longview), Trojan Nuclear Power Plant, Kalama Chemical, and the municipal wastewater facilities of St. Helens, Portland, and Gresham. The Portland, Gresham, Portland General Electric (Beaver Generating Plant), and Weyerhaeuser (Longview) typically reported undetectable levels of copper in their effluents. Kalama Chemical and the Trojan Nuclear Power facilities reported copper loadings averaging 0.11 and 0.03 lb/day in 1990.

There were no apparent sources of the elevated copper concentration at station W28 in the channel behind Sandy Island.

Iron. Iron was reported as detected at 11 of the 45 stations at concentrations ranging from undetected (DL of 100 μg/L) to 1,800 μg/L. The concentration of iron at four stations (stations W3, W16, W42, and W43) violated the chronic freshwater criterion of 1000 μg/L. However, much of this iron was likely in a mineral or adsorbed form that was unavailable to biota (Horowitz 1991). For example, measurements made on two rivers in Japan indicated that the suspended particulate fraction of iron (greater than 0.45 μm diameter particle size) ranged from 81 to 98.8 percent of the total river iron concentration (Tanizaki et al. 1992). Iron is the fourth most abundant element in the earth's crust (Krauskopf 1979), and therefore its presence in the water column at the levels observed may not be unusual. Typically, iron is associated with the suspended sediment in the water column. The fraction of iron in dissolved form was not determined in this study. Historically, measured levels of total iron in the lower Columbia River have ranged from 19 to 5000 μg/L (Tetra Tech 1992a). The WDOE did not measure iron concentrations at Bradwood or Warrendale in 1990.

Direct point source discharges to the lower Columbia River that are required to monitor effluent iron concentrations include the Beaver Generating Plant, Trojan Nuclear Power Plant, and the municipal wastewater facilities in Portland and Gresham (Tetra Tech 1992c). However, any obvious impact of discharges from these point sources on the water iron content was not evident during this survey. This was due to the high variability in iron concentrations measured in the river, the limited number of sampling stations, and the relatively small mass of iron discharged (156 lb/day) from point sources relative to the total dissolved iron discharge of the river (110,000 lb/day at Warrendale) (Tetra Tech 1992c). The high iron concentration reported for the shore-based bacterial sampling station W16 was likely due to the high suspended sediment concentration (TSS=46 mg/L) at this station. However, the high iron concentrations reported at stations W42 and W43 were not associated with high TSS concentrations. These stations were also upstream of the influence of tributaries and major point sources in the lower river. It is possible that the iron was not sediment-associated, but that the samples for TSS were poorly homogenized before filtering for analysis.

Lead. Lead was detected at 25 of the 45 stations with concentrations ranging from undetected (DL of 1 μg/L) to 8 μg/L. Almost all of the detected lead concentrations (21 of the 25) were above the chronic freshwater criterion of 1.6 μg/L. The high number of exceedances of the freshwater criterion indicate the potential for effects to biota in several areas of the river. Historical total lead concentrations at the USGS Bradwood station ranged from 4 to 130 μg/L (Tetra Tech 1992a). However, the WDOE reported that average total lead concentrations at Bradwood and Warrendale in 1990 ranged from 0.18 to 0.50 μg/L (see Table 2-13).

Sources of lead include smelter operations, surface mining of lead ore deposits, and atmospheric lead deposition due to combustion of leaded fuels. Point sources required to monitor effluent lead discharge include Weyerhaueser Paper Co. (Longview), Reynolds Metals (Longview), Kalama Chemical, and the municipal wastewater treatment facilities in St. Helens, Portland, and Gresham. Lead was typically undetected in the effluents monitored in 1989 and 1990 (Tetra Tech 1992c). However, none of these sources is likely to be large enough to sustain the concentrations of lead measured in the water column. The presence of detectable quantities of lead throughout the river suggests a large source or multiple sources of lead input to the lower river. It is possible that much of the lead is derived from exposure of lead-rich deposits, and surface mining and smelting operations in the upper drainage basin in Idaho (May and McKinney 1981).

Selenium. Selenium was detected at 3 of the 45 stations at concentrations ranging from undetected (DL of 5 μg/L) to 22 μg/L. No historical data on selenium concentrations were identified by Tetra Tech (Tetra Tech 1992a). The WDOE did not report selenium concentrations at Bradwood or Warrendale in 1990. No point sources of selenium have been identified in the lower Columbia River (Tetra Tech 1992c). However, irrigation return flows from areas with high soil selenium content may be a potential source of selenium (Hem 1970).

Zinc. Zinc was detected at 12 of the 45 stations at concentrations ranging from undetected (DL of 20 μg/L) to 84 μg/L. Three of these concentrations exceeded the chronic freshwater criterion of 66 μg/L. Although the number of exceedances were few, the detection of zinc above the criterion during the limited sampling of this survey indicates the potential for effects to biota in the lower Columbia River. Zinc levels measured in this survey are similar to historical total zinc concentrations at the USGS Bradwood station which ranged from undetected to 90 μg/L (Tetra Tech 1992a). However, the WDOE reported that average concentrations of total zinc at Bradwood and Warrendale in 1990 ranged from undetected (DL=0.33 μg/L) to 1.7 μg/L (see Table 2-13).

Elevated concentrations of zinc measured do not appear to be related to nearby point sources. Permitted point sources that are required to monitor effluent concentrations of zinc include Kalama Chemical, the municipal wastewater facilities of Portland, Gresham, and St. Helens, and ALCOA (Vancouver) (Tetra Tech 1992c). Detectable concentrations of zinc were reported in the effluents of Kalama Chemical (0.03 lb/day), Reynolds (Troutdale) (0.03 lb/day), ALCOA (Vancouver) (0.17 lb/day), Portland (33.4 lb/day), and Gresham (6.8 lb/day) facilities (Tetra Tech 1992c).

For cyanide and the metals that were not detected, historical data indicate that concentrations of these metals are also typically undetected or present at low concentrations (Tetra Tech 1992a). For example, total arsenic concentrations ranged from 1 to 5 μg/L. Dissolved beryllium was not detected at DLs ranging from 0.5 to 10 μg/L. Dissolved mercury concentrations ranged from undetected at a DL of 0.1 μg/L to 0.2 μg/L. Dissolved silver ranged from undetected at a DL of 1 μg/L to 1 μg/L. Dissolved cyanide concentrations ranged from zero to 4 μg/L. Although cyanide and these metals were not detected in previous studies, the detection limits for mercury and silver were higher than their chronic freshwater criteria. The detection limits for mercury and nickel were higher than the chronic marine criteria. Therefore, assessment of the potential environmental effect of these pollutants—based only on water column concentrations—is not possible.

The hardness of the water also influences the toxicity of metals. Lower hardness results in the increased toxic potential of these metals. The median hardness of samples above station W8 was 57 mg/L, but the hardness of three rivers (Cowlitz, Lewis, and Willamette rivers) was lower than 30 mg/L. The hardness of the Lewis River was the lowest measured (10 mg/L). Slightly higher hardness was noted for Lake River (68 mg/L). The hardness values reported here are typical of "soft" (0-60 mg/L) or "moderately hard" (61-120 mg/L) waters, as defined by Hem (1970), that are relatively low in calcium and magnesium. The hardness of a water affects the potential toxicity of several metals measured in this study, including cadmium, copper, lead, nickel, and zinc. It is possible, therefore, that these metals pose a more serious concern in the lower Columbia River than in waters with greater hardness.

2.7.4.2 Significance and Recommendations. Identification of sources of metal pollutants in the lower Columbia was not possible due to the limited number of sampling stations, and the single sample collected at each station. Exceedances of the chronic water quality criteria for a number of metals indicates the potential for effects to biota inhabiting the lower Columbia River. Comparison with the limited historical data compiled by Tetra Tech (1992a) indicates that the variation among stations in concentrations of some metals detected in this survey may be as great, or even greater, than the variation of the metal concentration at a single station monitored over the course of a year. The reconnaissance survey has identified problem areas and metals that may warrant further investigation. For example, the large number of elevated lead concentrations suggest a potential impairment of beneficial use. However, historical sampling data both for the Columbia River and other locations indicate that ultra-clean sampling and laboratory analysis techniques may be necessary to obtain accurate results for the metals that typically occur at relatively low concentrations. It is recommended that future studies of the lower Columbia River establish and follow rigorous sample collection and analysis protocols that minimize the potential contamination of metals samples.

Relevant questions for further research include the following:

- What are the major sources (point and nonpoint sources as well as background levels) of these metals to the river?
- What are the effects of these metals on the biota?
- Are the forms of the metals detected in this survey available to the biota?
- Are some metals and their various forms more available than others?
- Which is the most important pathway (water column or sediments) for metal contaminant exposure and accumulation?
- What are the residence times of these metals?
- How and in what forms are metals transported through the river system?
- What is the fate of the metals delivered to the river?

Answers to these questions are essential for identifying the most important sources of specific metals, and the acceptable limits of the input of these contaminants into the lower Columbia River system. An integrated monitoring program of both dissolved and total metals in the lower Columbia River, and the various point and nonpoint sources should be performed on a seasonal basis to improve the understanding of the sources, forms, and fate of metals in the lower Columbia River.

2.7.5 Organic Compounds

In general, semivolatile and volatile organic compounds, and pesticides and PCBs were not detected, with the exception of bis(2-ethylhexyl)phthalate. It is possible that some of the undetected compounds are present, but at concentrations that are undetectable using the conventional methods employed for this study. These compounds will be discussed together below. AOX was detected at 18 of the 19 stations surveyed; these results will be discussed separately.

2.7.5.1 Semivolatile and Volatile Organic Compounds, Pesticides and PCBs. With the exception of the phthalate ester bis(2-ethylhexyl)phthalate, all other organic pollutants of concern measured in the water column were below the detection limits achieved using conventional EPA-approved analytical methods. Bis(2-ethylhexyl)phthalate was detected at two stations (W26 and W37) at levels exceeding the freshwater criterion of 3 μg/L. Because this chemical is a common laboratory contaminant, it is possible that these results are due to contamination of the samples. However, laboratory method blanks associated with these samples were negative for this chemical, nor did the two field blank samples indicate contamination of the field samples (Appendix A-4). The QA/QC control checks suggest that the presence of bis(2-ethylhexyl)phthalate in the water samples was not an artifact of laboratory or handling contamination.

Bis(2-ethylhexyl)phthalate, also known as di(2-ethylhexyl)phthalate or DEHP, is a plasticizing compound used in resins and the manufacture of organic pump fluids. It is present in many plastics (especially vinyls), paints, flexible tubing, plastic bags, and medical supplies. Potential sources of bis(2-ethylhexyl)-phthalate to the environment include industrial and municipal effluents, landfill leachate, incineration of plastics, and nonpoint storm runoff from urban, industrial, and residential areas. Nonpoint storm runoff may be contaminated through improper disposal of paints and resins, atmospheric sources (plastics incineration), and through the weathering and decay of discarded plastic materials.

A potential source of this chemical at station W26 is Kalama Chemical approximately 2 km upstream. The permit limit for the effluent concentration of bis(2-ethylhexyl)phthalate is 139 μg/L (based on the maximum allowable daily flow and the discharge limit of 0.294 lb/d), but the relatively small total allowable discharge suggests that the detection of this compound downstream of the chemical plant, as a result of discharge of this chemical at concentrations greater than the detection limit, would be unlikely. The Kalama River is an additional potential source (due to possible point and nonpoint contamination) not monitored for organic compounds in this survey. Potential sources of this compound at station W37 in the Portland/Vancouver area include the large municipal wastewater facilities in Portland, Gresham, and Vancouver. Nonpoint sources in this highly urbanized and industrialized area may also have contributed to the elevated concentration of this chemical at station W37.

Comparison with Historical Data. Limited historical data on water column concentrations of organic compounds in the lower Columbia River were identified from previous studies (Tetra Tech 1992a). Historical data were limited to a small number of stations for a few compounds—primarily total phenols and some pesticides. Consistent with the results of the reconnaissance survey, phenols and pesticides have historically been undetected or detected at levels near the detection limits of conventional methods in the water column. Because no data on the water column concentration of bis(2-ethylhexyl)-phthalate were identified in previous studies (Tetra Tech 1992a), comparison with historical data is not possible.

Although dioxins and furans were not sampled during this survey, it should be mentioned that the Columbia River has recently been identified as water quality limited due to the prediction that water column dioxin (2,3,7,8-TCDD) concentrations exceed the water column criteria for the consumption of contaminated fish and water (0.013 pg/L) and the finding that Columbia River fish tissue levels of 2,3,7,8-TCDD exceeded the human cancer risk factor of an increase of one additional cancer for a population of 1 million people for consumption of Columbia River fish (U.S. EPA 1991c,d). This prediction was based on modeling inputs of 2,3,7,8-TCDD to the Columbia River, from pulp and paper mills on the mainstem of the river using the chlorine bleaching process, and the analysis of dioxin levels in fish tissue samples collected in the Columbia River (U.S.EPA 1991c,d). Eleven chlorine-bleaching pulp mills currently discharge to the Columbia River system. These mills are located in Canada (1), Idaho (1), Washington (4), and Oregon (3). Five major pulp and paper facilities discharge chlorine-bleached paper process effluent directly to the lower Columbia River below Bonneville Dam (Tetra Tech 1992c). The U.S. EPA has developed a total maximum daily load (TMDL) that will regulate the discharge of dioxin from U.S. pulp and paper mills in the Columbia River basin to reduce the level of 2,3,7,8-TCDD below the water quality standard (U.S. EPA 1991c,d). Further investigations are being conducted by U.S. EPA Region X and the states of Oregon and Washington to provide additional information for the refinement of the TMDL and to monitor the effect of the regulatory actions that have been implemented.

Significance and Recommendations. Although the reconnaissance survey was conducted during low-flow conditions when the dilution capacity of the river is lowest, extensive organic contamination of the water column was not evident during this period. This finding was likely due to the limited number of samples collected, the difficulty in detecting relatively low concentrations of these chemicals using conventional methods, and the absence of significant inputs of organic pollutants during the survey period. Many of the compounds measured in this survey were likely present in the water column, but at levels below the conventional detection limits achieved. Some of these compounds may also be present in detectable quantities at different times of the year. For example, the discharge of herbicides in rivers of the midwestern U.S. has been associated with late spring and early summer rainfall (Thurman et al. 1991). Stormwater tends to enter the lower Columbia River during the months of October to April, after the low-flow period. The higher-flow period in the lower river during these winter months is primarily due to rainfall runoff in the lower tributary basins, especially the Willamette and Cowlitz river basins (Tetra Tech 1992b). Therefore, although the Columbia River may be most sensitive to pollutant loading during low-flow conditions, many pollutants may only enter the water column episodically or seasonally. These pollutants may then be flushed out to sea or bind to fine sediments and be deposited in quiescent reaches of the lower river.

With the exception of episodic events, such as accidental chemical spills or increases in nonpoint runoff due to rainfall, the levels of organic pollutants present in the lower Columbia River are likely to be below the detection limits of conventional analytical methods. Organic pollutants are rarely detected in water column studies due to the transitory nature of water, the hydrophobicity of many compounds, and the limited number of samples collected for analytical expense considerations. Instead, studies are increasingly focusing on contaminants associated with suspended particles and sediments. The identification of areas and pollutants of concern for further study might be more appropriately based on the identification of elevated sediment and tissue concentrations of organic pollutants. It may also be possible to use less conventional analytical or sampling methods. Examples include analysis of the suspended sediments from large volumes of filtered river water or the use of more sensitive analytical methods on a seasonal basis to determine actual concentrations of a more limited suite of these pollutants in the water column. This may be most important for dioxin which has been identified as a contaminant that exceeds existing water quality criteria that are intended to protect human health.

Relevant questions for further research include the following:

- What are the major sources (point and nonpoint sources) of organic compounds to the river?
- What are the effects of these organic compounds on the biota?
- Are the forms of the organic compounds in the water column available to the biota?
- Are some organic compounds and their various forms more available than others?
- Which is the most important pathway (water column or sediments) for organic contaminant exposure and accumulation?
- What are the residence times of these organic compounds?
- How and in what forms are organic compounds transported through the river system?
- What is the fate of the organic compounds delivered to the river?

Answers to these questions are essential for identifying the most important sources of specific organic contaminants, and the acceptable limits of the input of these contaminants into the lower Columbia River system. An integrated monitoring program of organic compounds in the lower Columbia River, and the various point and nonpoint sources should be performed on a seasonal basis to improve the understanding of the sources, forms, and fate of organic compounds in the lower Columbia River.

2.7.5.2 AOX. The trend in water column AOX concentrations observed in the study area below Bonneville Dam suggests the influence of bleached kraft pulp and paper mill discharges, especially downstream of the paper mills in Longview. The persistence of elevated water column concentrations of AOX below Longview indicates that halogenated organic chemicals are transported relatively long distances in the water column to beneficial use areas such as the Lewis and Clark National Wildlife Refuge. Although there are additional sources of AOX, including municipal wastewater effluent, chemical industries that use or produce chlorinated organic compounds (e.g., wood treatment facilities), anthropogenically derived and biologically produced (i.e., natural) atmospheric sources, and *in situ* biological production (Enell et al. 1989; Imhoff 1989; Enell and Wennberg 1991; Grimvall et al. 1991), bleached kraft pulp and paper mills are likely one of the most significant sources of AOX in the study area below Bonneville Dam. For example, pulp and paper mills, municipal and other industrial sources, and nonpoint sources accounted for approximately 33, 21.5 and, 45.5 percent, respectively, of the AOX discharges to the Ruhr River, Germany (Imhoff 1989). Currently, limited data are available for the sources of AOX to the lower Columbia River. However, it should be noted that the environmental significance of the AOX from each source depends on the toxicity and persistence of the halogenated organic compounds that comprise the AOX that is measured from each source.

Four bleached kraft pulp and paper mills and one municipal wastewater treatment plant (the recipient of primary treated wastewater from Boise Cascade, St. Helens) that discharge directly to the lower Columbia River below Bonneville Dam are presently required to monitor AOX concentrations in their effluent. These facilities are the James River (Camas), Longview Fibre, Weyerhaeuser (Longview), James River (Wauna) mills, and the city of St. Helens municipal wastewater treatment plant. AOX monitoring data for the bleached kraft pulp and paper mills that discharge directly to the lower Columbia River below Bonneville Dam are presented in Table 2-14. In general, effluent AOX concentrations in bleached kraft pulp and paper mills ranged from 4.2 to 37.1 mg Cl^-/L. Longview Fibre reported the lowest AOX concentration due to the lower production of bleached pulp at this facility. However, these reported concentrations may be underestimates of total AOX discharge if the effluent solids are removed by filtration or are allowed to settle prior to analysis. Bousquet (1992) reported that many industry and contract laboratories remove effluent solids prior to analysis, even when the method employed specifies the inclusion of solids in the method. Statistically significant differences were noted between analyses conducted by the same method, but in which some analysts excluded solids from the analysis (Bousquet 1992).

TABLE 2-14. AOX DISCHARGE DATA FROM PULP AND PAPER MILLS THAT DISCHARGE DIRECTLY TO THE LOWER COLUMBIA RIVER BELOW BONNEVILLE DAM, SEPTEMBER-NOVEMBER 1991.

Facility	September			October			November		
	Date	Concentration (mg/L)	Discharge (MGD)	Date	Concentration (mg/L)	Discharge (MGD)	Date	Concentration (mg/L)	Discharge (MGD)
James River (Camas) River Mile 120.5	6	21.8	--	4	12.6	58.2	1	23.2	53.1
	13	23.2	--	11	20.0	57.3	8	25.8	54.8
	20	27.4	--	18	18.6	52.4	15	26.0	47.6
	27	10.4	--	25	23.5	56.5	12	37.1	55.1
							29	24.0	54.0
City of St. Helens River Mile 86.0	NA[a]	18.2	36.65	9	18.8	36.2	13	20.8	37.4
Longview Fibre River Mile 67.5		--	--		--	--	7	7.4	--
		--	--		--	--	14	4.6	--
		--	--		--	--	22	4.4	--
		--	--		--	--	27	4.2	--
Weyerhaeuser (Longview) River Mile 63.5		--	--	23	14.5	--	9	13.0	--
		--	--	30	12.0	--	16	14.0	--
		--	--				22	14.0	--
		--	--				28	14.5	--
James River (Wauna) River Mile 42.0	NA[a]	17.1	40.1	NA	15.5	41.1	NA[a]	12.9	37.8

NA = Not available [a] = Reported monthly values

SOURCE: Capur, R., 29 July 1992, personal communication
Yee, C., 28 July 1992, personal communication

Although other industrial facilities and municipal wastewater treatment plants are not presently required to monitor AOX in their effluents, Imhoff (1989) reports a municipal wastewater concentration of only 0.1 mg Cl^-/L for municipal wastewater treatment plants discharging to the Ruhr River.

Based on an average flow of 124,000 cfs in the Columbia River (see Section 1.2.2), an instream or background concentration of 25 μg Cl^-/L of AOX, an effluent discharge of 50 MGD, and assuming complete mixing of the wastestream with the river and no immediate losses of AOX to the sediments or to the atmosphere, the effluent concentration necessary to double the concentration in the river to 50 μg Cl^-/L would be 96 mg/L, or more than twice the highest concentration measured in the effluent of the pulp and paper mills in the study area. However, the cumulative AOX discharge of the five mills would be sufficient to noticeably elevate the river AOX concentration, if losses of AOX to the sediment and atmosphere are negligible.

To determine more precisely the relative contribution of the various sources of AOX to the lower Columbia River, AOX concentrations should be determined using consistent methodologies and protocols. Data are also needed on the AOX concentration and discharge rates of anthropogenic sources (including municipal, industrial, and nonpoint sources), the contribution of AOX in wet and dry deposition, and the rate of *in situ* biological production of AOX. The information on the sources of AOX, coupled with the rate of sedimentation of AOX and the removal of AOX to the atmosphere, would allow for the development of a numerical model and comparison with the measured concentration of AOX in the water column. Bleached kraft pulp and paper mills that discharge directly to the lower Columbia River have initiated weekly monitoring of AOX in their treated effluent.

Comparison with Historical Data. Tetra Tech (1992a) identified only one prior study of water column AOX concentrations in the lower Columbia River (Young 1989). In that study, concentrations of AOX upstream of the James River Camas mill were 18 to 25 μg Cl^-/L, while concentrations downstream of the mill's discharge increased to 61 to 106 μg Cl^-/L. The effluent AOX concentration measured during the study was 20 mg Cl^-/L. The concentrations of AOX in the upper reach of the river below Bonneville Dam measured in the lower Columbia River reconnaissance survey were consistent with, but slightly lower (10 to 15 μg Cl^-/L) than those measured in the previous study (18 to 25 μg Cl^-/L). Although the influence of the James River Camas mill on the downstream concentration of AOX was not evident in the lower Columbia River reconnaissance survey, the nearest downstream AOX monitoring station was over 5 RMs downstream of the mill's point source discharge. The concentration of AOX at this downstream monitoring station (station W39) was 15 μg Cl⁻/L.

Significance and Recommendations. Although sampling stations for AOX were limited (16 stations along the length of the river and one sample each from the Lewis and Clark, Cowlitz, and Willamette rivers), the influence of bleached kraft mill discharge of AOX was apparent. However, AOX was not an ideal tracer of pulp and paper mill effluent since there are additional sources of AOX, including natural biological production that compromise the use of AOX as a tracer of pulp and paper mill effluent.

Furthermore, the environmental significance of the levels detected cannot be assessed. Because AOX is a measure of all halogenated organic compounds, it does not distinguish the relative contribution of the more toxic constituent halogenated organic compounds. The absolute concentration of AOX does not accurately reflect the actual toxicity or carcinogenicity of the water sampled. The relative contribution of the more toxic halogenated organic compounds may vary from sample to sample and hence it is likely that AOX concentrations will be poorly correlated with toxicity. Determination of the relative contribution of the more toxic halogenated organic compounds in AOX measurements may prove more informative in assessing the biological significance of AOX measurements. The character and source of background levels of AOX entering the lower river from upriver above Bonneville Dam and from the Willamette River should also be assessed.

2.8 SUMMARY

The water column data collected for the reconnaissance survey has characterized conventional water quality (especially temperature and dissolved oxygen), phytoplankton levels, bacterial indicators of pathogens, and levels of chemicals of concern in the lower Columbia River. Levels of AOX were also studied to evaluate the influence of bleached kraft pulp and paper mill discharges to the river.

DO concentrations were below state standards for fresh water at ten stations and at one estuarine station. However, many of these exceedances were due to DO percent saturation falling not more than a few percent below the 90 percent standard. Significant DO standards exceedances occurred at station W4 in the estuary in the Skipanon River, station W34 (Lake River), and at the mid-channel station below Skamokawa Creek (W13).

Water temperature conditions during the survey were below the Washington established criterion (20° C). At several stations below Bonneville Dam, temperatures were above 19° C. These temperatures indicate near exceedances. However, historical data indicate that the 20° C standard is frequently exceeded, especially during July, August, and September. Elevated temperatures (above the established criterion of 20° C) have implications primarily for the river's anadromous fish species as well as for other resident biota. Historically (at least since 1938), the temperature of the lower Columbia River appears to have exceeded 20° C in August. The construction of various impoundments on the river, has served to mitigate water temperature in spring and summer and increase water temperature in fall and winter.

The phytoplankton data and historical nutrient data indicate that although nutrients are available for phytoplankton growth during the low-flow period, phytoplankton abundance and biomass were relatively low. Nuisance levels of phytoplankton, especially of the blue-green algae (cyanobacteria), were not observed during the survey.

Indicator bacteria concentrations (fecal coliform and enterococcus bacteria) were measured to assess the sanitary quality of river water at a few beneficial use areas including contact recreation and shellfish harvesting areas. Fecal coliform counts at three of the six stations sampled (W3, W35, and W38) exceeded state standards. Fecal coliform geometric mean concentration at station W3 in Ilwaco exceeded the state standard for marine and shellfish harvesting waters. Enterococcus counts were generally higher than those for fecal coliforms, and they exceeded federal standards at all stations sampled.

Metals were detected in a number of the samples collected during the survey. However, these data have been qualified as estimates due to the considerations outlined above. Cyanide was not detected. Based on comparison with available chronic marine and freshwater criteria, many of the concentrations of metals detected in the survey exceeded established criteria. Exceedances of the freshwater chronic criteria were noted for aluminum, cadmium, copper, iron, lead, and zinc. However, the DLs for some metals were higher than the available criteria. The freshwater criteria for lead, mercury, selenium, and silver and the marine chronic criteria for lead, mercury, nickel, and selenium were lower than the DLs achieved in this study. Due to possible laboratory contamination of the aluminum samples, many of the reported concentrations that exceeded the freshwater quality criterion were qualified as undetected. The available freshwater chronic criteria were not exceeded in any sample from a freshwater station for the metals antimony, beryllium, chromium, nickel, and thallium.

The reconnaissance survey results, however, did not compare favorably with recent measurements of water column concentrations of the trace metals cadmium, copper, lead, mercury, and zinc (Saunders, S. and B. Hopkins, 30 April 1991, personal communication). These data indicate that the reconnaissance survey metals results, at least for these metals, may have been positively biased due to contamination in the field or laboratory. Therefore, conclusions regarding water quality problems based on the reconnaissance survey metals data should be considered with caution. It is recommended that future sample collection and analyses for water column metals use rigorously clean field sampling and laboratory analysis techniques.

Although potential point sources were identified for the metals detected in the reconnaissance survey samples, nonpoint and in-place sources of these metals are also likely sources of these metals in the lower Columbia River. The data on the relative contribution of point, nonpoint, and in-place pollutant sources is extremely limited (Tetra Tech 1992c). Furthermore, the limited nature of a reconnaissance survey does not allow for the definitive identification of specific pollution sources.

All of the organic chemicals of concern were undetected in the samples collected during the survey, except for the phthalate ester bis(2-ethylhexyl)phthalate. This compound was reported from two stations: the Portland/Vancouver area (W37) and below the confluence of the Kalama and Columbia rivers (W26). Although this chemical is a common laboratory contaminant, neither field nor laboratory method blanks showed evidence of contamination from this compound. The reported concentrations at both stations exceeded the freshwater chronic criterion of 3 μg/L.

In several instances, the DLs for the organic compounds not detected in the water column during this survey were greater than the established marine and freshwater chronic criteria. These compounds include pentachlorophenol, hexachlorocyclopentadiene, forms of DDT and their metabolites, heptachlor, alpha-chlordane, aldrin, dieldrin, mirex, parathion, toxaphene, endrin, methoxychlor, and PCBs. It is possible that many of these compounds were present in the water column, but at concentrations below the detection limits of the conventional analytical methods used in this study. Although water column concentrations of dioxin were not measured in this study (since the expected concentrations are below conventional detection limits), a modeling study of the Columbia River indicates that water column dioxin levels are likely above the regulatory limits for this compound for the protection of human health due to inputs from chlorine bleach pulp and paper mills that discharge to the river (U.S. EPA 1991c,d).

AOX concentrations in the upper river above the influence of the bleached kraft pulp and paper mills ranged from 10 to 15 μg Cl^-/L. These concentrations increased to 40 to 60 μg Cl^-/L in samples collected below the bleached kraft pulp and paper mill outfalls near Longview. In the estuary, concentrations of 250 to 255 μg Cl^-/L were reported, although such levels are likely due to analytical interferences in the laboratory method used. Bleached kraft pulp and paper mill discharges from Camas, St. Helens, and Wauna did not appear to have an appreciable effect on AOX concentrations downriver of these facilities. This result is likely due to the relatively limited number of stations surveyed and possibly the relative quantity of AOX discharged by these facilities.

3.0 SEDIMENT CHEMISTRY

3.1 INTRODUCTION

Sediments in aquatic environments often represent a major repository for anthropogenic contaminants, and in turn may serve as a significant source of these contaminants to aquatic organisms and the animals and humans that feed on these organisms (Landrum and Robbins 1990). Contaminants introduced into the lower Columbia River from various sources enter both as dissolved and particulate forms. Many of the dissolved contaminants adsorb preferentially onto, or enter the river associated with, fine-grained suspended sediment particles as a result of physicochemical interactions and the larger surface area of the fine-grained materials. These suspended particles are either flushed into the Pacific Ocean or deposited in low-energy regions (e.g., backwaters, sloughs, and wetland areas) of the river.

Contaminated sediments can result in the exposure of river biota to potentially toxic chemicals, thus affecting the ecological health of the system. Actual transfer of contaminants to aquatic organisms and other animals is affected by many factors including the initial chemical form of the contaminant, its ability to be taken up by physiological processes, and its propensity to accumulate in tissues. Organisms residing in the sediments come into direct contact with contaminants which may then be absorbed through their body surfaces. Ingestion of sediments may further expose benthic organisms to sediment-bound contaminants by breaking down the chemical bond with the sediments or altering the form of the contaminant. Contaminants that are able to accumulate in tissues may then be transferred up the food chain by predator-prey interactions. Effects of contaminant exposure may be exhibited by alterations in the benthic community structure, decreased biomass or abundance, reproductive impairment or failure, presence of metabolic byproducts in tissues, and increased prevalence of diseases in biota (Myers et al. 1987; Nalepa and Landrum 1988; Weston 1990; Ferraro et al. 1991).

Although a number of earlier studies have assessed sediment contamination in the lower Columbia River, the reliability of the data from many of these studies is uncertain (see Tetra Tech 1992a for a review of these studies). Assessment of the current state of sediment contamination in the study area, based on the relatively few studies with reliable data, is difficult for several reasons. First, the studies were conducted between 1960 and 1990 and may not accurately reflect current conditions, given the dynamic nature of sediments in rivers. Second, the studies were designed to address specific objectives at particular sites along the river and do not provide complete spatial coverage of the lower 146 miles of the river. Finally, analytical parameters measured were not consistent among the studies and the methods used were not always comparable, limiting the use of these data for making an overall assessment of sediment quality in the study area.

Historical sediment studies conducted in the lower river include analyses of sediment grain size, mineralogy, and/or sediment transport (e.g., Conomos 1968; Whetten et al. 1969; Conomos and Gross 1972; Glenn 1973; Hubbel and Glenn 1973; Haushild et al. 1975; Karlin 1980; Fox 1981; Sherwood et al. 1984; Simenstad et al. 1984). Although sediment organic content has typically been measured in historical studies of sediment contaminants, Hedges et al. (1984) investigated the sources and distribution of sedimentary organic matter in the Columbia River drainage basin. Studies on sediment metal and organic chemical concentrations (i.e., volatile and semivolatile compounds, pesticides and PCBs, dioxin and furans, and resin acids) have also been conducted for a variety of sediment chemical constituents at a number of locations in the lower river using a variety of chemical methods (e.g.; Rickert et al. 1977b; Fuhrer and Rinella 1983; Fuhrer 1984; Fuhrer 1986; Johnson and Norton 1988; Fuhrer and Horowitz 1989; Young 1988; Young et al. 1988; Century West Engineering Corp. 1990; U.S. Army Corps of Engineers 1990,1991). Several studies of sediment radionuclide content in the lower Columbia River have also been conducted historically, primarily in regard to plutonium production operations at the Hanford facility in Richland, WA (e.g., Perkins et al. 1966; Johnson et al. 1967; Forster 1972; Glenn 1973; Hubbel and Glenn 1973; Haushild et al. 1975; Robertson and Fix 1977; Beasley et al. 1981; Beasley and Jennings 1984). No historical measurements of organotin compounds were identified in the review of historical sediment data (Tetra Tech 1992a).

Because no previous studies have systematically surveyed sediment contamination in the entire study area, the Bi-State Program directed the implementation of a reconnaissance survey to evaluate the current quality of sediments in the lower Columbia River. The objectives of the sediment survey were to:

- Determine the occurrence of selected, potentially toxic contaminants (chemicals of concern) in sediments of the lower Columbia River.

- Characterize broad-scale spatial trends in the distribution of contaminants in the sediments.

- Identify potential problem areas and reference areas in the study area.

This sediment chemistry section reports the results of the sediment sampling conducted as part of the lower Columbia River reconnaissance survey. The results are interpreted and discussed within the framework of the survey objectives outlined above.

3.2 SAMPLING LOCATIONS

Sediment stations sampled during the reconnaissance survey are shown in Figures 1-1 through 1-4. Geographic coordinates and river mile information are provided in Table 3-1 for each sampling station.

A Magnavox MX 200 GPS Navigator System on board the R/V Brendan DII was used to obtain the geographic coordinates of the stations sampled. Details of the navigation system operation are provided in Section 5.1 of the final QA/QC plan (Tetra Tech 1991b).

A total of 54 stations were sampled for sediment contamination. Selection of the sampling stations was based on the following considerations:

- The need to obtain broad-scale coverage of the entire lower Columbia River.

- The intention that most of the samples be of fine-grained sediments as an indicator of worst-case contamination.

- The need to identify potential effects of major industrial areas (e.g., the Ports of Longview, Vancouver, and Portland).

TABLE 3-1. LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY: LOCATIONS AND TIME OF SEDIMENT AND BENTHIC INFAUNA SAMPLING

Page 1 of 3

Station Number[a]	River Mile[b]	Latitude/Longitude	Sampling Date/Time	Water Depth (m)
D1	8.5	46-12.274N 123-56.986W	10-8-91 1400-1530	2.6
D2	2.5	46-18.042N 124-02.494W	10-8-91 1030-1115	5.4
E1	8	46-13.524N 123-56.303W	10-8-91 1630-1700 (Benthos)	5.6
			10-9-91 1120-1145 (Chem)	
D3 (D46 field duplicate)	13	46-10.90N 123-51.72W	10-9-91 1255-1350	2.1
D4	5.5	46-15.981N 123-58.261W	10-8-91 1220-1310	2.4
E2[D]	16	46-14.836N 123-48.510W	10-9-91 1555-1635	8.0
D5[E]	21	46-11.638N 123-42.104W	10-11-91 1200-1230	1.5
D6	21	46-17.882N 123-43.113W	10-10-91 1300-1350	1.8
E3	22	46-15.014N 123-41.261W	10-11-91 1530-1615	15.0
D7	22	46-13.019N 123-41.505W	10-11-91 1340-1410	1.8
D8	27	46-13.695N 123-35.223W	10-12-91 1210-1245	2.1
E4	30	46-15.976N 123-32.037W	10-12-91 0940-1030	15.0
D9	34	46-16.14N 123-27.34W	10-12-91 0805-0910	1.5
D10	38.5	46-12.198N 123-26.639W	10-7-91 1000-1115	1.6
D11 (D45 field duplicate)	29	46-14.49N 123-32.91W	10-7-91 1240-1345	1.8
D12	40	46-12.463N 123-23.375W	10-7-91 0815-0910	3.4
D13	43	46-09.78N 123-20.14W	10-6-91 0840-0950	4.6
D14	42.5	46-08.914N 123-23.424W	10-6-91 1310-1400	10.0
E5	46	46-09.535N 123-19.518W	10-5-91 1455-1550	5.5

TABLE 3-1. LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY: LOCATIONS AND TIME OF SEDIMENT AND BENTHIC INFAUNA SAMPLING

Page 2 of 3

Station Number[a]	River Mile[b]	Latitude/Longitude	Sampling Date/Time	Water Depth (m)
D15	49.5	46-08.347N 123-13.934W	10-5-91 1200-1255	6.6
D16	57.5	46-11.244N 123-05.429W	10-4-91 1445-1530	9.1
E6[D]	57.5	46-10.149N 123-06.470W	10-4-91 1245-1340	5.5
D17 (D44 field duplicate)	59	46-09.87N 123-02.76W	10-4-91 0940-1105	5.0 (Benthos) 7.0 (Chem)
D18	62.5	46-07.429N 123-01.307W	10-3-91 1240-1310	3.0
D19	63	46-08.32N 123-00.52W	10-3-91 1530-1615	4.0
E7	67	46-05.91N 122-56.23W	10-3-91 1020-1055	14.0
D20	71	46-03.596N 122-52.106W	10-2-91 1615-1655	2.5
D21	70	46-04.324N 122-53.934W	10-2-91 1455-1540	3.5
D22	75.5	46-00.584N 122-50.907W (Benthos)	10-2-91 0840-0950	Not Available
		46-00.586N 122-50.982W (Chem)		
D23 (D43 field duplicate)	80	45-57.378N 122-48.058W	10-1-91 1255-1325	5.0
D24	85	45-52.0N 122-47.8W	9-30-91 1000-1035	2.4
D25	88	45-50.408N 122-46.648W	9-29-91 1705-1735	3.4
E8	76.8	45-59.22N 122-50.23W	10-1-91 1445-1520	9.0
E9[D]	83	45-54.32N 122-48.82W	9-30-91 1600-1645	8.0
D26	92	45-46.921N 122-46.156W	9-29-91 1545-1615	13.7
D27	94.5	45-45.27N 122-46.669W	9-29-91 1415-1440	1.5
D28 (D42 field duplicate)	99	45-41.195N 122-46.14W	9-29-91 1145-1255	4.9

TABLE 3-1. LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY: LOCATIONS AND TIME OF SEDIMENT AND BENTHIC INFAUNA SAMPLING

Page 3 of 3

Station Number[a]	River Mile[b]	Latitude/Longitude	Sampling Date/Time	Water Depth (m)
E10^{D}	100	45-40.518N 122-46.529W	9-29-91 1045-1120	12.8
D29	101	45-40.12N 122-45.86W	9-29-91 1455-1525	2.4
D30	103	45-38.46N 122-44.68W	9-28-91 1010-1040	5.4
E11^{D}	104	45-38.448N 122-43.011W	9-28-91 0855-0925	12.0
D31	106	45-36.41N 122-40.48W	9-27-91 1430-1530	3.0
D32^{E}	107.5	45-37.03N 122-39.54W	9-27-91 1655-1740	5.5
D33	109	45-36.678N 122-37.613W	9-27-91 1255-1320	3.4
D34^{E}	112	45-35.604N 122-33.982W	9-27-91 1115-1145	1.7
E12	114.5	45-34.078N 122-31.191W	9-26-91 1510-1530	3.9
D35 (D41 field duplicate)	118	45-34.62N 122-26.781W	9-26-91 1705-1750	6.7
D36	118	45-33.516N 122-27.441W	9-26-91 1340-1410	4.0
D37	121	45-34.589N 122-23.73W	9-25-91 0920-1030	3.8
D38^{E}	124.5	45-33.464N 122-20.052W	9-25-91 1320-1530	4.0
E13	125.5	45-32.702N 122-18.935W	9-25-91 1645-1715	6.4
D39	128	45-32.604N 122-15.721W	9-24-91 1640-1830	5.4
E14	137	45-35.306N 122-05.979W	9-24-91 1240-1345	5.4
D40	142	45-37.327N 122-01.210W	9-24-91 0805-1055	5.4

[a] Station number prefixes "D" and "E" were assigned prior to sampling to stations expected to have fine-grained and coarse-grained sediments, respectively. Following sampling, some stations were reclassified based on the grain size analysis [> 20% fines (<100 μm) was considered a fine-grained sediment station]. Reclassified stations are identified by superscript "E" or "D".

[b] Approximate River Mile (to the nearest half mile) calculated from geographic coordinates.

- The need to begin to fill data gaps and investigate "hot spots" identified from a review of previous studies.

- The need to identify potential problem areas as well as reference areas in the river that could be the focus of future studies.

- Prevention of duplicate efforts in cases where recent (or ongoing) studies have provided useful data.

Sampling stations were strategically located within each segment of the study area based on the above considerations. Station locations were selected to represent predominantly fine-grained sediments. A subset (one-third) of the total number of stations were also located to represent coarse-grained areas typical of the main channel, higher energy areas of the river. A more detailed rationale for selection of station locations is provided in Section 5.4 and Table 5 of the final sampling plan (Tetra Tech 1991c). Some deviations from the sampling plan occurred during implementation of the field survey. These deviations [detailed in Section 2.2 of the Cruise Report (Tetra Tech 1991a)] consisted primarily of relocating ten sampling stations from the locations proposed earlier in the Sampling Plan. Station relocation was necessary because of navigational difficulties encountered (insufficient water depth) or the lack of fine-grained sediments in areas selected *a priori* as being depositional in nature.

3.3 SAMPLING METHODS

Forty of the 54 sediment sampling stations were located in areas expected to be fine-grained based on hydraulic characteristics. To gain a broad-scale view of the river's sediments, 14 sampling stations were located in higher energy areas designated as coarse grained, even though sediment contamination was not expected to be high in such areas. Chemical parameters measured in the sediments included conventional variables (grain size, total organic carbon, total solids, acid volatile sulfides), metals, and organic compounds, as well as several additional compounds identified by the Bi-State Program as being of concern due to specific industrial and land-use activities in the lower Columbia River subbasin (listed in Table 1-1). Specific stations where the above measurements were conducted are shown in Table 3-2.

TABLE 3-2. LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY STATIONS AT WHICH SEDIMENT PARAMETERS WERE MEASURED

(Page 1 of 2)

Station[a]	Conventionals[b]	Metals	Radionuclides	Organic Compounds[c]	Dioxins and Furans	Organotin Compounds
D1	X	X		X		
D2	X	X		X		X
E1	X	X		X		
D3	X	X		X		X
D4	X	X		X	X	
E2[D]	X	X		X		
D5[E]	X	X		X	X	
D6	X	X		X	X	
D7	X	X		X		
D8	X	X	X	X	X	
E4	X	X		X		
D9	X	X		X		
D10	X	X		X	X	
D11	X	X		X	X	
D12	X	X		X		X
D13	X	X		X		
D14	X	X	X	X	X	
E5	X	X		X		
D15	X	X		X	X	
D16	X	X		X	X	
E6[D]	X	X		X		
D17	X	X		X		
D18	X	X		X	X	
D19	X	X		X	X	X
E7	X	X		X		
D20	X	X	X	X	X	
D21	X	X		X		
D22	X	X		X		X
D23	X	X		X	X	
D24	X	X		X	X	X
D25	X	X		X		
E8	X	X		X		
E9[D]	X	X		X		
D26	X	X		X	X	
D27	X	X		X		
D28	X	X	X	X	X	
E10[D]	X	X		X		
D29	X	X		X		X
D30	X	X		X	X	
E11[D]	X	X		X		
D31	X	X		X		X
D32[E]	X	X		X		
D33	X	X		X		
D34[E]	X	X		X		
E12	X	X		X		
D35	X	X	X	X	X	

TABLE 3-2. LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY STATIONS AT WHICH SEDIMENT PARAMETERS WERE MEASURED

(Page 2 of 2)

Station[a]	Conventionals[b]	Metals	Radionuclides	Organic Compounds[c]	Dioxins and Furans	Organotin Compounds
D36	X	X		X		
D37	X	X		X		X
D38	X	X		X	X	
E13	X	X		X		
D39	X	X		X		
E14	X	X		X		
D40	X	X	X	X	X	X

[a] Station number prefixes "D" and "E" were assigned prior to sampling to stations expected to have fine-grained and coarse-grained sediments, respectively.

Following sampling, some stations were reclassified based on the grain size analysis [> 20% fines (<100 um) was considered a fine-grained sediment station].

Reclassified stations are identified by superscript "E" or "D".

[b] Conventional parameters include grain size, total organic carbon, total solids, and acid volatile sulfides.

[c] Organic compounds include semivolatile organic compounds and selected pesticides and PCBs.

Sediment sampling was conducted concurrently with water and benthos sampling from the R/V Brendan D II during the low-flow period between September 23 to October 12, 1991. The date and time of sampling at each station is provided in Table 3-1. Sediment samples were collected using a stainless steel, modified 0.1 m^2 van Veen grab sampler. A minimum of three grab samples were collected at each station. At a few stations, up to five grabs were necessary to obtain sufficient sediment volume for all the chemical analyses. The top 2 cm of sediment from each grab were collected to represent the biologically available portion of the sediment, and in depositional areas, the most recently deposited sediments. These sediments were then composited by thorough mixing before placing aliquots of sediment in the laboratory sample containers. Sample containers were stored on ice until delivery to the laboratory. Detailed descriptions of the sampling methods used and quality assurance procedures followed were provided in Section 5.2 of the final sampling plan (Tetra Tech 1991c) and Section 5.4 of the final QA/QC plan (Tetra Tech 1991b). Field sampling method deviations from the Sampling and QA/QC Plans were minor; they are outlined in Section 2.2 of the Cruise Report (Tetra Tech 1991a).

3.4 LABORATORY METHODS

All laboratory analytical procedures were performed by contract laboratories approved by the Bi-State Program. Sediment metals and conventionals (grain size, total organic carbon, fluoride, cyanide) analyses were conducted by Precision Analytics Inc. of Pullman, WA. All sediment organics analyses (with the exception of dioxins and furans) were performed by Alden Laboratories of Seattle, WA. Acid volatile sulfides (AVS) were analyzed by Analytical Resources Inc. of Seattle. Keystone/NEA of Portland conducted the analyses for sediment dioxins and furans. Sediment radionuclides were measured by the Washington State Department of Health (WSDH).

Analyses of sediment chemistry were conducted according to U.S. EPA-approved methods listed in Table 5 of the final QA/QC plan (Tetra Tech 1991b). Analyses for silver, aluminum, barium, copper, chromium, iron, nickel, antimony, thallium and zinc in the sediments were conducted by the inductively coupled plasma/atomic emission spectroscopy (ICP/AES) method 6010 and not the inductively coupled plasma/mass spectrometry (ICP/MS) 6020 method as specified in the QA/QC Plan.

The method employed by the WSDH for the analysis of americium-241 and plutonium-239/240 included an extraction procedure that involved decomposition of the sample with a combination of potassium fluoride and pyrosulfate fusion which resulted in a cake that was dissolved in diluted hydrochloric acid. All actinide elements were precipitated from the solution with barium sulfate. The precipitate was then dissolved in acidic aluminum nitrate. Plutonium was extracted into an organic solvent (Aliquot-336) and then removed with a mixture of perchloric and oxalic acids. The aqueous fraction containing americium and the organic fraction containing plutonium were then precipitated on cerious fluoride for analysis by alpha spectrometry (Silverstone, M., 20 January 1993, personal communication).

An extensive QA/QC review of the analytical data was performed by Tetra Tech according to the data validation guidance provided in U.S. EPA (1988a,b). QA/QC reviews of the sediment chemistry data included assessments of sample holding times, initial and continuing calibration, blank results, interference check samples, matrix spikes, surrogate spikes and laboratory replicates. Some of the data were further qualified based on this review. Details of the QA/QC reviews are provided in the QA memoranda in Appendix A (under separate cover). A brief summary of the QA/QC reviews is provided with the results in the following sections.

3.5 STATISTICAL METHODS

Statistical and graphical analyses of the reconnaissance survey data were used as tools to:

- Identify the relationships among physical, chemical, and biological features within the study area.
- Test for differences in the nature and extent of contamination among stations grouped by habitat characteristics.
- Identify areas of concern based on evidence of anthropogenic enrichment and comparison with sediment quality guidelines.

The results of these analyses provided information that could be used to guide the development of a long-term monitoring program. These analyses were performed using the computer programs in SYSTAT (Wilkinson 1989). Chemistry data were initially tabulated and summarized for each station. Only a single chemical concentration was reported at each station for individual metals and organic substances, which precluded calculation of summary statistics at a station or statistical comparisons among stations. However, comparisons of chemical concentrations among habitat types were made for stations grouped by sediment grain size characteristics (i.e., fine-grained and coarse-grained sediments) in the estuarine and freshwater reaches of the river.

In general, chemistry data tend to be skewed (i.e., not normally distributed). This tendency affects the choice of how average values will be calculated for a given chemical when station groups are compared. Use of an arithmetic mean will tend to under- or over-estimate the average concentration, depending on which direction the data are skewed. A common procedure for calculating average values with skewed data distributions is to use the median (50th percentile). Inter-quartile ranges (IQR; 75th minus the 25th quartile value), rather than the standard deviation, can then be used to represent the variability or spread of the data about the middle point.

Calculation of average concentrations for station groups required a decision about the treatment of concentrations below the detection limits. Rather than treat such concentrations as zero, undetected values were represented by one-half of the detection limit, thus providing a compromise estimate of the actual concentration. Only chemicals that were detected at least once were included in subsequent comparisons among areas of the river.

3.5.1 Tests of Relationships Among Biotic and Abiotic Variables

The relationship among chemical variables, biological variables, and physical habitat characteristics (e.g., total organic carbon and sediment fines) at all stations in the river was examined using correlation analyses. Correlation analysis reveals the intensity or strength of an association between two variables (e.g., mollusc abundance increases with increasing percent sediment fines), but involves no assumption of dependency between the variables (i.e., both variables have a describable relationship, but are independent of one another). The Pearson correlation coefficient (r) was used as a measure of the strength of the linear association among the chemical, ecological, and conventional variables. A correlation coefficient can have a value ranging from 0 to 1.00. Values approaching 1.0 indicate stronger linear relationships; low values indicate a weak association or other than a linear association. Bonferroni's probability (SYSTAT CORR procedure) was computed to test the significance of the correlation. A regression analysis was also performed to estimate the degree of association between two variables [in this type of analysis, one variable is assumed to be dependent upon the other (e.g., benthic abundance decreases with increasing chemical concentration)]. Scatter plots (SYSTAT SPLOM procedure) were used to illustrate the relationships among ecological variables, sediment chemistry, and habitat characteristics. Significant ($P \leq 0.05$) relationships between chemical or biological and physical variables were used to define station groups for further statistical tests.

3.5.2 Tests of Differences Among station Groups

Relationships between stations grouped according to habitat characteristics were examined using two-sample hypothesis tests. Independent *t*-tests were used to determine whether chemical concentrations in estuarine sediments differed from those in riverine sediments. The independent *t*-test procedure is based on the assumption that the data are approximately normally distributed, but it does not assume that the samples have equal variances. Because the distribution of the data affects the validity of the test results, the distributions of chemistry data were examined using normal probability plots from the SYSTAT PROB'Y procedure. Plots resulting in an approximate straight line have a normal distribution. Most metals and some organic compounds appeared to be normally distributed. However, some departures from normality were suggested by the plots for a few compounds (e.g., arsenic). These data were transformed by calculating the log of each concentration and were again plotted against the theoretical normal distribution. Because transformation improved the distribution of some chemistry data, statistical analyses based on assumptions of normality were conducted with log-transformed data for all chemistry values. This transformation is a conservative measure that does not affect the test results for those substances that appeared to be normally distributed before the transformation.

As part of the *t*-test procedure, the probability was calculated for the paired variables to determine which station groups were significantly different from other station groups. To conservatively retain possible but realistic differences, a probability of $P \leq 0.05$ was used as the significance level in each of these tests; i.e., all comparisons with probabilities less than or equal to 0.05 were considered significantly different.

3.5.3 Identification of Areas of Concern

Areas and constituents of concern were determined on the basis of evidence of anthropogenic (i.e., derived from human activities) elevations of the chemical substances. To evaluate the ecological significance of elevated sediment chemistry, chemical concentrations were compared to effects-based sediment quality guidelines used in other programs.

3.5.3.1 Anthropogenic Contributions. Concentrations of metals and organic compounds in sediments from the lower Columbia River represent both naturally occurring sources and those derived from human activities. Several approaches were used to attempt to distinguish between the concentrations expected due to the natural abundance of elements (primarily metals) in the earth's crust (or "background levels") and potentially elevated concentrations due to anthropogenic pollutant inputs.

Metals are a normal constituent of fluvial sediments and occur naturally at some level due to their abundance in the earth's lithosphere. Many metals are associated with the aluminum or iron oxide coatings found on the surface of sediment particles and within the sediment mineral matrix. Metal concentrations therefore tend to vary in relationship to the sediment concentration of aluminum or iron. However, large inputs of metals other than iron or aluminum, especially metals that typically occur at relatively low concentrations (but are concentrated and utilized by humans), may enrich the sediments in that metal relative to iron or aluminum. To identify elevated levels (potentially indicating anthropogenic contributions) of metals in the sediments, regression analyses were used to examine the relationship between individual metals and iron. This regression approach (which is essentially a normalization technique) has been applied in other studies to identify areas of anthropogenic influence (e.g., Luoma 1990; Din 1992; Pardue et al. 1992). Iron from natural sources is usually present in sufficiently high concentrations such that anthropogenic loadings rarely have substantial effects on background measured levels. Although sediment aluminum concentrations would also have been appropriate for regression analyses, aluminum was not used for identification of potential areas of anthropogenic influence due to the possibility that sediment aluminum concentrations may have been influenced by inputs of aluminum from point source discharges. However, available data indicate that present direct point source discharges of aluminum to the lower river are relatively insignificant when compared to tributary and upstream loadings (Tetra Tech 1992c). Concentrations of individual metals that exceeded the 90 percent confidence limits for the regression with iron were interpreted as indications of possible contribution by human activities.

This method of identifying possible anthropogenic contributions is appropriate only where there is a strong correlation between the chemical concentration and the independent regression variable (i.e., iron). Additional methods based on identification of outliers from ranked chemical concentrations were used to identify anomalously high concentrations for metals that were not significantly correlated with iron. In the latter method, chemical concentrations for each substance are ranked from highest to lowest and the difference between the 75th percentile and the 25th percentile is calculated (i.e., the inter-quartile range). Concentrations that exceeded 1.5 times the inter-quartile range were used to identify potential areas of concern in the river (Moore and McCabe 1989).

The concentrations of organic compounds in sediments were treated differently because these chemicals originate primarily from human activities (i.e., all locations and concentrations where organic substances were detected were assumed to have been anthropogenically influenced). The identification of stations with the highest organic compound concentrations measured during the reconnaissance survey was considered to be of value for directing future investigations and to identify potential source areas. However, because the organic compounds analyzed were undetected at most stations, or were not significantly correlated with a sediment-conventional variable (e.g., total organic carbon or sediment grain size), the regression-based approach was not used. For these compounds, concentrations were ranked from highest to lowest, and concentrations exceeding 1.5 times the inter-quartile range were used to identify areas where the concentrations were the highest relative to other stations.

This approach for identifying anomalously high concentrations of contaminants does not necessarily identify concentrations that may have adverse effects on biota or otherwise be of concern. This issue is addressed by comparing the measured contaminant concentrations to the effects-based sediment reference levels identified for the reconnaissance survey, based on concentrations of contaminants observed to have adverse biological effects, as discussed in the following section.

3.5.3.2 Comparison to Sediment Quality Guidelines. The concentrations of selected substances were also compared with reference values developed by other regulatory or resource management programs. The Effects Range-Low (ER-L) concentrations (based on the lower-range of the concentrations in marine and estuarine sediments associated with adverse biological effects) compiled by Long and Morgan (1990), the Ontario Ministry of the Environment's Provincial Sediment Quality Guidelines for freshwater sediments (Persaud et al. 1991), and the five recently issued draft EPA freshwater sediment criteria

(U.S. EPA 1991e,f,g,h,i), were used for screening purposes. Where appropriate, sediment organic carbon-normalized chemistry data were compared to the reference values. Chemicals that exceeded available reference values were flagged. The magnitude and spatial distribution of these exceedances were used to delineate problem areas. Identifying exceedances by comparison to reference values does not imply that regulatory exceedances occurred, but rather it assists in the identification of areas that may pose potential threats to Columbia River resources.

Each of the various reference values identified (i.e., Long and Morgan's ER-Ls, Ontario's guidelines, and the draft EPA criteria) are effects-based guidelines; that is, the guidelines are based on a consideration of the concentrations associated with adverse effects on aquatic organisms. The need for a means to evaluate marine sediment data collected as part of the National Oceanic and Atmospheric Administration's (NOAA's) National Status and Trends Program resulted in the development of ER-L and Effects Range-Medium (ER-M) concentrations (Long and Morgan 1990). The potential for biological effects is higher where sediment chemical concentrations exceed the ER-M concentrations; the potential is lower where chemical concentrations exceed the ER-L concentration, but not the ER-M concentration. However, the effects range concentrations are only guidelines for evaluating sediment chemistry data. Similarly, the Ontario Ministry of the Environment has compiled a set of numerical guidelines for the protection of freshwater biological resources (Persaud et al. 1991). Emphasis has been placed on the protection of benthic organisms that are directly affected by contaminated sediment. The Ontario guidelines are used to address issues associated with dredged-material disposal activities and the suitability of sediments for the restoration of benthic habitats. Sediment quality guidelines have been developed for the no-effect level, lowest-effect level, and severe-effect level categories. The no-effect level and lowest-effect level guideline concentrations are comparable to the ER-L's developed by Long and Morgan (1990). EPA draft criteria have been developed for the protection of marine and freshwater benthic organisms for the pesticides endrin and dieldrin, and the PAHs fluoranthene, acenaphthene, and phenanthrene. These effects-based concentrations have been developed using the equilibrium partitioning approach for the development of standards for non-polar, non-ionic compounds. These criteria are based on sediment organic carbon concentrations and are valid only for sediments with greater than 0.2 percent carbon content.

There are several limitations associated with each of these sets of guidelines. Although each is designed to address sediment toxicity to aquatic biota, the chemical (e.g., proportion of sediment organic carbon) and physical (e.g., proportion of fine sediment) character of the sediment can strongly influence the potential effect of toxic substances on benthic organisms (e.g., Luoma 1989; Landrum and Robbins 1990; Farrington 1991). The effects-based standards are also for single chemical constituents; sediments normally contain a mixture of contaminants and the potential additive, synergistic, or antagonistic effects of these mixtures is not necessarily accounted for in these standards and guidelines. However, exceedance of these guidelines should indicate the potential that adverse effects will occur to biological resources as a result of exposure to the contaminated sediments. Exceedances can be used to identify reasons for altered benthic community structure, decreased biomass or abundance, or physiological effects (e.g., physical aberrations, reduced reproductive success, physiological stress, or mortality).

After these two independent analyses, a preponderance-of-evidence approach was used to delineate areas of potential concern (Section 3.6.3.3). Stations where chemical concentrations represented likely contribution by human activities, and where the concentrations exceeded sediment quality reference values, were ranked based on the number of substances exceeding the reference values at each station. The geographic distribution of stations with the greatest number of substances exceeding the reference values was further examined in light of potential contaminant sources (e.g., urban areas, agricultural areas, and industrial discharges).

3.6 RESULTS

The following section summarizes the chemical results for 54 surface sediment (0-2 cm) samples collected at 54 stations in the Columbia River below Bonneville Dam. All sediment samples were analyzed for sediment grain size, total organic carbon content (TOC), 17 metals, and 122 organic compounds, including polycyclic aromatic hydrocarbons (PAHs), pesticides, and PCBs. Analyses were performed at a more limited number of stations for polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) (i.e., dioxins and furans), organotin compounds, and radionuclides. For a complete listing of analytes, see Table 1-1. The stations where specific chemical analyses were performed are identified in Table 3-2. Raw data are presented under separate cover in Appendix C.

3.6.1 Physical Characteristics, Total Organic Carbon, and Acid Volatile Sulfides

Sediment samples collected from the lower Columbia River were analyzed for conventional sediment constituents including grain size, TOC, and acid volatile sulfides (AVS) at all sediment sampling stations. A field duplicate was collected at stations D3, D11, D17, D23, D28, and D35 (identified as samples D46, D45, D44, D43, D42, and D41, respectively). Raw data for sediment grain size, TOC, and AVS are provided in Appendix C-1.

3.6.1.1 Summary of Quality Assurance/Quality Control. TOC concentrations were qualified when the sediment sample concentrations were below the DL with a "U" (sample concentration below the detection limit). The detection limits reported by the laboratory were somewhat higher than those reported in the QA/QC plan (Tetra Tech 1991b). Reported detection limits ranged from 257 to 502 mg/kg rather than the 200 mg/kg detection limit specified in the QA Plan. TOC method blank analyses indicated consistent method blank contamination (generally less than 432 mg/kg). Therefore, all sediment TOC results have been blank corrected and the results have been reported using the qualifier "Z" (blank corrected). The results of matrix spike and matrix spike duplicate analyses indicated that the precision and accuracy of the reported data were within acceptable limits.

Sediment grain size results were reported for all stations. Although no laboratory replicate samples were analyzed, analysis of six field duplicates indicated large variations in sample results, especially for size fractions with low measured weights of sediment. Without an estimate of analytical precision (based on laboratory replicates) these data should be considered estimates and have been qualified with an "E" (value is an estimate). Although these data have been qualified as estimated they should be suitable for their intended use in this study.

All sediment samples were analyzed for AVS. Method blanks were analyzed for AVS and none of the blanks contained AVS at concentrations above the laboratory detection limit. However, due to poor analytical accuracy and precision determined from analyses of reference standards, laboratory duplicates, and matrix spikes, these data were considered unacceptable for use in this study and have been qualified using "R" (data unusable). The AVS data are provided in Appendix C-1, but will not be used in this report.

Results and summary statistics of blind laboratory and field replicate samples [e.g., mean and relative percent differences (RPDs)] for these data are presented under separate cover in the QA memoranda, Appendix A-2.

3.6.1.2 Sediment Grain Size Classification. In the lower Columbia River, the majority of sediments are coarse grained and distributed among various sand fractions (Figure 3-1a). Because the sampling was biased toward sediments that permitted adequate grab penetration, finer sands (63-125 μm) often were a major fraction of the sediments. Silt dominated the sediment composition only at two stations: the station in Baker Bay (D2) where it constituted over 90 percent of the sediments, and at station D22 near Kalama, which contained 52 percent silt. Clay-sized sediments did not constitute a major component of the sediments at any station sampled. There were no apparent consistent spatial trends in the composition of the sediments, with similar sediments being collected from all segments of the river. The one exception may be the possible trend toward finer-grained sediments near the mouth of the river, but that trend is indicated by too few stations to be considered well established.

Sediment particles finer than 100 μm in size are small enough to be transported as suspended material in the water column because of the high energy nature of the Columbia River (Conomos and Gross 1972, Sherwood et al. 1984, Tetra Tech 1992b). Glenn (1973) indicated that during low-flow, only sediment grains less than 62 μm were transported downriver, but during high-flow sediment grains as large as 500 μm could be transported. Presence of these finer fractions of particles in the sediments was, therefore, considered to be indicative of areas that were more depositional in nature. The fraction of the sediments with grain size less than 100 μm has also been used by previous investigators of the Columbia River to assess the potential biological availability of sediment contaminants in the less than 100 μm fraction (Fuhrer and Horowitz 1989). This sediment fraction was considered by Fuhrer and Horowitz (1989) to represent the sediment consumed by selective deposit-feeding benthic invertebrates.

Throughout the river, the percent of sediments finer than 100 μm (the sum of fine sands, silts, and clays) ranged from <1 to 98 percent (Figure 3-1b). While no data were available to clearly use the grain-size data to distinguish actual depositional areas from less stable locations, it was considered reasonable to use these data to classify the location as either comparatively stable/depositional (finer-grained) and unstable/erosional (coarser grained). Based on reasonably conservative judgement, the presence of the fine sediment size fraction in amounts greater than 20 percent of the total sample weight was used to

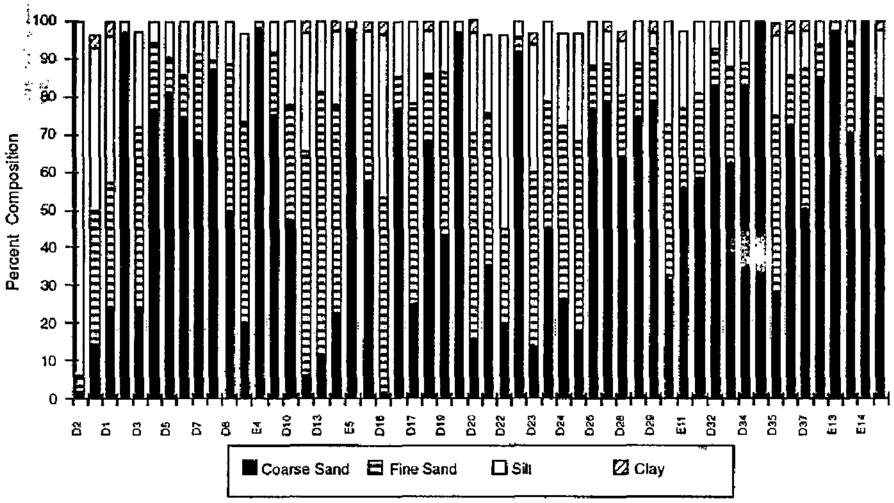


Figure 3-1a. Composition of sediments at 54 stations in the Columbia River below Bonneville Dam (Rm 146).

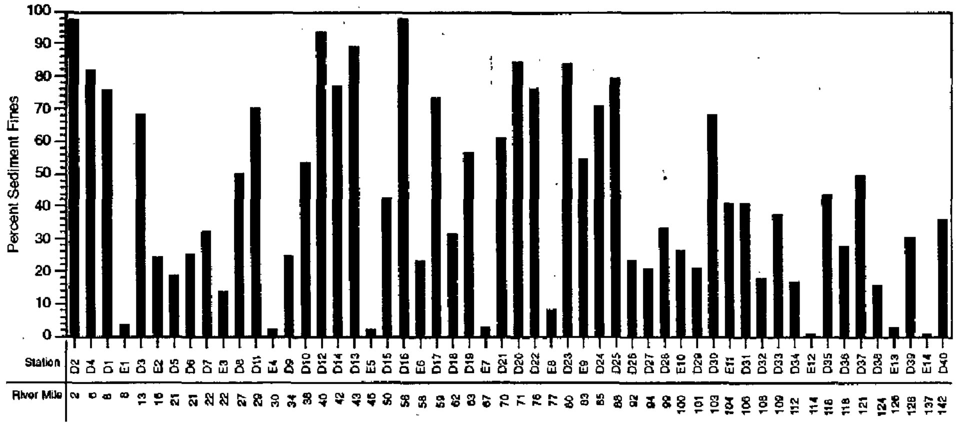


Figure 3-1b. Percent sediment fines (percent finer than 100 µm - sum of fine sands, silts, and clays) at 54 stations in the Columbia River below Bonneville Dam (RM 146).

distinguish the two habitat types in the river. A total of 41 fine-grained and 13 coarse-grained stations were sampled on the basis of this classification. Although most of the samples collected in areas of the river predicted to be coarse-grained prior to the reconnaissance survey had less than 20 percent fines, nine stations had to be reclassified. Stations D5, D32, D34, and D38 were reclassified as coarse-grained habitats; stations E2, E6, E9, E10, and E11 were reclassified as fine-grained sediments. These changes will be noted in the text by using a superscript ^{D} or ^{E} (e.g., E2^D). As was the case with the overall sediment texture comparisons, no spatial trends were apparent in the distribution of fine-grained sediments among the stations sampled.

A major focus of the sediment sampling effort was to sample a range of sediment sizes, including sampling as far up into backwater and sloughs as permissible, to collect the finest sediments possible as a potential indication of worst-case contamination. This effort was largely successful, with the fine-grained content of the samples collected ranging from less than 1 to 98 percent, as noted above. However, sampling in shallow backwater areas was limited by the draft of the research vessel (4 ft) and the fact that sampling occurred during low-flow conditions (see Section 1.2.2). Therefore, it is possible that sediments with a higher proportion of fine silts and clay content than found in the survey are present in the river's backwaters. It is also possible, therefore, that worst-case contaminant conditions present in the river system were not sampled during the survey. This should be kept in mind when reviewing the results presented in the sediment section. In future sampling on the lower river as part of this program, additional steps (sampling from shallow-draft boats or from shore, and sampling during higher river stages) should be taken to sample fine-grained sediments in sloughs and backwaters.

3.6.1.3 Total Organic Carbon. TOC is known to affect the bioavailability and toxicity of some substances, can be used to discriminate locations of sediment deposition and erosion, and influences the composition and abundances of benthic communities. TOC content of the sediments was low (less than 1.6 percent) at all but one station (station D35 in Camas Slough) in the lower Columbia River, and showed no obvious spatial trends. TOC data are presented in Figure 3-2a.

TOC also tends to accumulate to greater concentrations in finer-grained sediments because finer-grained particles have greater surface area per mass and hence sorb relatively greater concentrations of TOC. As a result, TOC correlates positively with the percentage of finer-grained sediments (see Figure 3-2b). The high TOC content observed at station D35, however, was anomalous.

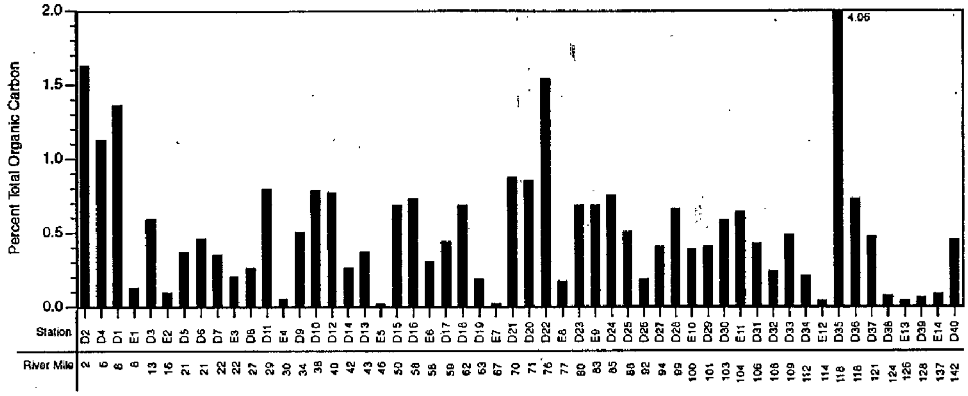


Figure 3-2a. Percent total organic carbon (TOC) at 54 stations in the Columbia River below Bonneville Dam (RM146).

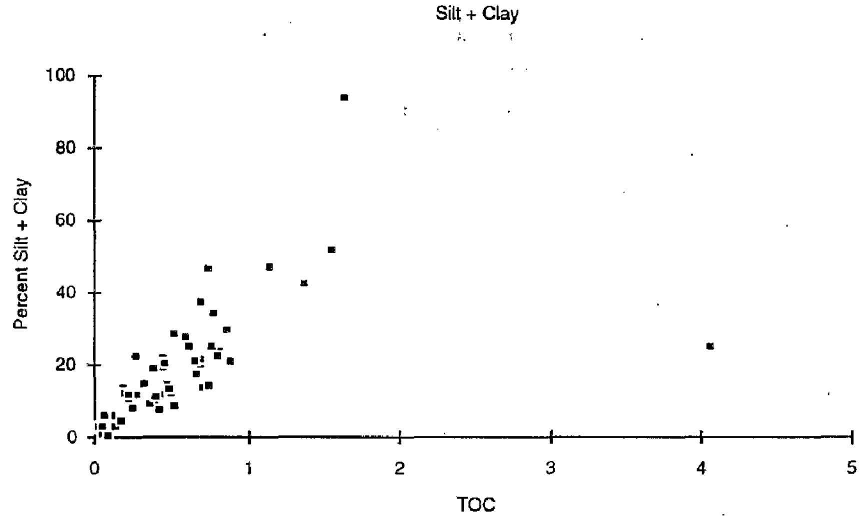


Figure 3-2b. Scatter plot indicating the relationship between total organic carbon (TOC) and the percentage of fine sediments.

3.6.2 Metals, Cyanide, Radionuclides, and Organic Compounds

All raw data for metals and cyanide are provided in Appendix C-2. Raw data for organic compounds are provided in Appendices C-3 through C-14. Data for radionuclides are provided in Appendix C-15. Data for organic compounds, including data on sediment dioxin and furan content, are provided under separate cover in Appendices C-3 through C-14. Data for butyltin compounds are provided in Appendix C-16.

3.6.2.1 Metals, Cyanide, and Radionuclides. Results for sediment metals, cyanide, and radionuclides are presented below, including a brief summary of the results of the data validation for these parameters.

Summary of Quality Assurance/Quality Control. Metals and cyanide were measured at all sediment quality sampling stations. Radionuclides were measured at six locations (D8, D14, D20, D28, D35, and D40). A field duplicate was collected at stations D3, D11, D17, D23, D28, and D35 (identified as samples D46, D45, D44, D43, D42, and D41, respectively. The metals data were considered acceptable for use in this report, although some of the data for barium and zinc have been qualified as estimates (using the qualifier "E") due to poor recovery and precision of MS and MSDs (i.e., those metals with MS/MSDs outside of the range of 60-145 percent and RPDs greater than 35 percent) (Appendix A-3). All of the metals data, with the exception of cadmium, have also been qualified as estimates due to the lack of supporting QA information on QC check standards and instrument calibration data. Much of the data for antimony, silver, thallium, selenium, and mercury were qualified with a "U" for values at or below the DL. However, some of the DLs reported were not within those established in the QA Plan, specifically those for antimony, thallium, and selenium. The detection limits reported for two beryllium analyses were also below those specified in the QA/QC Plan. However, Contract Laboratory Program (CLP)-required detection limits were met for all metals except thallium. The laboratory detection limit reported for thallium ranged from approximately 11 to 26 mg/kg compared to 0.08 mg/kg specified in the QA/QC plan and 10 mg/kg specified in U.S. EPA's guidelines for evaluating inorganics analyses (U.S. EPA 1988a). Method blank analyses indicated concentrations of aluminum and iron above the DL at concentrations of 93 and 150 μg/L, respectively. However, the iron and aluminum data have not been blank corrected, although this level of possible contamination may indicate an overestimation of actual sample concentrations of aluminum and iron. Field blanks were not reported for the metals data; therefore, an assessment of possible contamination of the samples in the field cannot be made.

Comparison of the field replicate data for metals indicates that variability associated with field sampling and analysis is generally not greater than 20 percent, although a few replicates had RPDs much greater than 25 percent. These included cadmium at station D35 (43 percent); lead at station D28 (27 percent); silver at station D17 (44 percent); aluminum, chromium, and silver at station D11 (29 to 31 percent); and silver at station D3 (36 percent).

Results and summary statistics of field replicate metals samples are presented under separate cover in the QA memorandum in Appendix A-3.

Results for sediment cyanide concentrations were qualified as unusable ("R") due to unacceptable exceedance of the analytical holding time for cyanide. Therefore, these data will not be discussed in this report. Results and summary information for the cyanide data reported by the laboratory are presented under separate cover in the QA memorandum in Appendix A-3.

No formal QC criteria have been developed for the radionuclide method used by the WSDH laboratory. No holding time for sediment samples has been established. An error associated with the alpha spectrometer used to quantify isotope levels was calculated for each sample. The error associated with each measurement was relatively large (up to 100 percent of the reported activity), but was frequently comparable to the lower limit of detection (LLD). The LLD ranged from 0.001 for plutonium-239/240 to 0.1 pCi/g for europium-152 which were both below the 0.5 pCi/g detection limit specified in the QA/QC plan (Tetra Tech 1991b). Results and summary information for the radionuclide data reported by the laboratory are presented under separate cover in the QA memorandum in Appendix A-2.

Trends in Metals Concentrations. The frequency of detection for metals is presented in Table 3-3 and Figure 3-3. Ten (i.e., aluminum, arsenic, barium, cadmium, chromium, copper, iron, lead, nickel, and zinc) of the 17 metals analyzed were detected at more than 95 percent of the stations (see Table 3-3). Antimony and thallium were never measured at concentrations above their detection limits, while beryllium and selenium were detected in only one and two samples, respectively. Mercury and silver were present at concentrations that exceeded their detection limits at 10 stations each. Cyanide data were not evaluated because the data were rejected due to analytical problems. All of the metals

TABLE 3-3. SUMMARY OF SEDIMENT METALS AND CYANIDE DATA FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY.

Parameter	Frequency of Detection[a]	Detection Limit(s)	Coarse-Grained[b] (n=13)		Fine-Grained[c] (n=4)		Reference Levels	
			Range	Median	Range	Median	ER-L[d] (marine)	Ontario[e] (freshwater)
			Units in mg/kg Dry Sediment					
Aluminum	54/54	- -	2,794 - 9,032	4,747	4,605 - 15,060	7,650		
Antimony	0/54	4.3 - 11.1	4.3U - 10.2U	- -	4.6U - 11.1U	- -	2.0	
Arsenic	54/54	- -	0.46 - 2.9	1.8	0.95 - 8.92	2.4	33	6
Barium	54/54	- -	8.5 - 164.5	51.4	23.7 - 127.7	77.4		
Beryllium	1/54	2.9 - 8.0	2.8U - 3.5U	- -	3.2U - 4.0	- -		
Cadmium	53/54	0.06	0.06U - 0.9	0.19	0.07 - 2.66	0.41	5	0.6
Chromium	52/54	2.3 - 4.5	2.3U - 7.5	5.18	2.9 - 14.6	7.9	80	26
Copper	54/54	- -	1.8 - 8.5	4.8	2.4 - 26.9	10.3	70	16
Iron	54/54	- -	3,906 - 17,742	9,988	6,579 - 24,408	12,414		20,000
Lead	54/54	- -	0.6 - 8.0	3.87	2.2 - 20.5	7.33	35	31
Mercury	10/54	0.06 - 0.09	0.06U - 0.07U	- -	0.06U - 0.125	0.096	0.15	0.2
Nickel	54/54	- -	4.2 - 14.2	6.92	5.0 - 20.1	9.4	30	16
Selenium	2/54	0.3 - 0.8	0.3U - 0.7U	- -	0.3U - 0.8	0.55		
Silver	10/54	0.3 - 0.6	0.3U - 1.22	0.69	0.3U - 1.49	0.68	1	0.5
Thallium	0/54	10.3 - 24.4U	10.3U - 24.4U	- -	11.1U - 26.8U	- -		
Zinc	54/54	- -	16.4 - 103	40.8	28.3 - 161	72.7	120	120
Cyanide[f]	- -	- -	- -	- -	- -	- -	- -	0.1

U = Undetected above the laboratory detection limit.

[a] The frequency of occurrence of detectable concentrations of the parameter at the 54 sediment metal sampling stations.

[b] Coarse-grained sediments have been defined for this project as those sediments samples with less than or equal to 20 percent of the sample weight consisting of sediment grain sizes less than 100 μm.

[c] Fine-grained sediments have been defined for this project as those sediments samples with greater than 20 percent of the sample weight consisting of sediment grain sizes less than 100 μm.

[d] The Effects Range-Low of Long and Morgan (1990).

[e] Provincial Sediment Quality Guidelines; Lowest Effect (Persaud et al. 1991).

[f] The sediment cyanide data were considered unuseable for this report.

SEDIMENT–METALS

● = Depositional Station

■ = Non-depositional Station

					Astoria, OR			Grays Bay			Marsh Island				Clifton Channel	Elochoman Slough				Wallace Slough	Coal Creek Slough				Longview, WA		Goble, OR	Carrolls Channel	Port of Kalama, WA		Burke Slough		St. Helens, OR		Bachelor Point, WA		Sauvie Island		Willamette River Mouth			N. Portland Harbor					Camas Slough			Reed Island				Beacon Rock
CHEMICAL CLASS	RM 2 D2	RM 6 D4	RM 8 D1	RM 8 E1	RM 13 D3	RM 16 E2	RM 21 D5	RM 21 D6	RM 22 D7	RM 22 E3	RM 27 D8	RM 29 D11	RM 30 E4	RM 34 D9	RM 38 D10	RM 40 D12	RM 42 D14	RM 43 D13	RM 46 E5	RM 50 D15	RM 54 D16	RM 58 E6	RM 59 D17	RM 62 D18	RM 63 D19	RM 67 E7	RM 70 D21	RM 71 D20	RM 76 D22	RM 77 E8	RM 80 D23	RM 83 E9	RM 85 D24	RM 88 D25	RM 92 D26	RM 94 D27	RM 99 D28	RM 100 E10	RM 101 D29	RM 103 D30	RM 104 E11	RM 105 D31	RM 108 D32	RM 109 D33	RM 112 D34	RM 114 E12	RM 116 D35	RM 118 D36	RM 121 D37	RM 124 D38	RM 126 E13	RM 128 D39	RM 137 E14	RM 142 D40
METALS																																																						
Aluminum	●	●	●	■	●	●	■	●	●	■	●	●	■	●	●	●	●	●	■	●	●	●	●	●	●	■	●	●	●	■	●	●	●	●	●	●	●	●	●	●	●	●	■	●	■	■	●	●	●	■	■	●	■	●
Arsenic	●	●	●	■	●	●	■	●	●	■	●	●	■	●	●	●	●	●	■	●	●	●	●	●	●	■	●	●	●	■	●	●	●	●	●	●	●	●	●	●	●	●	■	●	■	■	●	●	●	■	■	●	■	●
Barium	●	●	●	■	●	●	■	●	●	■	●	●	■	●	●	●	●	●	■	●	●	●	●	●	●	■	●	●	●	■	●	●	●	●	●	●	●	●	●	●	●	●	■	●	■	■	●	●	●	■	■	●	■	●
Beryllium																																			●																			
Cadmium	●	●	●	■	●	●	■	●	●	■	●	●	■	●	●	●	●	●	■	●	●	●	●	●	●		●	●	●	■	●	●	●	●	●	●	●	●	●	●	●	●	■	●	■	■	●	●	●	■	■	●	■	●
Chromium	●	●	●	■	●	●	■	●	●	■	●	●		●	●	●	●	●	■	●	●	●	●	●	●		●	●	●	■	●	●	●	●	●	●	●	●	●	●	●	●	■	●	■	■	●	●	●	■	■	●	■	●
Copper	●	●	●	■	●	●	■	●	●	■	●	●	■	●	●	●	●	●	■	●	●	●	●	●	●	■	●	●	●	■	●	●	●	●	●	●	●	●	●	●	●	●	■	●	■	■	●	●	●	■	■	●	■	●
Iron	●	●	●	■	●	●	■	●	●	■	●	●	■	●	●	●	●	●	■	●	●	●	●	●	●	■	●	●	●	■	●	●	●	●	●	●	●	●	●	●	●	●	■	●	■	■	●	●	●	■	■	●	■	●
Lead	●	●	●	■	●	●	■	●	●	■	●	●	■	●	●	●	●	●	■	●	●	●	●	●	●	■	●	●	●	■	●	●	●	●	●	●	●	●	●	●	●	●	■	●	■	■	●	●	●	■	■	●	■	●
Mercury	●				●																●								●			●	●	●				●									●	●						
Nickel	●	●	●	■	●	●	■	●	●	■	●	●	■	●	●	●	●	●	■	●	●	●	●	●	●	■	●	●	●	■	●	●	●	●	●	●	●	●	●	●	●	●	■	●	■	■	●	●	●	■	■	●	■	●
Selenium																																		●														●						
Silver				■	●			●	●	■		●	■	●									●																															
Zinc	●	●	●	■	●	●	■	●	●	■	●	●	■	●	●	●	●	●	■	●	●	●	●	●	●	■	●	●	●	■	●	●	●	●	●	●	●	●	●	●	●	●	■	●	■	■	●	●	●	■	■	●	■	●

Figure 3-3. Locations of the Sediment Sampling Stations Where Metals Were Detected During the Lower Columbia River Reconnaissance Survey.

evaluated are natural components of soils and sediments. Therefore, even the undetected substances were probably present in the sediments, but at concentrations below achieved analytical detection limits.

Concentrations of individual metals varied by as much as two orders of magnitude among the samples collected from the full length of the study area. However, limited spatial patterns were evident. The concentrations of those elements detected in the sediments are presented in Figures 3-4a through 3-4f. Overall, a number of elements (barium, cadmium, chromium, lead, and zinc) appeared to be present at slightly lower concentrations in most of Segments 1 and 2 (downstream of the Cowlitz River) compared to Segments 3 and 4 (above the Cowlitz River, but below Bonneville Dam). Conversely, silver was only detected in Segments 1 and 2. Anomalously high concentrations of a number of elements (arsenic, lead, nickel, silver, and zinc) were found at station D6 (Grays River mouth) and cadmium was also elevated relative to all other stations at station D9, near Skamokawa. Differences in chemical concentrations between the estuarine and freshwater portions of the river were not apparent.

Trends in Radionuclide Concentrations. Of the seven long-lived radionuclides that were analyzed in sediment from the six stations selected for radioanalysis, only cesium-137 was consistently detected (Table 3-4). All of the sediment stations sampled for radionuclides were classified as having fine-grained sediments (see Section 3.6.1.2). Concentrations of the other radionuclides were at or below their respective detection limits, with the exception of europium-152 and plutonium-239/240 (see Table 3-4). The limited sampling for radionuclides did not allow for comparison of the results among station sediment types.

3.6.2.2 Organic Compounds. The results of sediment analysis for organic compounds, including analyses for semivolatile organic compounds, pesticides, PCBs, dioxins and furans, and organotin compounds, and a brief summary of the results of the data validation for these compounds are presented below.

Summary of Quality Assurance/Quality Control.

Semivolatile Organic Compounds — A total of sixty sediment samples were analyzed for semivolatile organic compounds. Fifty-four of the samples were field samples (D1 through D40 and E1 through E14), while six of the samples were field replicates for samples D3, D11, D17, D23, D28, and

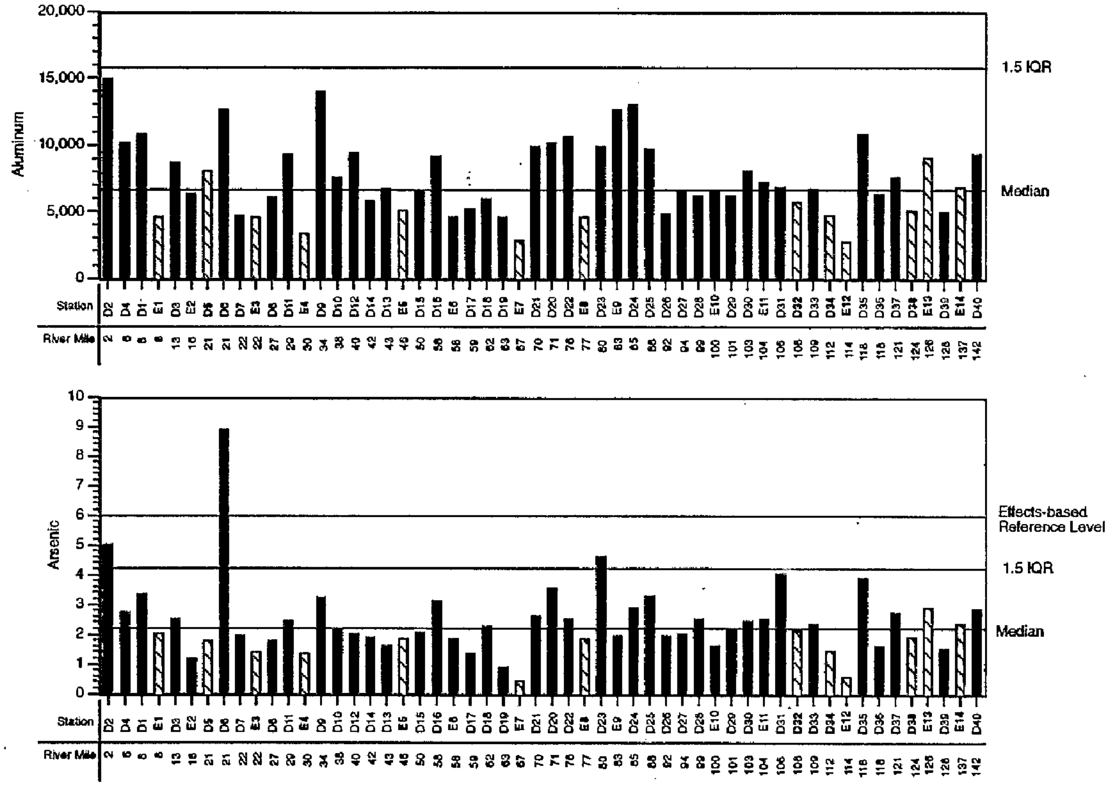


Figure 3-4a. Concentrations of aluminum and arsenic (mg/kg dry wt) at 54 stations in the Columbia River below Bonneville Dam (RM 146). Hatched bars indicate coarse-grained stations; solid bars indicate fine-grained stations; stippled bars indicate one-half detection limit. 1.5 IQR indicates the concentration that is 1.5 times the Inter-Quartile Range.

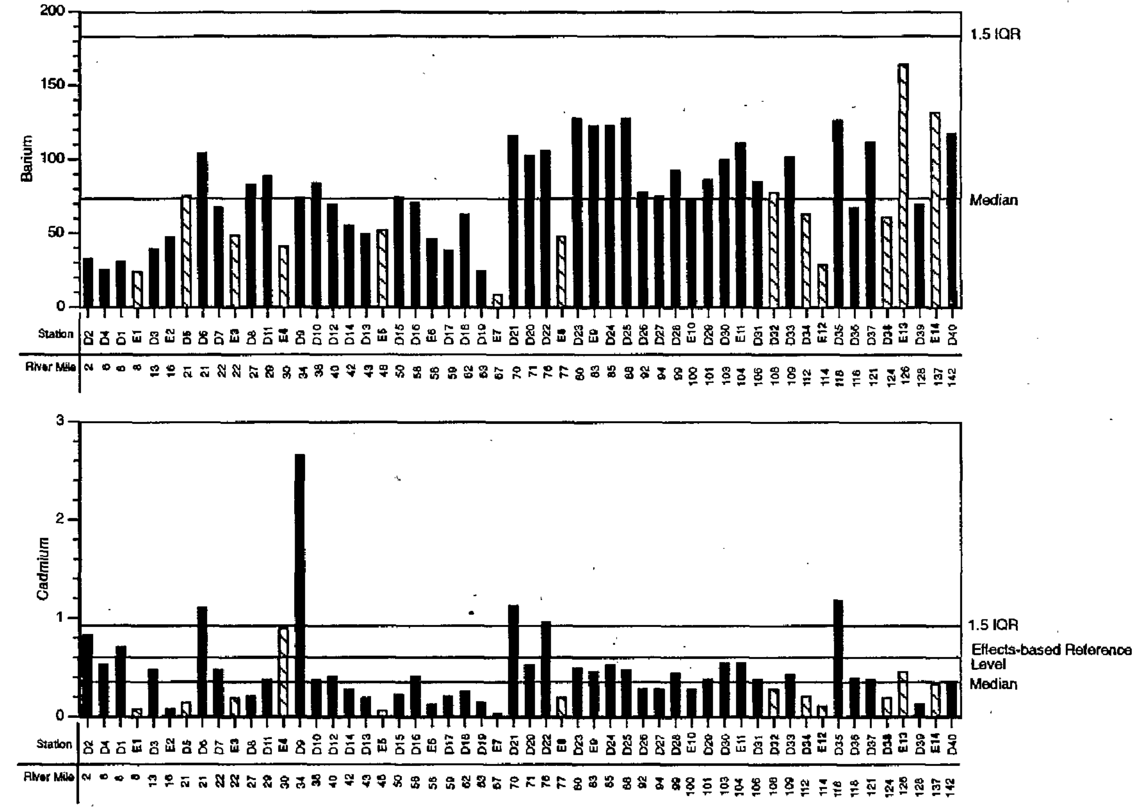


Figure 3-4b. Concentrations of barium and cadmium (mg/kg dry wt) at 54 stations in the Columbia River below Bonneville Dam (RM 146). Hatched bars indicate coarse-grained stations; solid bars indicate fine-grained stations; stippled bars indicate one-half detection limit. 1.5 IQR indicates the concentration that is 1.5 times the Inter-Quartile Range.

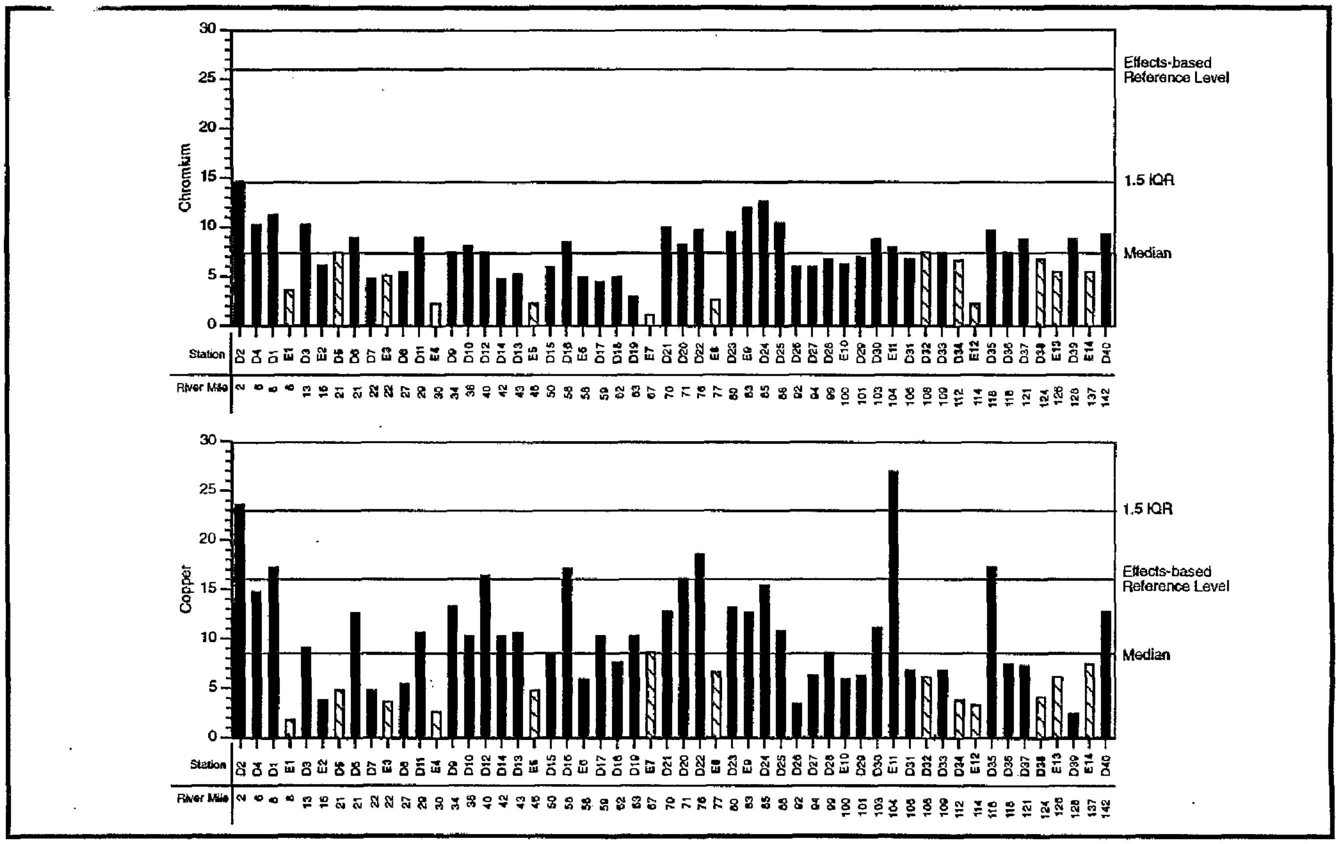


Figure 3-4c. Concentrations of chromium and copper (mg/kg dry wt) at 54 stations in the Columbia River below Bonneville Dam (RM 146). Hatched bars indicate coarse-grained stations; solid bars indicate fine-grained stations; stippled bars indicate one-half detection limit. 1.5 IQR indicates the concentration that is 1.5 times the Inter-Quartile Range.

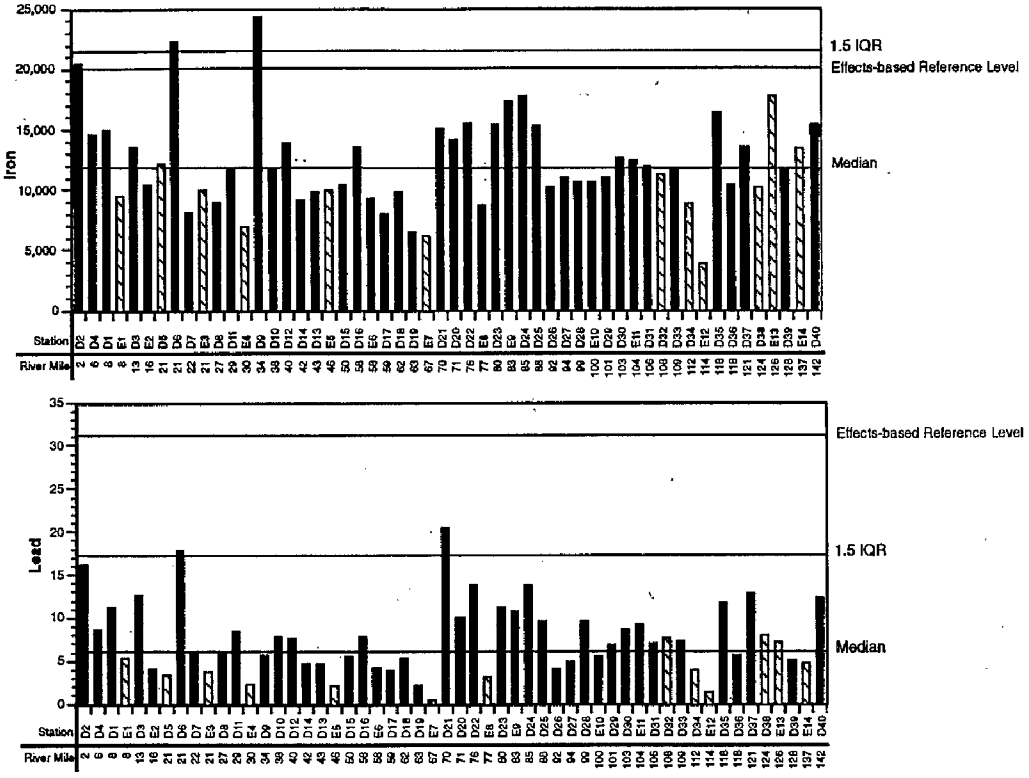


Figure 3-4d. Concentrations of iron and lead (mg/kg dry wt) at 54 stations in the Columbia River below Bonneville Dam (RM 146). Hatched bars indicate coarse-grained stations; solid bars indicate fine-grained stations; stippled bars indicate one-half detection limit. 1.5 IQR indicates the concentration that is 1.5 times the Inter-Quartile Range.

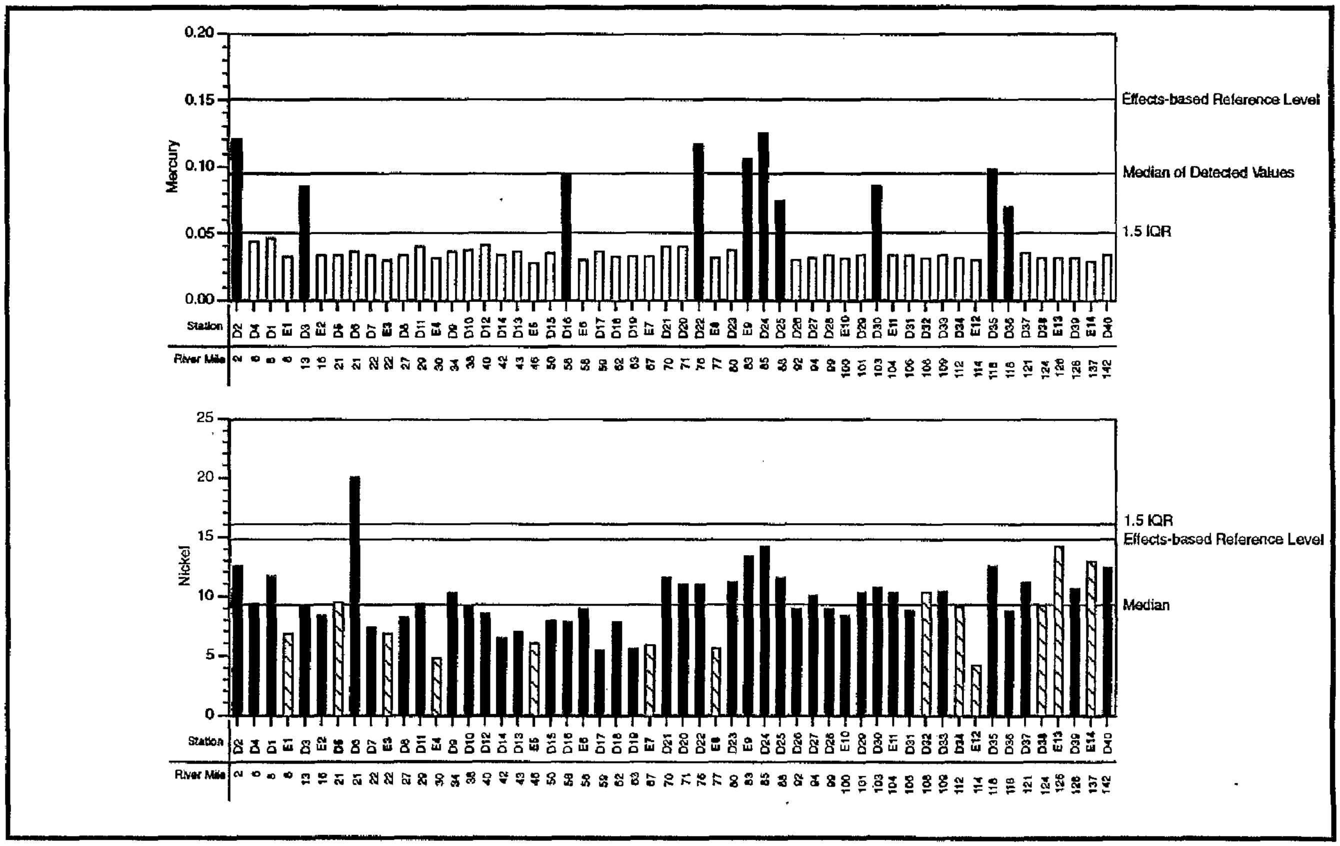


Figure 3-4e. Concentrations of mercury and nickel (mg/kg dry wt) at 54 stations in the Columbia River below Bonneville Dam (RM 146). Hatched bars indicate coarse-grained stations; solid bars indicate fine-grained stations; stippled bars indicate one-half detection limit. 1.5 IQR indicates the concentration that is 1.5 times the Inter-Quartile Range.

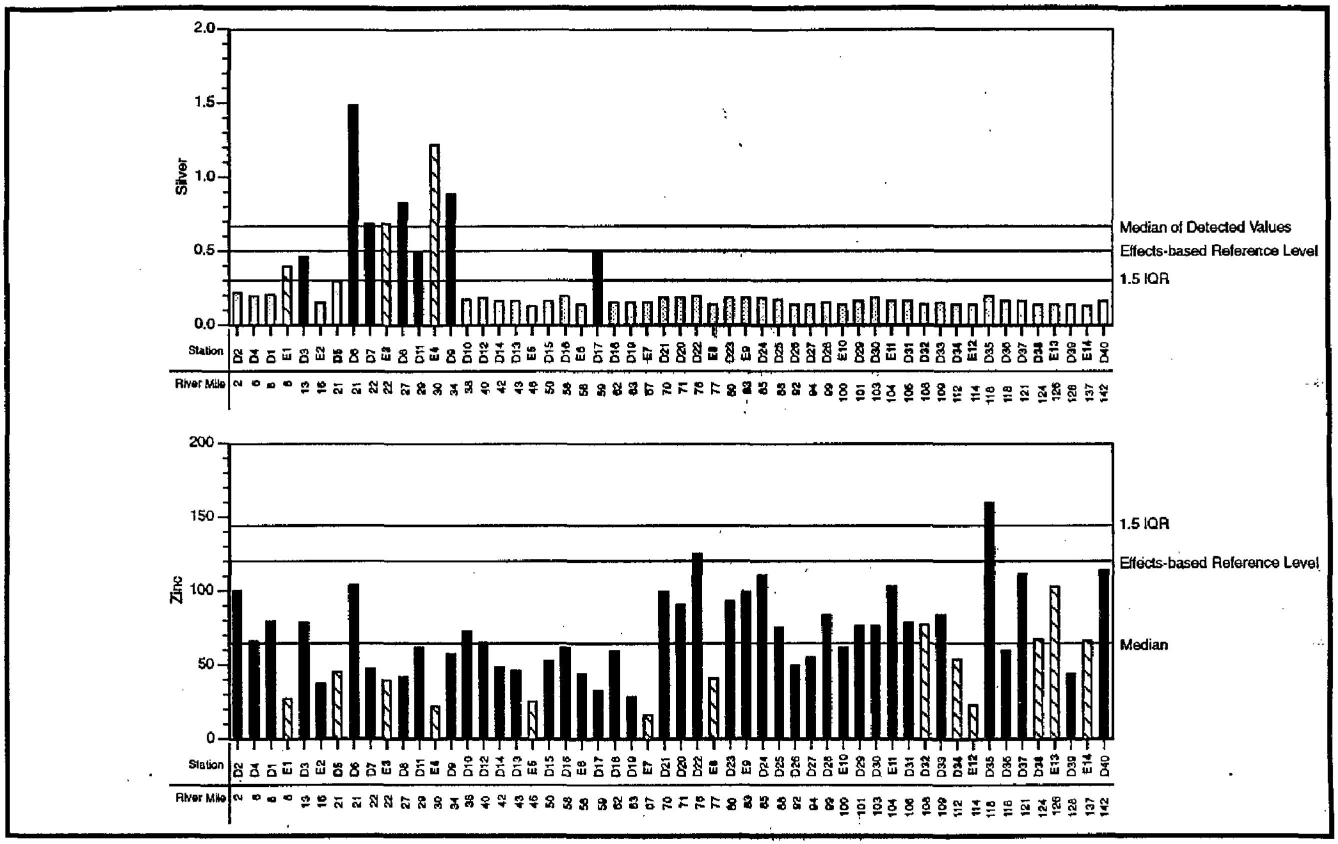


Figure 3-4f. Concentrations of silver and zinc (mg/kg dry wt) at 54 stations in the Columbia River below Bonneville Dam (RM 146). Hatched bars indicate coarse-grained stations; solid bars indicate fine-grained stations; stippled bars indicate one-half detection limit. 1.5 IQR indicates the concentration that is 1.5 times the Inter-Quartile Range.

TABLE 3-4. SUMMARY OF SEDIMENT RADIONUCLIDE DATA FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

Parameter	Radiologic Half-Life (years)	Frequency of Detection[a]	Detection Limit(s)[b]	Range[b]	Median[b]
Americium-241	458	0/6	0.003 - 0.006	-	-
Cesium-137	30	6/6	-	0.07 - 0.29	0.15
Cobalt-60	5.3	0/6	0.03 - 0.05	-	-
Europium-152	13	2/6	0.08 - 0.10	0.08U - 0.14	0.13
Europium-155	1.8	0/6	0.07 - 0.10	-	-
Plutonium-239/240	24,400/6,580	3/6	0.001 - 0.002	0.001U - 0.005	0.003
Plutonium-238	86	0/6	0.002 - 0.006	-	-

U = Undetected above the laboratory reporting limit.

[a] Frequency of occurrence of detectable concentrations of the parameter at the six sediment radionuclide sampling stations.

[b] Units pCi/gm dry sediment

D35. The semivolatile organic data were considered acceptable for use in this report with few qualifications. The large majority of the semivolatile organic compounds have been qualified as undetected. Blank contamination for bis(2-ethylhexyl)phthalate was noted for two of the seven analytical blanks. In the samples all positive values for this compound associated with these blanks were qualified as undetected. The reported DLs (40 to 2700 μg/kg) were less than or equal to the DLs established in the QA/QC plan (Tetra Tech 1991b).

Analytical results, including surrogate and matrix spike recoveries and blind laboratory and field replicate samples, are presented under separate cover in the QA memorandum in Appendix A-4.

__Pesticides/PCBs__ — A total of sixty sediment samples were analyzed for pesticides/PCBs. Fifty-four of the samples were field samples (D1 through D40 and E1 through E14), while six of the samples were field replicates. The pesticide/PCB data were considered acceptable for use in this report. For 29 of the sediment samples, one to three pesticides were qualified as estimates because QC criteria for continuing calibration were not met. No blank contamination was noted for any of six method blanks. The large majority of the pesticide/PCB data have been qualified as undetected. The reported DLs (2 to 100 μg/kg) were less than or equal to the DLs established in the QA/QC plan (Tetra Tech 1991b).

Analytical results, including surrogate and matrix spike recoveries and blind laboratory and field replicate samples, are presented under separate cover in the QA memorandum in Appendix A-6.

__Dioxins and Furans__ — A total of twenty-three sediment samples were analyzed for dioxins and furans. Twenty of these samples were field samples, one sample was a field duplicate (D45 for sample D11), and two samples were laboratory duplicates for samples D6 and D40. The dioxin and furan data were considered acceptable for use in this report. No indication of blank contamination above the lower method calibration limit (LMCL) was noted. A number of sample results were qualified as estimates by the laboratory because the reported levels were less than the LMCL. The reported estimated detection limits (EDLs) were less than or equal to those specified in the QA/QC plan (Tetra Tech 1991b).

Analytical results, including internal standard, precision and recovery (PAR) samples, and matrix spike recoveries, are presented under separate cover in the QA memorandum in Appendix A-7.

Organotin Compounds — Analyses were conducted for three butyltin compounds at 10 sediment sampling stations located primarily in the areas of major port and marina centers along the river. All of the sediments sampled at these stations were classified as fine-grained for this study based on sediment grain size analysis (see Section 3.6.1.2). One field duplicate was analyzed from station D3. The butyltin data have been qualified as estimates (using the "E" qualifier) due to exceedance of the limit of extraction time and the lack of tuning and calibration data from the analytical laboratory. No contamination was noted in the method blank and, although surrogate spike recoveries were relatively low for a few samples (54 percent), there are no U.S. EPA-established control limits for surrogate recovery. Therefore, the data were not qualified based on surrogate recoveries. In general, these data were considered acceptable for use in this report.

Results and summary information for the butyltin data reported by the laboratory are presented under separate cover in the QA memorandum in Appendix A-2.

Trends. The frequency of detection for the organic compounds detected at least once is presented in Tables 3-5 through 3-7 and Figures 3-5 through 3-7. Dioxins, furans, and organotins were among the most frequently detected organic compounds during the reconnaissance survey. Other organic compounds analyzed were detected infrequently. Forty-nine organic compounds were detected at least once.

Several semivolatile organic compounds (primarily PAHs), pesticides, and PCBs were detected at several locations in the lower Columbia River (see Table 3-5). PAHs were detected in five samples. Aroclor 1254, the only PCB detected, was detected at station D19 below Longview. Of the pesticides measured, methyl parathion was found in 13 samples throughout the river. Ten other pesticides, including 4,4'-DDT, 4,4'-DDE, dieldrin, endrin, aldrin, and isomers of BHC, were detected at one or two stations each. At 5 stations o,p'-DDT was detected; however, because this compound was released only as a contaminant in technical 4,4'-DDT mixtures, it should only be present in samples where the 4,4'-isomers were also present. This was not the case in this study and therefore the presence of this compound should be confirmed in future studies. One phthalate ester [bis(2-ethylhexyl)phthalate] was found at 18 locations. Bis(2-ethylhexyl)phthalate was not detected at any station above station D35 in Camas Slough. The maximum concentration of 790 μg/kg of bis(2-ethylhexyl)phthalate was measured at station E10^{D} below the confluence of the Willamette and Columbia rivers.

TABLE 3-5. SUMMARY OF SEDIMENT ORGANIC COMPOUNDS FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY
(Page 1 of 3)

Parameter	Frequency of Detection[a]	Detection Limit(s)	Coarse-Grained[b] (n=13)		Fine-Grained[c] (n=41)		Reference Levels		
			Range	Median	Range	Median	ER-L[d] (marine)	Ontario[e] (freshwater)	Draft EPA[f] (freshwater)
			Units in µg/kg dry sediment						$\mu g/g_{oc}$ [d]
PAHs									
Benzo(a)anthracene	3/54	40-144	40U-94U	- -	42U-260	180	230	2,000[g]	
Benzo(b)fluoranthene	3/54	80-288	80U-188U	- -	84U-400	170		2,000[g]	
Benzo(k)fluoranthene	1/54	80-288	80U-188U	- -	84U-210	- -[h]		2,000[g]	
Benzo(a)pyrene	3/54	80-288	80U-188U	- -	84U-260	250	400	2,000[g]	
Benzo(g,h,i)perylene	2/54	80-288	80U-188U	- -	84U-200	150		2,000[g]	
Chrysene	4/54	40-144	40U-48	- -[h]	44U-630	280	400	2,000[g]	
Fluoranthene	5/54	40-144	40U-72	71	44U-280	250	600	2,000[g]	1020 (470-2190)
Indeno(1,2,3-cd)pyrene	3/54	80-288	80U-188U	- -	84U-170	140		2,000[g]	
Phenanthrene	4/54	40-144	40U-48	- -[h]	44U-210	110	225	2,000[g]	120 (56-260)
Pyrene	5/54	40-144	40U-110	77	44U-420	360	350	2,000[g]	
Phthalate Esters									
bis(2-ethylhexyl)phthalate	18/54	40-250	40U-500	58	42U-790	185			
PCBs									
Aroclor	1/54	25-250	25U	- -	25U-85	- -[h]	50[i]	70[i]	

TABLE 3-5. SUMMARY OF SEDIMENT ORGANIC COMPOUNDS FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

(Page 2 of 3)

Parameter	Frequency of Detection[a]	Detection Limit(s)	Coarse-Grained[b] (n=13)		Fine-Grained[c] (n=41)		Reference Levels		
			Range	Median	Range	Median	ER-L[d] (marine)	Ontario[e] (freshwater)	Draft EPA[f] (freshwater)
			Units in μg/kg dry sediment						$\mu g/g_{oc}$[d]
Pesticides									
Aldrin	1/54	2-20	2U	- -	2U-3.1	- -[h]		2	
alpha-BHC	4/54	2-20	2U	- -	2U-4	3.0		3[j]	
delta-BHC	3/54	2-20	2U	- -	2U-7.9	5.5		3[j]	
gamma-BHC	1/54	2-20	2U	- -	2U-2.2	- -[h]		3[j]	
Dacthal	1/54	2-20	2U-9	- -[h]	2U-20U	- -			
o,p-DDD	1/54	2-20	2U-6.6	- -[h]	2U-20U	- -	1 - 3[k]	5-8[k]	
o,p-DDE	2/54	2-20	2U-3.6	- -[h]	2U-3.2	- -[h]	1 - 3[k]		
o,p-DDT	5/54	2-7	2U-8.3	7.0	2U-20	9.4	1 - 3[k]		
4,4'-DDE	3/54	2-20	2U	- -	2U-5.6	2.8	1 - 3[k]		
4,4'-DDT	2/54	2-20	2U-3.3	- -[h]	2U-100	- -[h]	1 - 3[k]		
Dieldrin	1/54	2-20	2U-3.3	- -[h]	2U-20U	- -	0.02	2	9.0 (4.2-19)
Endrin	1/54	2-20	2U-4.5	- -[h]	2U-20U	- -	0.02	3	4.0(1.9-8.6)
Heptachlor	3/54	2-20	2U	- -	2U-6.1	2.5			
Malathion	1/54	2-20	2U-2.3	- -[h]	2U-20U	- -			
Methyl parathion	13/54	2-20	2U-4.9	4.0	2U-68	5.9			
Mirex	2/54	2-20	2U-4.8	- -[h]	2U-5.2	- -[h]		7	
Parathion	2/54	2-20	2U-5.1	- -[h]	2U-4.4	- -[h]			

TABLE 3-5. SUMMARY OF SEDIMENT ORGANIC COMPOUNDS FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

(Page 3 of 3)

Parameter	Frequency of Detection[a]	Detection Limit(s)	Coarse-Grained[b] (n=13)		Fine-Grained[c] (n=41)		Reference Levels		
			Range	Median	Range	Median	ER-L[d] (marine)	Ontario[e] (freshwater)	Draft EPA[f] (freshwater)
			Units in $\mu g/kg$ dry sediment						$\mu g/g_{oc}$[d]

FOOTNOTES

U = Undetected above the laboratory detection limit.

[a] The frequency of occurrence of detectable concentrations of the parameter at the 54 sediment semivolatile, PCB and pesticide sampling stations.

[b] Coarse-grained sediments have been defined for this project as those sediments samples with less than or equal to 20 percent of the sample weight consisting of sediment grain sizes less than 100 µm.

[c] Fine-grained sediments have been defined for this project as those sediments samples with greater than 20 percent of the sample weight consisting of sediment grain sizes less than 100 µm.

[d] The Effects Range-Low of Long and Morgan (1990).

[e] Provincial Sediment Quality Guidelines; Lowest Effect (Persaud et al. 1991).

[f] Draft EPA freshwater sediment criteria are based on the concentration of contaminant relative to the sediment organic carbon concentration. Sources include U.S. EPA (1991e,f,g,h,i). Values in parentheses are the 95 percent confidence limits.

[g] Reference value for total PAHs.

[h] Median not reported. Parameter detected above the laboratory detection limit only once.

[i] Reference value for total PCBs.

[j] Reference value for total BHC.

[k] Range for total DDT and individual compounds.

TABLE 3-6. SUMMARY OF SEDIMENT DIOXIN AND FURAN DATA FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

Parameter	Frequency of Detection[a]	Detection Limit(s)	Coarse-Grained[b] (n=2)		Fine-Grained[c] (n=18)	
			Range	Median	Range	Median
	Units in μg/kg Dry Sediment					
2,3,7,8 - TCDD	19/20	0.09-0.1	0.09U-0.12	- -	0.10U-0.35	0.18
1,2,3,7,8 - PeCDD	16/20	0.08-0.13	0.1U-0.17	- -	0.08U-0.52	0.17
1,2,3,4,7,8 - HxCDD	19/20	0.17	0.17U-0.15	- -	0.1-1.92	0.28
1,2,3,6,7,8 - HxCDD	20/20	- -	0.14-0.78	0.46	0.44-5.95	1.30
1,2,3,7,8,9 - HxCDD	20/20	- -	0.10-0.58	0.34	0.20-5.04	0.89
1,2,3,4,6,7,8 - HpCDD	20/20	- -	0.90-12.6	6.8	5.93-188	18.25
Octachlorodibenzo-p-dioxin	20/20	- -	6.76-159	82.9	45.9-1480	176.0
2,3,7,8 - TCDF	20/20	- -	0.06-1.23	0.65	0.85-64.6	1.39
1,2,3,7,8 - PeCDF	19/20	0.07	0.07U-0.79	- -	0.17-1.37	0.30
2,3,4,7,8 - PeCDF	19/20	0.07	0.07U-0.54	- -	0.16-1.46	0.27
1,2,3,4,7,8 - HxCDF	20/20	- -	0.31-1.69	1.00	0.43-7.47	0.72
1,2,3,7,8,9 - HxCDF	16/20	0.1-0.24	0.1U-0.1	- -	0.19U-7.21	0.29
1,2,3,6,7,8 - HxCDF	20/20	- -	0.11-0.63	0.37	0.16-2.22	0.14
2,3,4,6,7,8 - HpCDF	20/20	- -	0.24-0.86	0.55	0.23-6.21	0.46
1,2,3,4,7,8,9 - HpCDF	20/20	- -	0.15-1.14	0.65	0.12-15.5	3.35
1,2,3,4,6,7,8 - HpCDF	20/20	- -	0.51-4.5	2.51	1.52-27.8	0.37
Octachlorodibenzofuran	20/20	- -	1.19-14.9	8.05	3.58-128	8.72

U = Undetected above the laboratory detection limit.

[a] Frequency of occurrence of detectable concentrations of the parameter at the 20 sediment dioxin and furan sampling stations.

[b] Coarse-grained sediments have been defined for this project as those sediments samples with less than or equal to 20 percent of the sample weight consisting of sediment grain sizes less than 100 μm.

[c] Fine-grained sediments have been defined for this project as those sediments samples with greater than 20 percent of the sample weight consisting of sediment grain sizes less than 100 μm.

TABLE 3-7. SUMMARY OF SEDIMENT BUTYLTIN DATA FROM THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

Parameter	Frequency of Detection[a]	Detection Limit(s)[b]	Range[b]	Median[b]
Triethyl butyltin	7/10	7.2 - 11.0	7.2U - 110.0	5.6
Diethyl dibutyltin	6/10	7.2 - 11.0	7.2U - 17.3	8.2
Ethyl tributyltin	5/10	7.1 - 11.0	7.1U - 155.6	21.0

U = Undetected above the laboratory detection limit.

[a] Frequency of occurrence of detectable concentrations of the parameter at the 10 sediment butyltin sampling stations.

[b] Units µg/kg dry sediment.

SEDIMENT–SEMIVOLATILE ORGANIC COMPOUNDS

● = Depositional Station

■ = Non-depositional Station

					Astoria, OR			Grays Bay			Marsh Island				Clifton Channel	Elochoman Slough				Wallace Slough	Coal Creek Slough				Longview, WA		Goble, OR
CHEMICAL CLASS	RM 2 D2	RM 6 D4	RM 8 D1	RM 9 E1	RM 13 D3	RM 18 E2	RM 21 D5	RM 21 D6	RM 22 D7	RM 22 E3	RM 27 D8	RM 29 D11	RM 30 E4	RM 34 D9	RM 35 D10	RM 40 D12	RM 42 D14	RM 43 D13	RM 46 E5	RM 50 D15	RM 54 D16	RM 58 E6	RM 59 D17	RM 62 D18	RM 63 D19	RM 67 E7	RM 70 D21
SEMIVOLATILE COMPOUNDS																											
PAHs																											
Benzo(a)anthracene																									●		
Benzo(b)fluoranthene																									●		
Benzo(k)fluoranthene																											
Benzo(a)pyrene																									●		
Benzo(g,h,i)perylene																											
Chrysene																									●		
Fluoranthene																									●		
Indeno(1,2,3-c,d)pyrene																									●		
Phenanthrene																									●		
Pyrene																									●		
PHTHALATE ESTERS																											
Bis(2-ethylhexyl)phthalate	●	●	●	■		●									●					●		●					

	Carrols Channel	Port of Kalama, WA		Burke Slough		St. Helens, OR		Bachelor Point, WA		Sauvie Island		Willamette River Mouth			N. Portland Harbor					Camas Slough			Reed Island				Beacon Rock
CHEMICAL CLASS	RM 71 D20	RM 76 D22	RM 77 E6	RM 80 D23	RM 83 E9	RM 85 D24	RM 88 D25	RM 92 D26	RM 94 D27	RM 99 D28	RM 100 E10	RM 101 D29	RM 103 D30	RM 104 E11	RM 106 D31	RM 106 D32	RM 109 D33	RM 112 D34	RM 114 E12	RM 118 D35	RM 118 D36	RM 121 D37	RM 124 D38	RM 126 E13	RM 128 D39	RM 137 E14	RM 142 D40
SEMIVOLATILE COMPOUNDS																											
PAHs																											
Benzo(a)anthracene					●	●																					
Benzo(b)fluoranthene					●	●																					
Benzo(k)fluoranthene						●																					
Benzo(a)pyrene					●	●																					
Benzo(g,h,i)perylene					●	●																					
Chrysene					●	●										■											
Fluoranthene			■		●	●										■											
Indeno(1,2,3-c,d)pyrene					●	●																					
Phenanthrene					●	●										■											
Pyrene			■		●	●										■											
PHTHALATE ESTERS																											
Bis(2-ethylhexyl)phthalate		●	■		●	●				●	●			●	●	■				●							

Figure 3-5. Locations of the Sediment Sampling Stations Where Semivolatile Organic Compounds Were Detected During the Lower Columbia River Reconnaissance Survey.

SEDIMENT–PESTICIDES AND PCBs

● = Depositional Station

■ = Non-depositional Station

					Astoria, OR			Grays Bay			Marsh Island				Clifton Channel	Elochoman Slough				Wallace Slough	Coal Creek Slough				Longview, WA		Goble, OR	Carrolls Channel	Port of Kalama, WA		Burke Slough		St. Helens, OR		Bachelor Point, WA		Sauvie Island		Willamette River Mouth			N. Portland Harbor					Camas Slough			Reed Island				Beacon Rock
CHEMICAL CLASS	RM 2 D2	RM 6 D4	RM 6 D1	RM 6 E1	RM 13 D3	RM 16 E2	RM 21 D5	RM 21 D6	RM 22 D7	RM 22 E3	RM 27 D8	RM 29 D11	RM 30 E4	RM 34 D9	RM 38 D10	RM 40 D12	RM 42 D14	RM 43 D13	RM 46 E5	RM 50 D15	RM 58 D16	RM 58 E6	RM 59 D17	RM 62 D18	RM 63 D19	RM 67 E7	RM 70 D21	RM 71 D20	RM 76 D22	RM 77 E8	RM 80 D23	RM 83 E9	RM 85 D24	RM 88 D25	RM 92 D26	RM 94 D27	RM 99 D28	RM 100 E10	RM 101 D29	RM 103 D30	RM 104 E11	RM 106 D31	RM 108 D32	RM 109 D33	RM 112 D34	RM 114 E12	RM 116 D35	RM 118 D36	RM 121 D37	RM 124 D38	RM 126 E13	RM 128 D39	RM 137 E14	RM 142 D40
PESTICIDES, PCBs																																																						
PCBs																																																						
Aroclor-1254																									●																													
PESTICIDES																																																							
o,p'-DDD																														■																								
o,p'-DDE																														■			●																					
o,p'-DDT			●																											■			●				●						■											
p,p'-DDE																					●												●														●							●
p,p'-DDT																														■		●																						
Heptachlor																													●			●															●							
Aldrin																																●																						
Dieldrin																														■																								
Endrin																														■																								
Mirex																														■																	●							
Dacthal																														■																								
Methyl parathion			●				■	●			●					●						●		●					●	■	●		●							●		●												
Parathion																														■																								●
Malathion																														■																								
alpha-BHC																													●			●	●														●							
delta-BHC																●					●		●																															
gamma-BHC																															●																							

Figure 3-6. Locations of the Sediment Stations Where Pesticides and PCBs Were Detected During the Lower Columbia River Reconnaissance Survey

SEDIMENT–DIOXINS, AND FURANS

● = Depositional Station

■ = Non-depositional Station

CHEMICAL CLASS	RM 2 D2	RM 6 D4	RM 8 D1	RM 9 E1	RM 10 D3	RM 18 E2	RM 21 D5	RM 21 D6	RM 22 D7	RM 23 E3	RM 27 D8	RM 29 D11	RM 30 E4	RM 34 D9	RM 38 D10	RM 40 D12	RM 42 D14	RM 43 D13	RM 45 E5	RM 50 D15	RM 58 D16	RM [illegible] E6	RM [illegible] D17	RM 62 D18	RM 63 D19	RM 67 E7	RM 70 D21	RM 71 D20	RM 76 D22	RM 77 E8	RM 80 D23	RM 84 E9	RM 85 D24	RM [illegible] D25	RM 92 D26	RM [illegible] D27	RM 99 D28	RM 100 E10	RM 101 D29	RM 103 D30	RM 104 E11	RM 105 D31	RM 109 D32	RM [illegible] D33	RM 112 D34	RM 114 E12	RM 118 D35	RM 119 [illegible]	RM 123 D37	RM 124 D38	RM [illegible]	RM [illegible] D39	RM 137 [illegible]	RM 142 D40
						Astoria, OR		Grays Bay				Marsh Island			Clifton Channel	[illegible] Slough				Wallace Slough	Coal Creek Slough				Longview, WA		Goble, OR	Carrolls Channel	Port of Kalama, WA		Burke Slough		St. Helens, OR			Bachelor Point, WA	Sauvie Island		Willamette River Mouth			N. Portland Harbor					Camas Slough			Reed Island				Beacon Rock
DIOXINS AND FURANS																																																						
2,3,7,8-TCDD		●					■	●			●	●			●		●			●	●			●	●			●			●		●				●			●							●							●
1,2,3,7,8-PeCDD		●					■	●			●	●			●		●			●	●			●				●			●		●				●			●														●
1,2,3,4,7,8-HxCDD		●					■	●			●	●			●		●			●	●			●	●			●			●		●		●		●			●							●							●
1,2,3,6,7,8-HxCDD		●					■	●			●	●			●		●			●	●			●	●			●			●		●		●		●			●							●			■				●
1,2,3,7,8,9-HxCDD		●					■	●			●	●			●		●			●	●			●	●			●			●		●		●		●			●							●			■				●
1,2,3,4,6,7,8-HpCDD		●					■	●			●	●			●		●			●	●			●	●			●			●		●		●		●			●							●			■				●
OCDD		●					■	●			●	●			●		●			●	●			●	●			●			●		●		●		●			●							●			■				●
2,3,7,8-TCDF		●					■	●			●	●			●		●			●	●			●	●			●			●		●		●		●			●							●			■				●
1,2,3,7,8-PeCDF		●					■	●			●	●			●		●			●	●			●	●			●			●		●		●		●			●							●							●
2,3,4,7,8-PeCDF		●					■	●			●	●			●		●			●	●			●	●			●			●		●		●		●			●							●							●
1,2,3,4,7,8-HxCDF		●					■	●			●	●			●		●			●	●			●	●			●			●		●		●		●			●							●			■				●
1,2,3,6,7,8-HxCDF		●					■	●			●	●			●		●			●	●			●	●			●			●		●		●		●			●							●			■				●
2,3,4,6,7,8-HxCDF		●					■	●			●	●			●		●			●	●			●	●			●			●		●		●		●			●							●			■				●
1,2,3,7,8,9-HxCDF		●					■					●			●		●			●	●			●	●			●			●		●		●					●							●							●
1,2,3,4,6,7,8-HpCDF		●					■	●			●	●			●		●			●	●			●	●			●			●		●		●		●			●							●			■				●
1,2,3,4,7,8,9-HpCDF		●					■	●			●	●			●		●			●	●			●	●			●			●		●		●		●			●							●			■				●
OCDF		●					■	●			●	●			●		●			●	●			●	●			●			●		●		●		●			●							●			■				●

Shaded columns indicate stations where samples were not analyzed for dioxins and furans

Figure 3-7. Locations of the Sediment Sampling Stations Where Dioxins, and Furans Were Detected During the Lower Columbia River Reconnaissance Survey

PAHs were found at station D19 (below Longview); stations D24, E8, and E9^{D} (all between Kalama and the city of St. Helens); and station D32^{E} (near Vancouver). The only station where PCBs were detected was station D19 below Longview.

Although pesticides were infrequently detected, stations where pesticides were detected were distributed throughout the study area. Methyl parathion was found at 13 stations that were distributed in all river reaches. The distribution of pesticides did not show any clear spatial trends, although five of the 17 pesticides that were detected (i.e., o,p'-DDD, dieldrin, dacthal, malathion, and endrin) were found at station E8 near Kalama and nowhere else. Several pesticides were detected at stations D24 (near St. Helens) and D35 (Camas Slough), including o,p'-DDE, o,p'-DDT, 4,4'-DDE, heptachlor, mirex, and alpha-BHC.

Dioxins and furans were analyzed in sediments collected from 20 of the 54 sediment sampling stations. All of these compounds were detected in the majority of the samples analyzed. The spatial distributions of dioxins and furans are presented in Figures 3-8 and 3-9. Median concentrations were compared with data grouped from fine-grained and coarse-grained areas (results are presented in Table 3-6). Concentrations of dioxins and furans were higher at the fine-grained stations in the river, although only two of the 20 stations where dioxins or furans were measured were classified as coarse-grained sediments. Differences in chemical concentrations between the estuarine and freshwater portions of the river were not apparent.

Dioxins and furans were detected at all 20 of the sediment sampling stations, although some congeners were not detected at station D38^{E} near Reed Island. The high frequency of dioxin and furan detection is due in part to the very low detection limits achieved (approximately 0.1 pg/g) with the high resolution analytical methods used for these compounds. The concentrations of most of the dioxins were elevated at stations D10 and D24 compared to the concentrations at the other stations. 2,3,7,8-Tetrachlorodibenzodioxin (TCDD) was present in greatest concentration at station D16 in Coal Creek Slough and was also relatively high at station D35 in Camas Slough (see Figure 3-8). 2,3,7,8-Tetrachlorodibenzodifuran (TCDF) was also elevated at station D16 in Coal Creek Slough, but most of the furans were detected in greatest concentrations at stations D10 (below Wauna, OR), D18, D24, and D35 (see Figure 3-9).

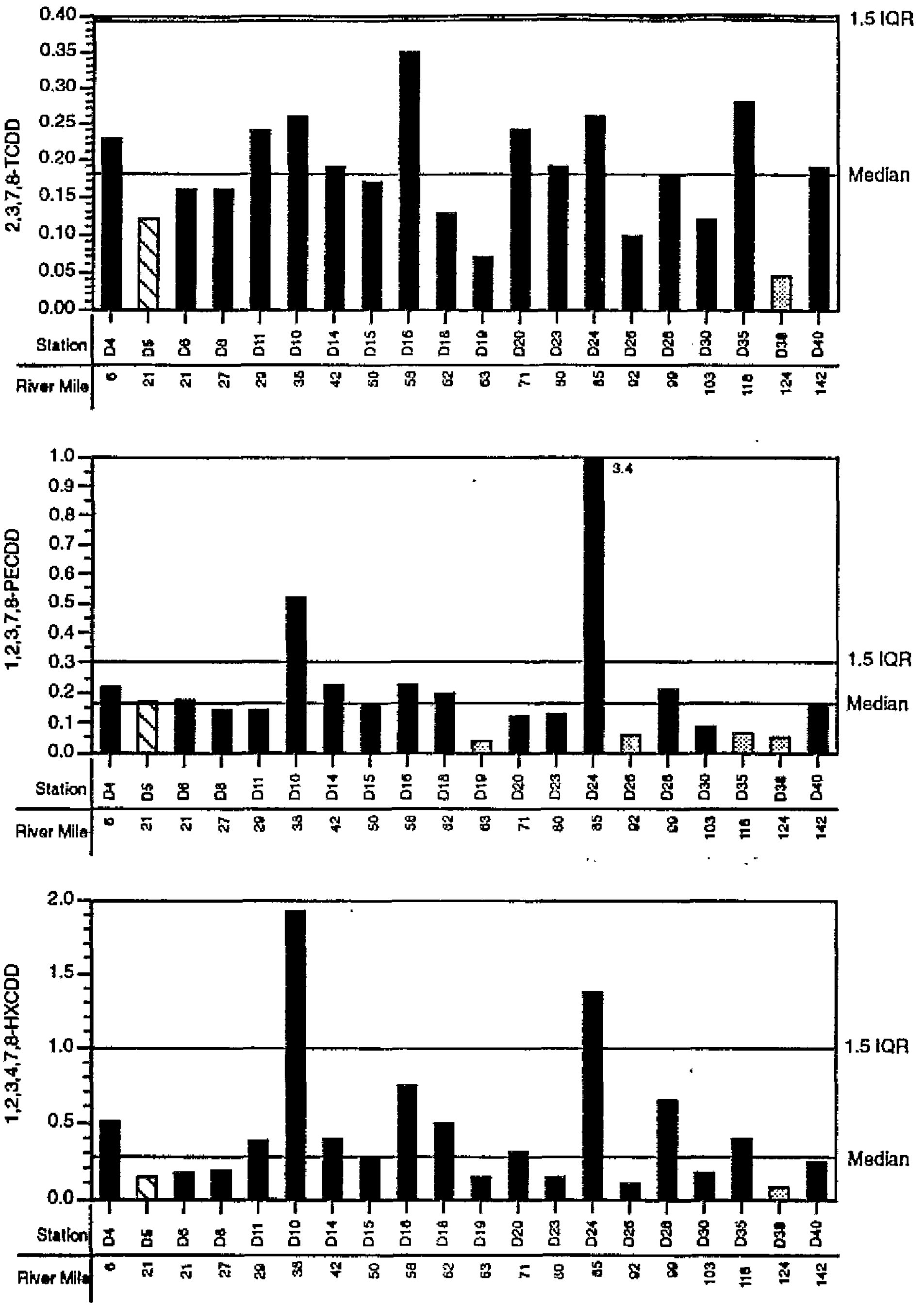


Figure 3-8. Concentrations (pg/g dry wt) of dioxin congeners in sediments from 20 stations in the Columbia River below Bonneville Dam (RM 146). *Hatched bars indicate coarse-grained stations; solid bars indicate fine-grained stations; stippled bars indicate one-half detection limit. 1.5 IQR indicates the concentration that is 1.5 times the Inter-Quartile Range.*

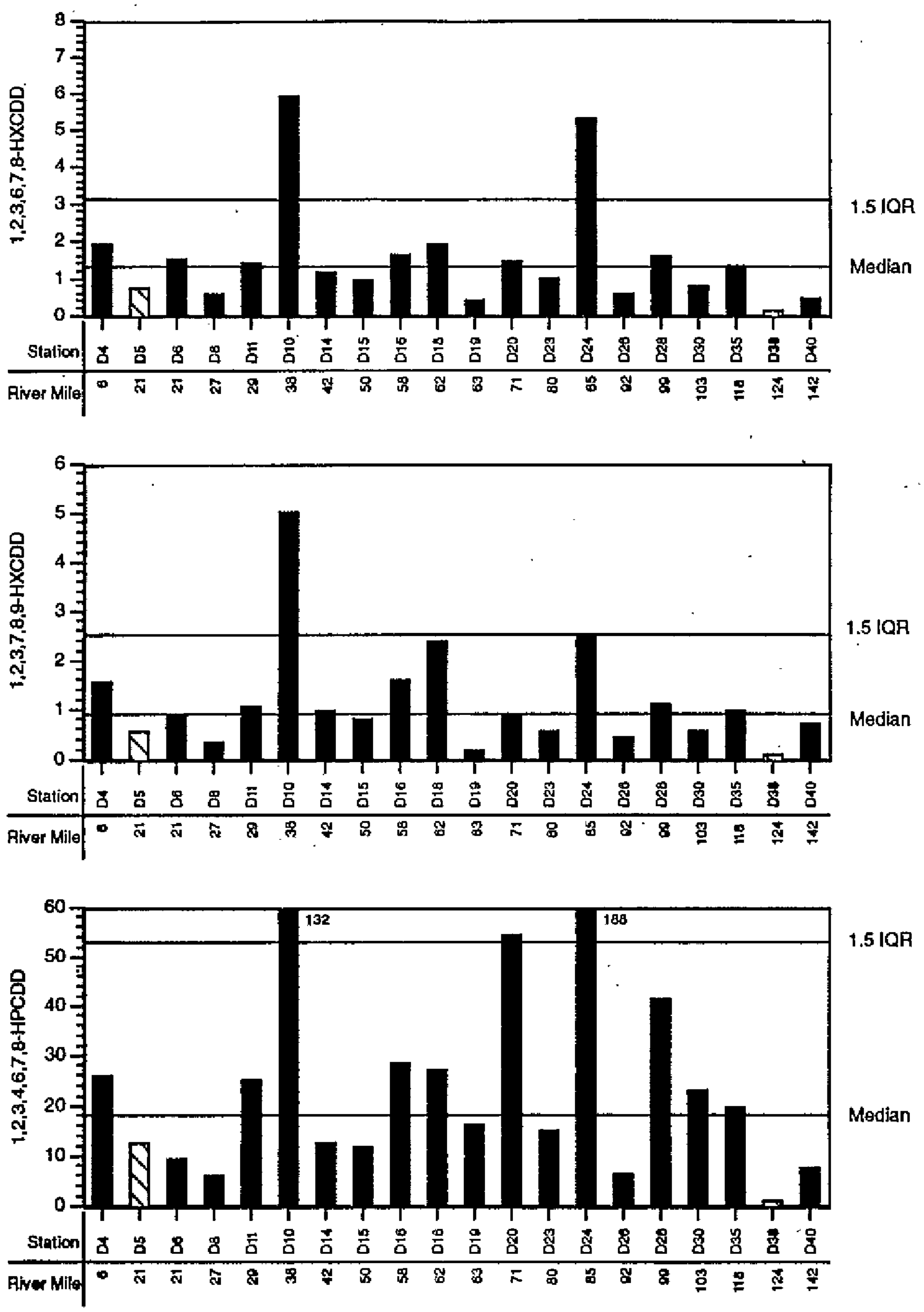


Figure 3-8. Concentrations (pg/g dry wt) of dioxin congeners in sediments from 20 stations in the Columbia River below Bonneville Dam (RM 146). *Hatched bars indicate coarse-grained stations; solid bars indicate fine-grained stations; stippled bars indicate one-half detection limit. 1.5 IQR indicates the concentration that is 1.5 times the Inter-Quartile Range.*

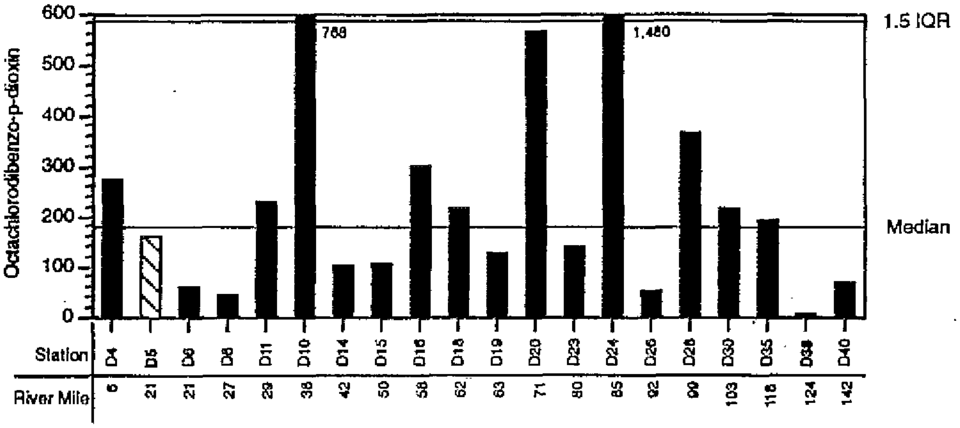


Figure 3-8. Concentrations (pg/g dry wt) of dioxin congeners in sediments from 20 stations in the Columbia River below Bonneville Dam (RM 146). *Hatched bars indicate coarse-grained stations; solid bars indicate fine-grained stations; stippled bars indicate one-half detection limit. 1.5 IQR indicates the concentration that is 1.5 times the Inter-Quartile Range.*

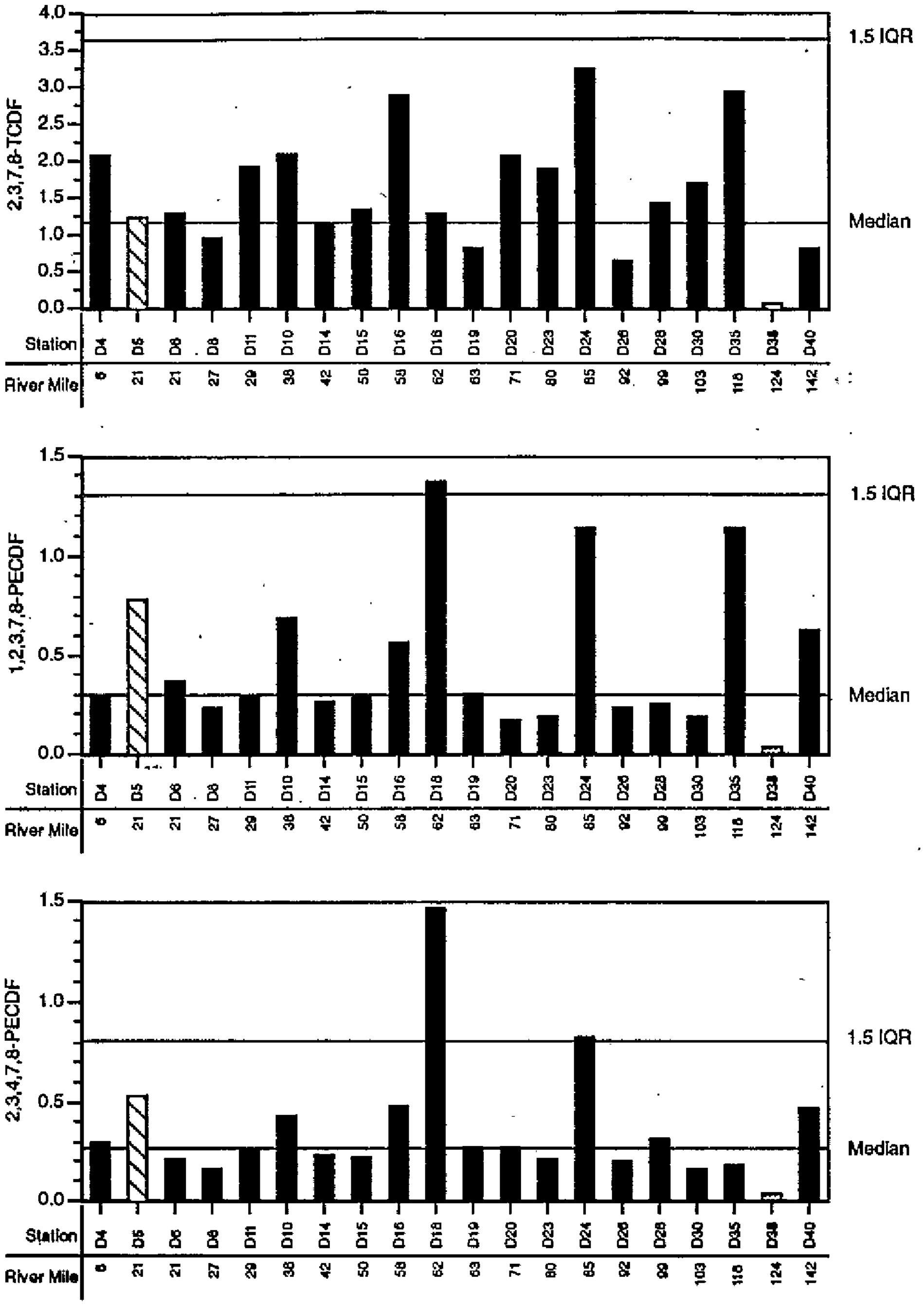


Figure 3-9. Concentrations (pg/g dry wt) of furan congeners in sediments from 20 stations in the Columbia River below Bonneville Dam (RM 146). *Hatched bars indicate coarse-grained stations; solid bars indicate fine-grained stations; stippled bars indicate one-half detection limit. 1.5 IQR indicates the concentration that is 1.5 times the Inter-Quartile Range.*

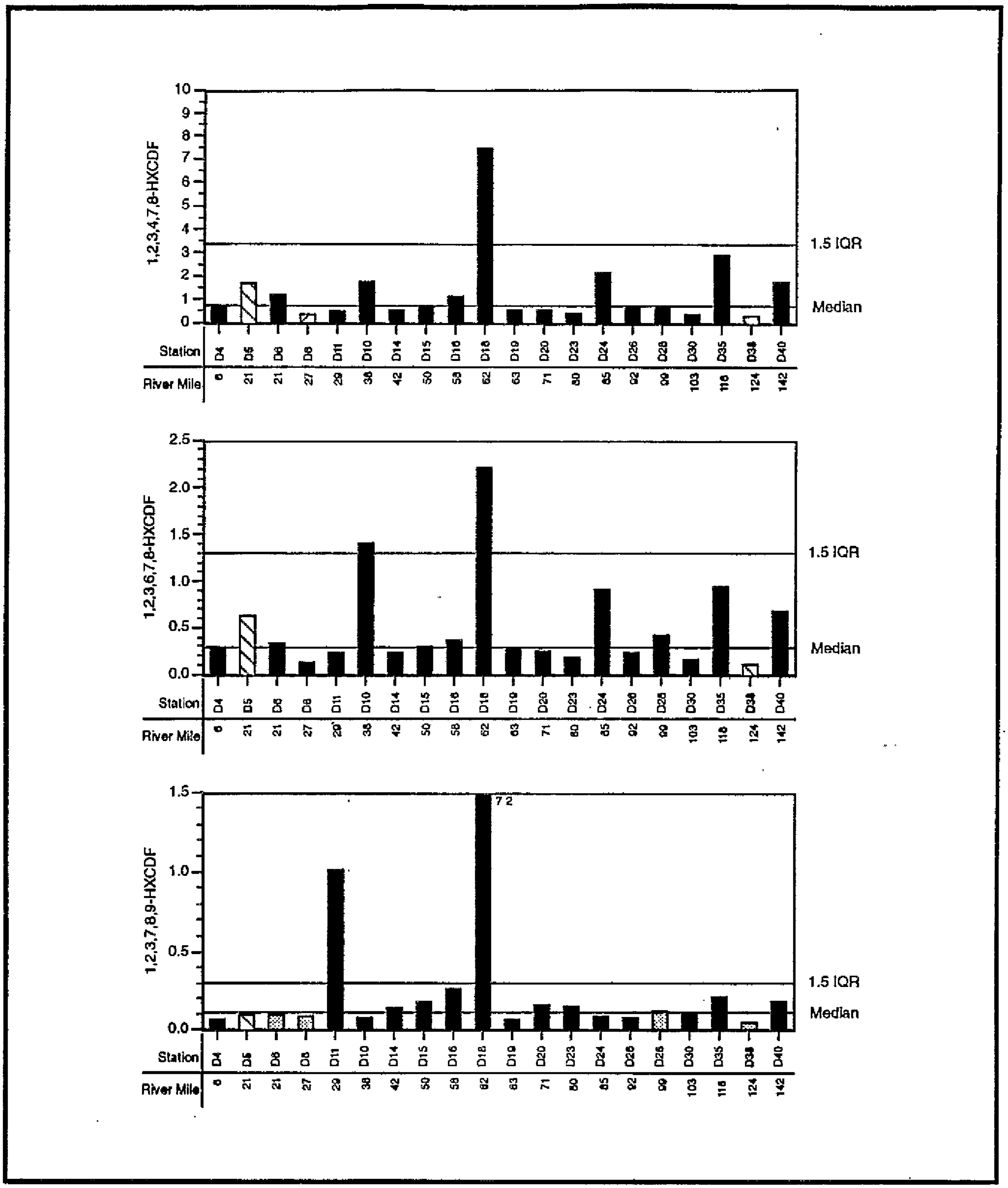


Figure 3-9. Concentrations (pg/g dry wt) of furan congeners in sediments from 20 stations in the Columbia River below Bonneville Dam (RM 146). *Hatched bars indicate coarse-grained stations; solid bars indicate fine-grained stations; stippled bars indicate one-half detection limit. 1.5 IQR indicates the concentration that is 1.5 times the Inter-Quartile Range.*

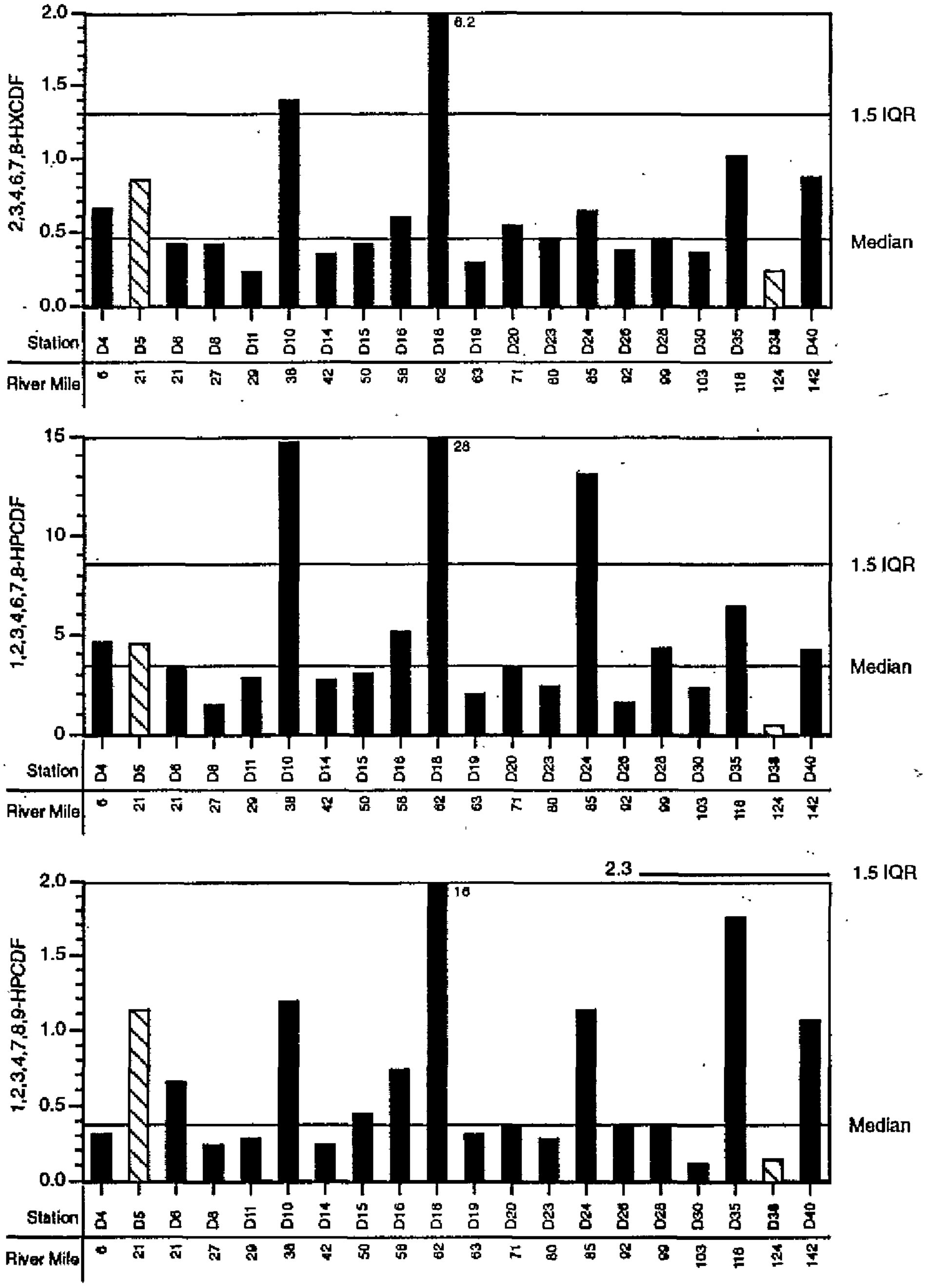


Figure 3-9. Concentrations (pg/g dry wt) of furan congeners in sediments from 20 stations in the Columbia River below Bonneville Dam (RM 146). *Hatched bars indicate coarse-grained stations; solid bars indicate fine-grained stations; stippled bars indicate one-half detection limit. 1.5 IQR indicates the concentration that is 1.5 times the Inter-Quartile Range.*

Organotin compounds were detected at 7 of the 10 sediment stations sampled (see Table 3-7, Figure 3-10). The relatively high frequency of detection is likely related to the selection of marina areas for reconnaissance sampling, and therefore the concentrations measured are probably not representative of the bulk of lower Columbia River sediments. However, these samples provide reconnaissance information on potential problems due to organotin contamination at several port and marina areas along the lower river. Concentrations did not vary substantially among the samples with detected concentrations of butyltin (Figure 3-10). The one exception was the concentration of triethyl butyltin at station D19 (below Longview) which was an order of magnitude greater than concentrations measured at the other stations. Diethyl dibutyltin was not detected at this station.

Because of the difficulties in identifying relatively low concentrations of organic compounds in environmental media, the results of the reconnaissance survey (particularly for those compounds that were detected only rarely, for example) should be viewed with caution. For the purposes of this study, it was deemed appropriate to treat organic substances that were never measured above detection limits as absent. Organic substances that were detected were treated as present at those stations where they were identified.

3.6.2.3 Correlation with Sediment Grain Size and Total Organic Carbon Content. Sediment chemical concentrations are typically correlated with the sediment variables, sediment grain size and sediment organic carbon content. The relationship of the detected metals, and a limited number of organic chemicals, with these sediment variables are examined below. Because of the limited nature of the radionuclide sampling results, no attempt was made to correlate sediment variables with the levels of radionuclides detected at the six radionuclide sediment sampling stations.

Metals. Median concentrations of the metals were calculated, using the data grouped for fine-grained and coarse-grained sediments, and then compared (Table 3-3). Concentrations of all of the tested metals, except silver, were higher at the fine-grained stations in the river. Similarly, differences in the concentrations of the grouped metals between sediment types was examined to provide another estimate of the differentiation. Total concentrations were derived by summing the concentrations of individual metals at each station. Statistical comparisons of mean total concentrations were used to test whether chemical concentrations in fine-grained and coarse-grained sediments were different. Results indicated that the concentrations of metals were significantly higher in fine-grained than in coarse-grained areas of the river (Table 3-8). These differences appear to be the result of the differences in concentrations

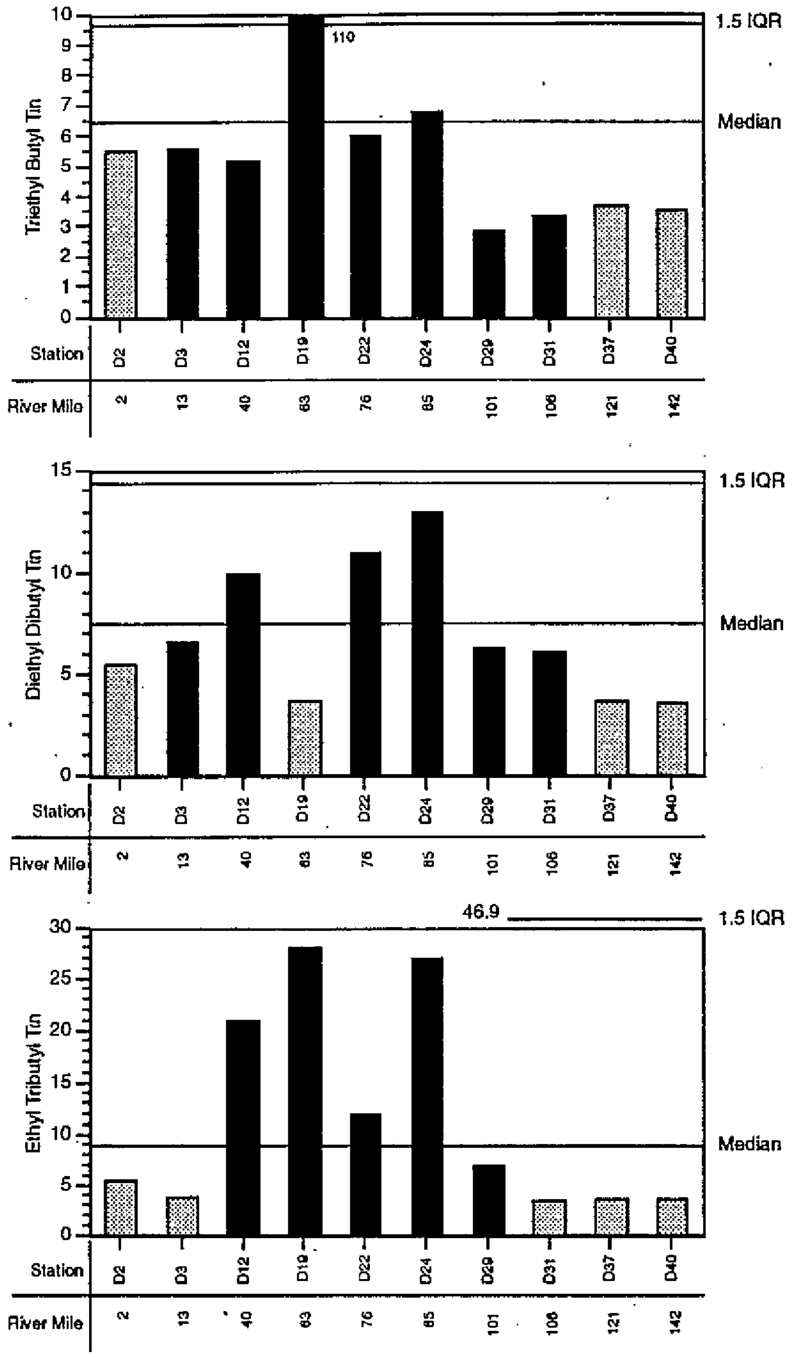


Figure 3-10. Concentrations (µg/kg dry wt) of organotins in sediments from 10 stations in the Columbia River below Bonneville Dam (RM 146). Stippled bars indicate one-half detection limits. 1.5 IQR indicates the concentration that is 1.5 times the Inter-Quartile Range.

TABLE 3-8. COMPARISON OF TOTAL METALS CONCENTRATIONS AMONG SEDIMENT TYPES. PROBABILITIES ≤ 0.05 INDICATE SIGNIFICANT DIFFERENCES.

	TOTAL METALS		
	All Stations	Estuarine Stations	Freshwater Stations
Fine-Grained	Coarse-Grained 0.003	Coarse-Grained 0.196	Coarse-Grained 0.007

between sediment types within the freshwater reaches of the river. No significant differences were found between sediment types in the estuary.

Because metals distribution is affected by sediment grain size and TOC concentrations, the correlations between these variables and the concentrations of the metals were tested. Scatter plots illustrating the relationships are presented in Figure 3-11. All of the metals except barium, nickel, and silver were significantly correlated ($P < 0.05$) with either the TOC content of the sediments or the percentage of silt and clay. Aluminum, arsenic, chromium, copper, lead, and mercury were significantly correlated with both variables.

Organic Compounds. Concentrations of organic compounds are often higher in finer, organic-rich sediments than in coarse-grained sediments. Dioxins and furans were measured primarily in fine-grained areas [only two coarse-grained stations ($D5^E$ and $D38^E$) were sampled for dioxins and furans] and at only two or three stations located in the estuary. All organotin sampling locations were classified as fine-grained sediment stations. The distribution of these compounds by sediment type could not, therefore, be examined.

The limited locations at which most of the organic compounds were detected precluded precise testing of such relationships. Limited testing showed that 2,3,7,8-tetrachlorodibenzofuran (TCDF) was significantly correlated ($P < 0.05$) with the TOC concentrations in the sediment (Figure 3-12). The other dioxin and furan congeners appeared to show some relationship, but were not highly correlated with either sediment variable. No correlation between organotins and sediment variables was found. Visual examination of the sediment characteristics associated with the stations where PAHs, PCBs, and pesticides were found did not indicate that either grain-size or TOC was related to those measurements, except perhaps for station D35 in Camas Slough. This station had very high TOC concentrations, as well as numerous pesticides and high concentrations of 2,3,7,8-tetrachlorodibenzodioxin (TCDD) and some furans. Sediments from station D35 were not analyzed for organotin compounds.

3.6.3 Identification of Potential Areas of Concern

The data were used to delineate areas of concern within the lower river on the basis of chemical concentrations above those expected due to natural occurrences, or those associated with deleterious biological

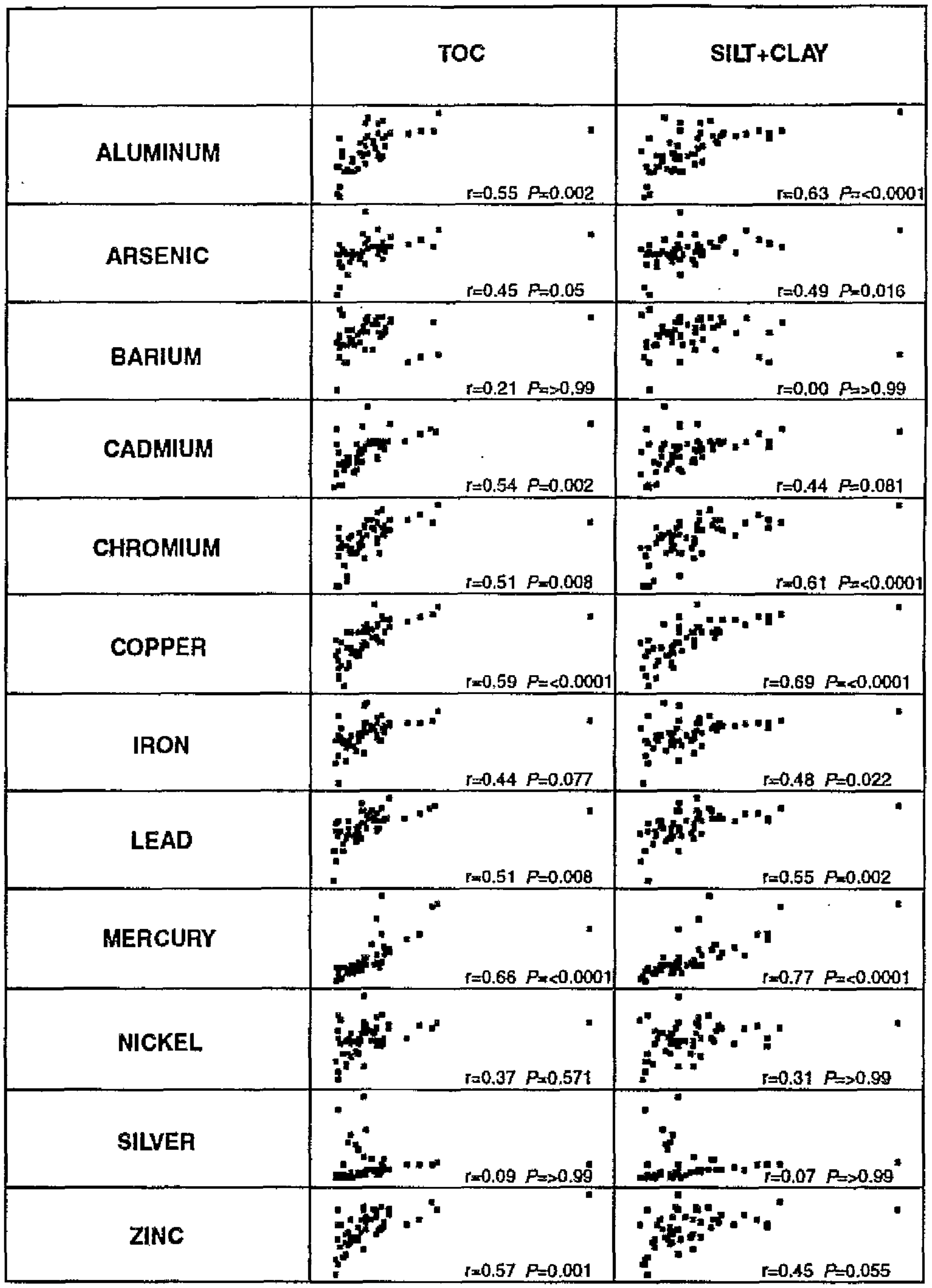


Figure 3-11. Scatterplots illustrating relationships between inorganic chemicals and sediment conventional variables.

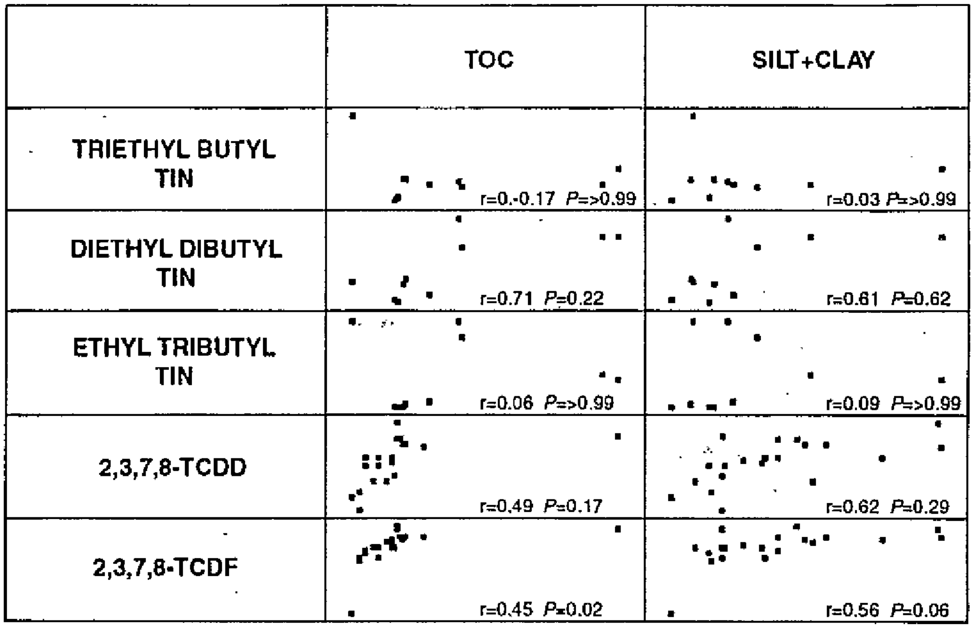


Figure 3-12. Scatterplots illustrating relationships between organic chemicals and sediment conventional variables.

effects as reported by Long and Morgan (1990) and the Ontario Ministry of the Environment (Persaud et al. 1991) for other areas. Using these screening techniques, potential areas of concern are identified below.

The radionuclide data were not incorporated into this section for reasons that will be outlined below. These reasons include the generally ubiquitous but low levels of these radionuclides in Columbia River sediments, primarily due to global fallout, as a result of historic above-ground nuclear weapons testing. Although it is acknowledged that there is no accepted threshold level for radionuclide concentration, at present there are no established standards for sediment radionuclide concentrations which would allow for the evaluation of these sediment data. However, the radionuclide data will be discussed in more detail in relation to past radionuclide releases from plutonium production operations at Hanford and in relation to the historical operation of the Trojan Nuclear Power Plant. Section 3.7.3 will compare the reconnaissance survey data to historical data and available information on these radionuclide sources.

3.6.3.1 Identification of Potentially Anthropogenically Influenced Sediments. Several techniques were used to identify sediment chemical concentrations that indicated the influence of anthropogenic point and nonpoint pollution sources. These techniques include the use of regression analysis to identify possible areas with significantly higher metals concentrations, comparison of the data with the IQR to identify locations with relatively higher sediment concentrations of metals and organic compounds, and, in the case of organic compounds, consistently detected concentrations were considered evidence of anthropogenic enrichment.

Although the radionuclide cesium-137 was consistently detected at the six stations sampled for radionuclides, and cesium-137 is primarily of anthropogenic origin [due to historic above-ground nuclear weapons testing (Beasley and Jennings 1984)], the radionuclide data were not incorporated into the identification of anthropogenically influenced sediment areas.

Metals. Regression analyses, using iron as the independent variable, were used as a screening tool to identify sediments that might be anthropogenically influenced. Those concentrations, within or below the 90 percent confidence envelope for the regression, were considered to be part of the natural component of the river sediments. Those concentrations that exceeded the confidence level were considered to indicate possible anthropogenic contributions to the sediments. This approach was applied to metals that were highly correlated with iron including: aluminum, arsenic, barium, cadmium, chromium, copper, nickel, lead, and zinc. For those metals that were not correlated with iron (i.e., the regression was not appropriate), frequency distribution outliers were used to identify anomalously high concentrations of these metals.

The regression plots between the selected metals and iron are presented in Figure 3-13a through 3-13c. Concentrations higher than the expected values are considered indicative of possible contributions of metals by other than natural sources. The upper confidence limit establishes the expected value for each substance as a function of iron. For other metals, outlying concentrations were identified from the ranked frequency data. Concentrations that exceeded 1.5 times the IQR were considered to be indicative of areas of concern. Stations with concentrations of metals identified as elevated by either method are summarized in Table 3-9.

Organic Compounds. For the purposes of this study, any detection of organic compounds in the sampled sediments was considered to be derived from human sources. However, where the data would support the evaluation, it was considered appropriate to compare the extent of contamination at the different stations in order to identify those sites with particularly high concentrations. The latter information should be useful in identifying possible sources of the compounds, as well as directing future investigations.

Exceedance of IQR screening values was used as the criterion to identify the stations with high concentrations of dioxin and furans in the sediments relative to all samples analyzed (Figure 3-14). Dioxins and furans were detected at all 20 stations sampled; the highest concentrations occurred at stations D10 (below Wauna on the south side of Tenasillahe Island), D11 (between Horseshoe and Woody islands), D18 (near Lord Island), D20 (in Carrolls Channel), and D24 (downstream of the St. Helens marina). One furan congener exceeded IQR screening values at station D11 (near Goose Island) and one dioxin congener exceeded IQR screening values at station D20 (in Carrolls Channel). Station D10 (below Wauna) and D24 (near St. Helens) had the highest concentrations of six dioxin and several furan congeners. All exceedances at station D18 (across from Longview) were due to furan congeners.

Organotins were detected in 7 of the 10 samples collected [stations D2 (Ilwaco), D12 (Cathlamet marina), D19 (Longview), D22 (Kalama), D24 (St. Helens), D29 (Columbia River near confluence with the

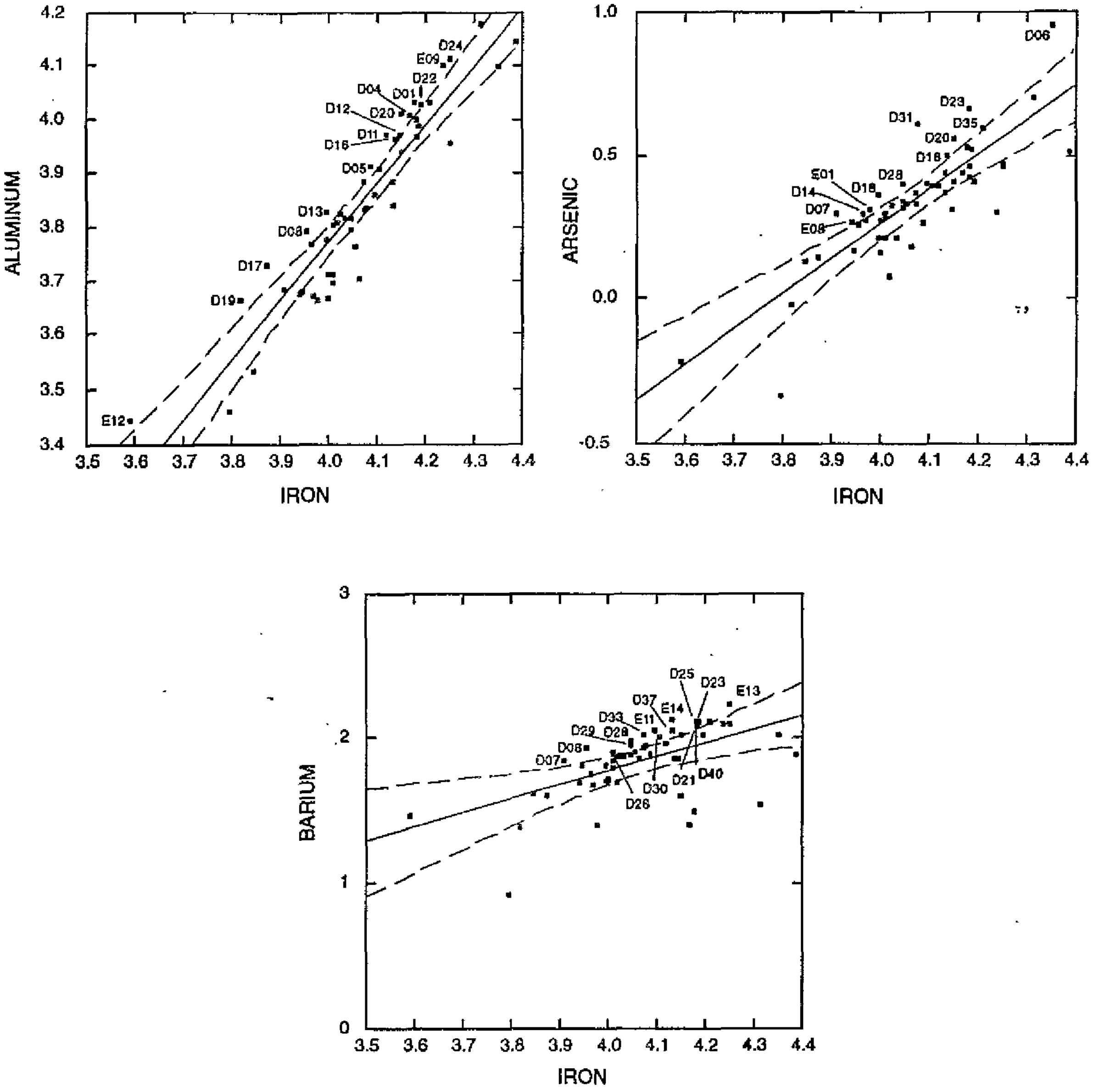


Figure 3-13a. Linear regression results of sediment iron vs. aluminum, arsenic, and barium measured at 54 stations in the lower Columbia River.

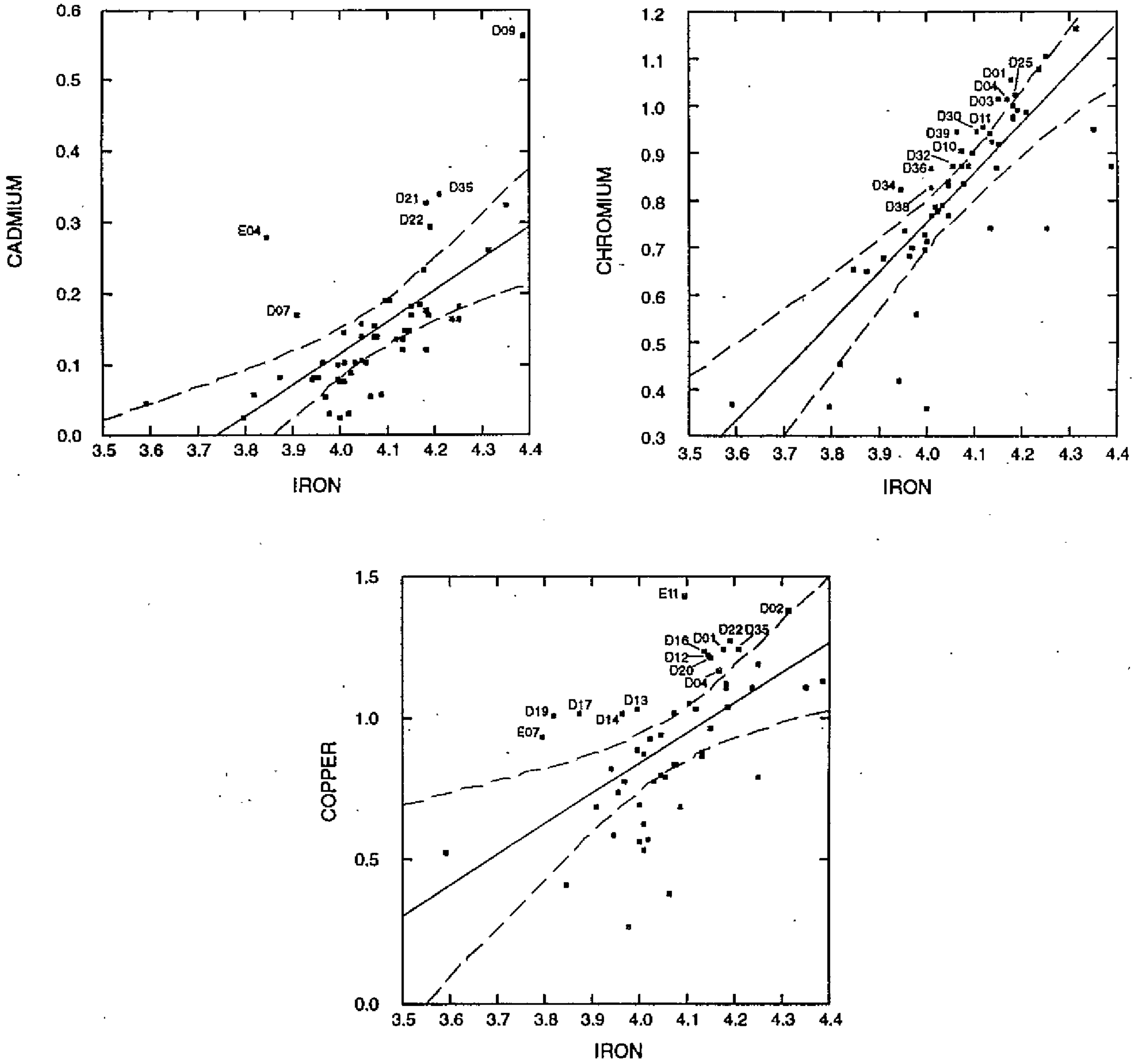


Figure 3-13b. Linear regression results of sediment iron vs. cadmium, chromium, and copper measured at 54 stations in the lower Columbia River.

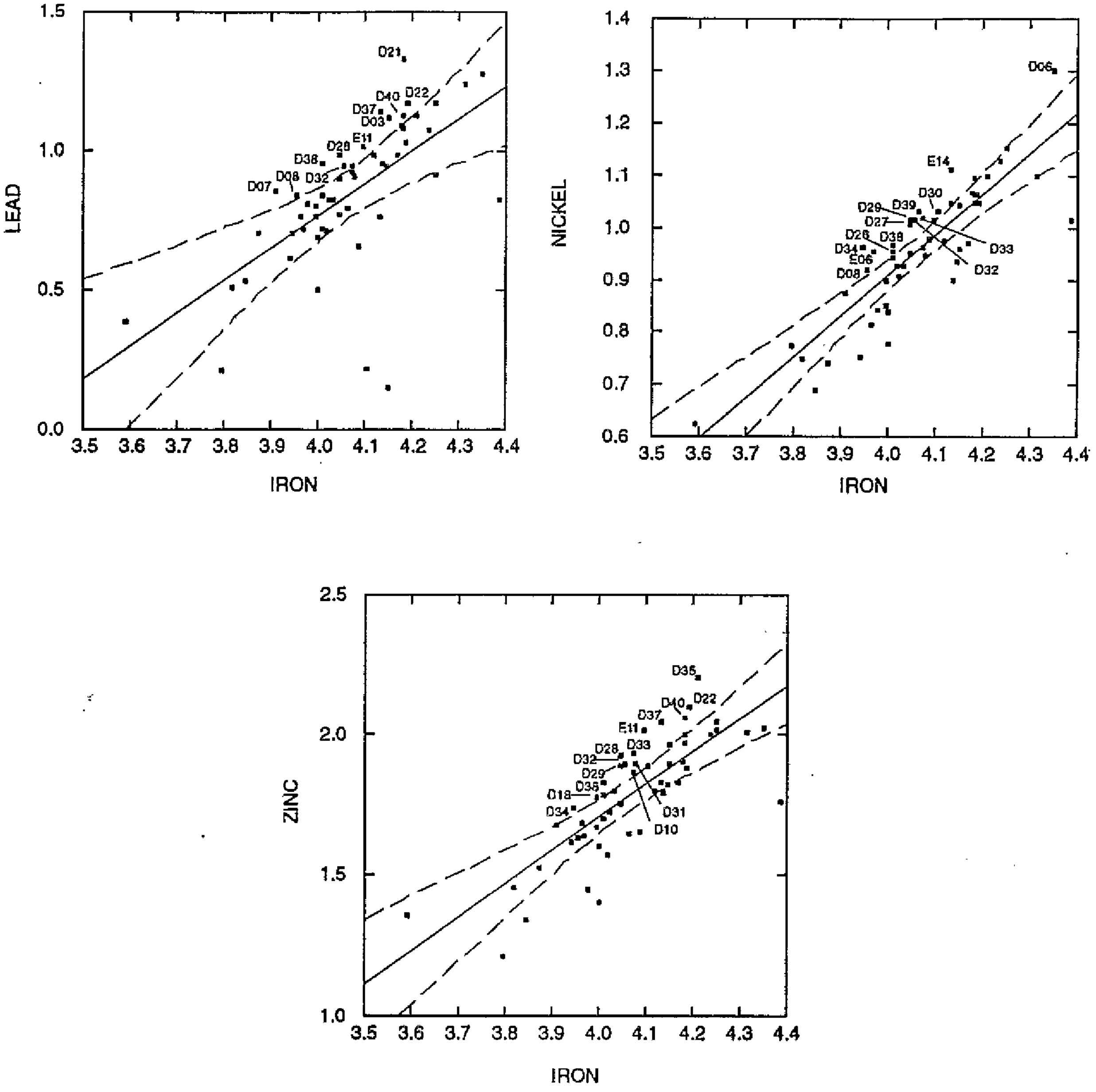


Figure 3-13c. Linear regression results of sediment iron vs. lead, nickel, and zinc measured at 54 stations in the lower Columbia River.

TABLE 3-9. IDENTIFICATION OF SEDIMENTS THAT MAY POTENTIALLY BE ELEVATED IN THE INDICATED METAL DUE TO INPUT FROM ANTHROPOGENIC SOURCES

(Page 1 of 2)

Station[a]	Aluminum	Arsenic	Barium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Silver	Zinc
D1	X				X	X					
D2		+			+	X+		+			
D3					X		X	+		+	
D4	X				X	X					
D5^E	X									+	
D6		X+		+			+		X+	+	
D7		X	X	X			X			+	
D8	X		X				X			+	
D9				X+						+	
D10					X					+	X
D11	X				X						
D12	X					X					
D13	X					X					
D14	X	X				X					
D15											
D16	X	X						+			
D17	X					X				+	
D18		X									X
D19	X					X					
D20	X	X									
D21			X	X+			X+				
D22	X			X+		X	X	+			X
D23		X+	X								
D24	X							+			
D25			X		X			+			
D26			X						X		
D27									X		
D28		X	X				X				X
D29			X						X		X
D30			X		X			+			
D31		X	X								X
D32^E					X		X		X		X
D33			X						X		X

TABLE 3.9. IDENTIFICATION OF SEDIMENTS THAT MAY POTENTIALLY BE ELEVATED IN THE INDICATED METAL DUE TO INPUT FROM ANTHROPOGENIC SOURCES
(Page 2 of 2)

Station[a]	Aluminum	Arsenic	Barium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Silver	Zinc
D34^{E}			X		X				X		X
D35		X		X+		X		+			X+
D36					X			+			
D37			X				X				X
D38^{E}					X		X		X		X
D39					X				X		
D40			X				X				X
E1		X								+	
E2^{D}											
E3										+	
E4				X						+	
E6^{D}									X		
E7						X					
E8		X									
E9^{D}	X							+			
E10^{D}											
E11			X			X+	X				X
E12	X										
E13			X								
E14			X						X		

X = Enrichments identified by regression analyses.

+ = Potential enrichments identified by frequency distribution analyses.

[a] Station number prefix "D" and "E" were assigned prior to sampling to stations expected to be fine-grained and coarse-grained, respectively. Following sampling, some stations were reclassified based on the grain size analysis [>20% fines (<100 um effective diameter) was considered a fine-grained sediment station]. Reclassified stations are identified by superscript "E" or "D".

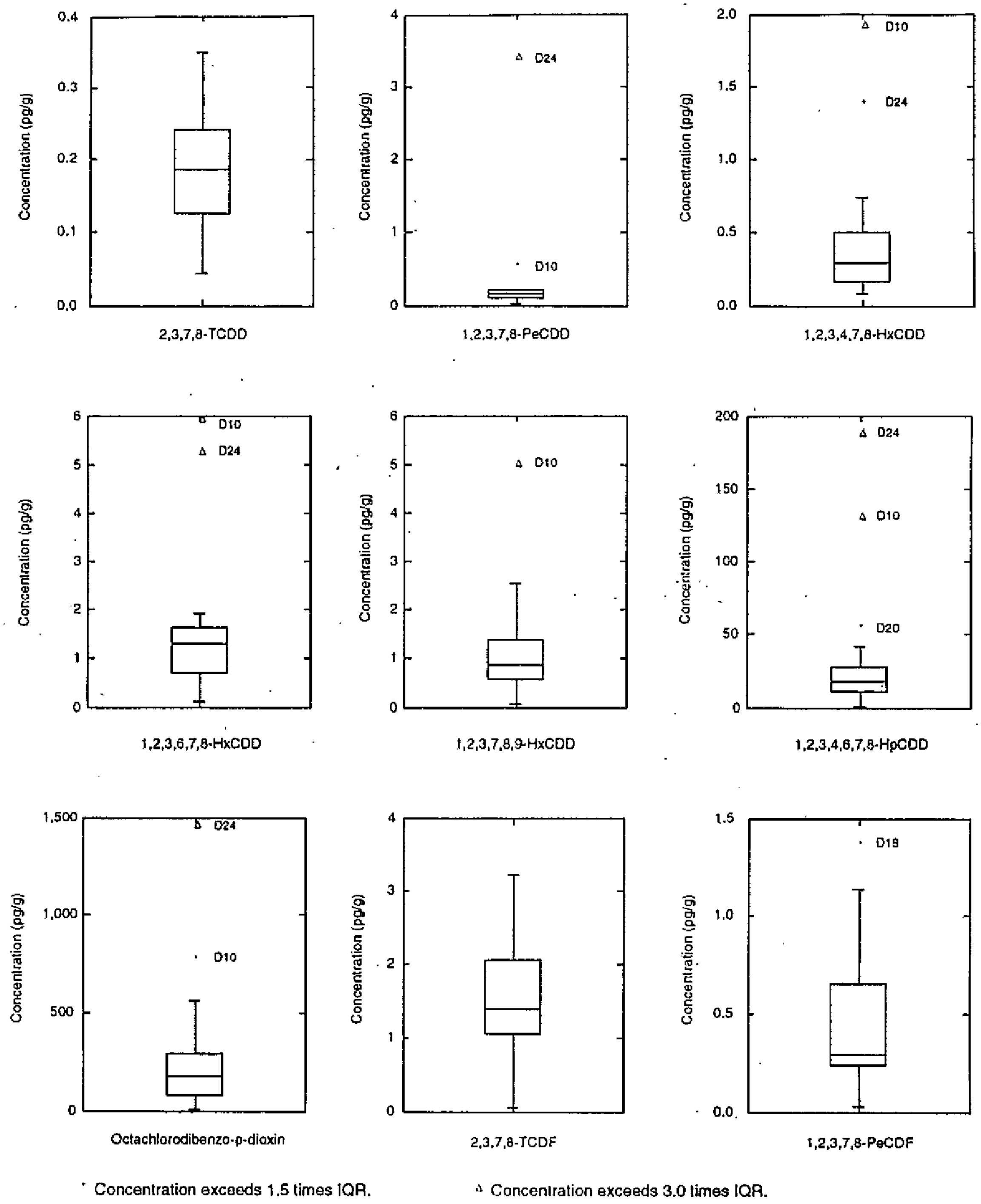


Figure 3-14. Distributions of dioxins and furans measured at 54 stations in the lower Columbia River.

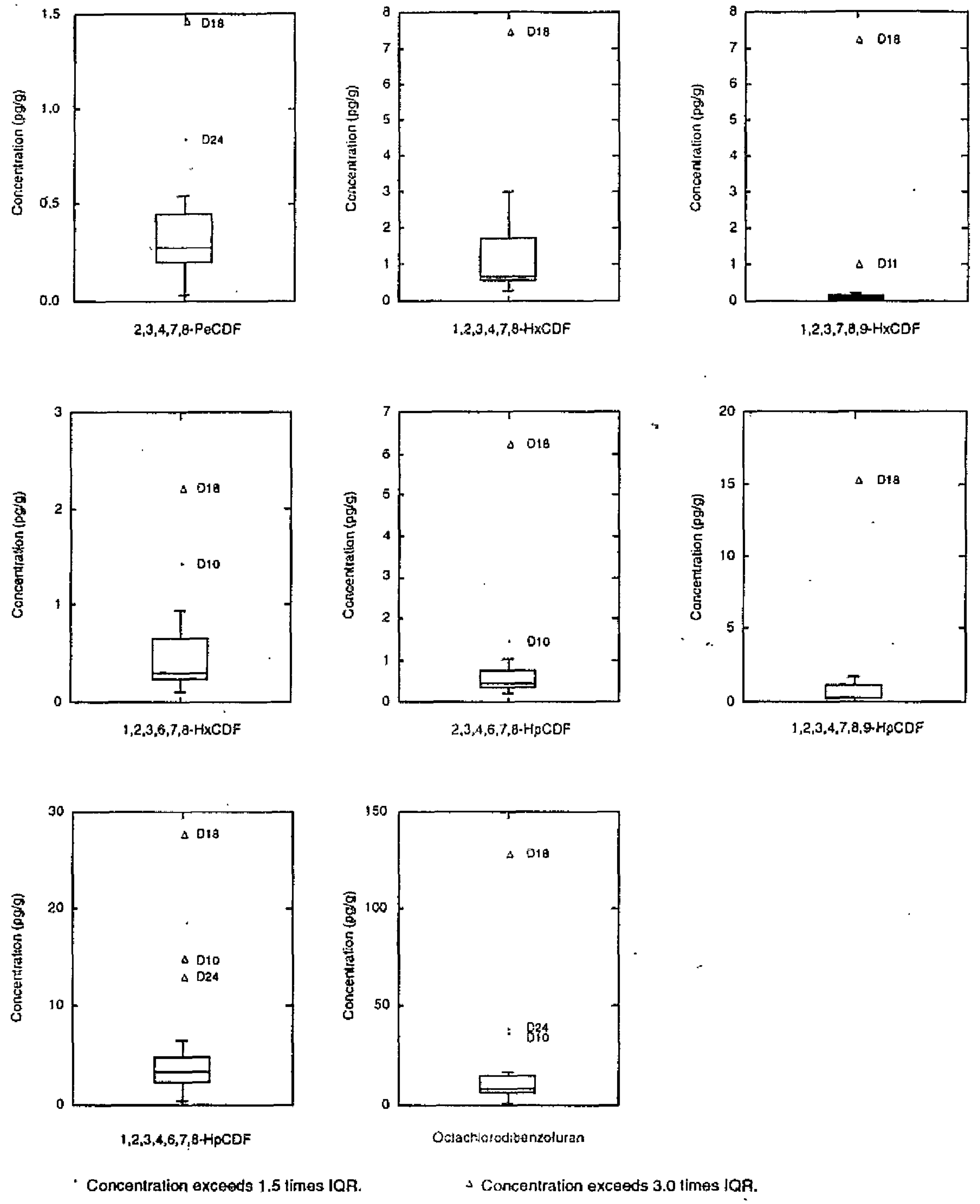


Figure 3-14. Distributions of dioxins and furans measured at 54 stations in the lower Columbia River.

Willamette River), and D31 (Oregon Slough/Portland Harbor)]. Triethyl butyltin was identified as anomalously high (i.e., it exceeded three times the IQR) at station D19 (below Longview) in comparison with concentrations at other stations (Figure 3-15). Based on this analysis, station D19 was taken forward to help identify areas of concern.

Few PAHs were found in the Columbia River sediment samples. Most PAH compounds detected occurred in sediments from five stations [stations D19 (below Longview), D24 (below St. Helens), D32^{E} (near Vancouver), E8 (below Trojan), and E9^{D} (below Columbia City, OR)]. Too few data were available to calculate IQR values to assist in identifying areas of concern (calculating percentiles based on fewer than about 10 data points is not meaningful). Therefore, as a conservative screening approach, all of these stations were used in the identification of areas of concern.

PCBs (as Aroclor 1254) were detected at station D19 below Longview, and this finding was used in the identification of areas of concern.

Seventeen pesticides were detected in Columbia River sediment samples collected from 22 stations. Only one or two compounds were detected at 16 of the 22 stations, but three or more pesticides were detected in the sediments at 6 stations [stations D22 (near Kalama), E8 (below Trojan), D23 (Martin Slough), E9^{D} (below Columbia City), D24 (below St. Helens), and D35 (Camas Slough)]; the greatest number were detected at station E8. Too few data were available to calculate IQR values for individual pesticides; therefore, using a conservative screening approach, all six stations were included in the delineation of problems areas in the study area.

This approach for identifying elevated concentrations does not necessarily identify locations or concentrations that are of concern based on the potential for adverse biological effects. This potential is addressed by comparing measured concentrations to effects-based reference values, as discussed in the following section.

3.6.3.2 Effects-Level Comparisons. As a second independent approach for identifying areas of concern within the study area, chemical concentrations observed in the sediments were compared with existing freshwater sediment quality guidelines developed by the Ontario Ministry of the Environment (Persaud et al. 1991), the lower 10th percentile (the ER-L) of the concentrations associated with adverse effects

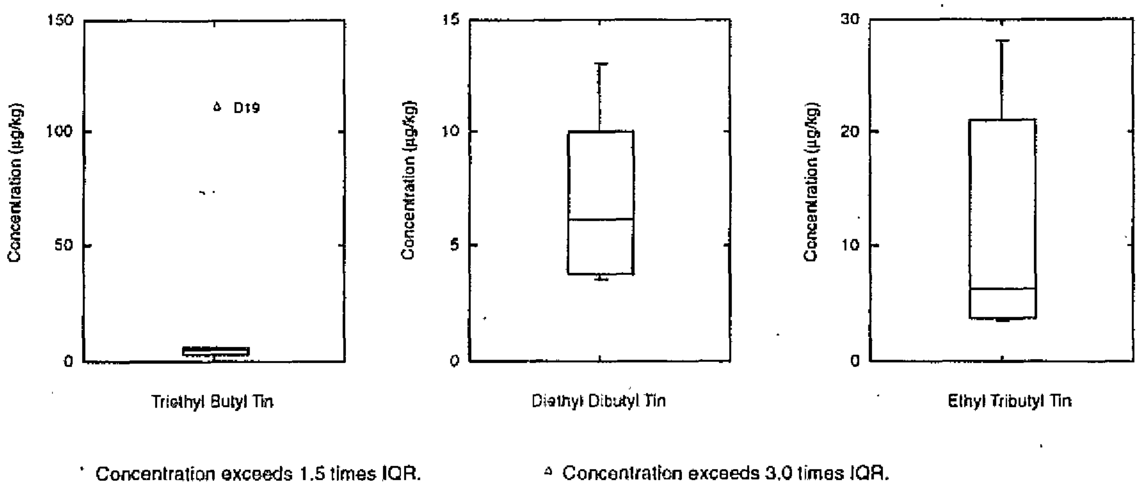


Figure 3-15. Distributions of organotins measured at 10 stations in the lower Columbia River.

in laboratory and field studies (compiled by Long and Morgan 1990), and the most recent U.S. EPA draft freshwater sediment criteria (available for five organic compounds) (U.S. EPA 1991e,f,g,h,i). As a conservative screening approach, the lowest concentration reported among the three freshwater-based sources was used to identify the study area sediments that may pose a threat to biota. The draft EPA freshwater sediment criteria were compared to sediment contaminant concentrations normalized for organic carbon content. Effects concentrations for metals have also been included in Figure 3-4. The effects concentrations for metals are compared to the summary of the sediment data in Table 3-3 and the effects concentrations for organic compounds are presented along with the summary data in Table 3-5.

As discussed above, effects levels for radionuclides in sediment have not been established; therefore, the radionuclide data will not be covered in this section. However, these data will be discussed in more detail in Section 3.7.3 on comparisons to historical data, potential sources, and environmental significance.

Metals. No effects-based reference values were available from the three sets of values chosen for use in this study for aluminum, barium, beryllium, selenium or thallium. The detection limits achieved for antimony (4.3 to 11.1 mg/kg) were insufficient for adequate comparison to the reference level used in this study (2.0 mg/kg, see Table 3-3). The concentrations of chromium, lead, and mercury never exceeded effects concentrations. Arsenic, cadmium, copper, iron, nickel, silver, and zinc exceeded effects levels at 18 stations. The stations at which several metals were present at concentrations exceeding one or more reference level were stations D6 in Grays Bay (arsenic, cadmium, iron, nickel, and silver), D9 near Skamokawa (cadmium, iron, and silver), D22 near Kalama (cadmium, copper, and zinc), and D35 in Camas Slough (cadmium, copper, and zinc). Compared to other metals, copper exceeded its reference value at the most stations; it was present at stations throughout the river (D1, D2, D12, D16, D20, D22, E11^{D}, D35, and D40). Silver was not detected over the same range in the river, but did exceed its effects-based reference value at the six stations where it was detected (D6, D7, D8, D9, E3, and E4). All of these stations are in the lower river below RM 30. Cadmium was present at concentrations that exceeded its reference value at five stations (D6, D9, D21, D22, and D35) that spanned most of the river. The remaining metals exceeded their reference values at three (iron at D2, D6, and D9) or fewer stations (zinc at D22 and D35; arsenic and nickel only at D6).

Organic Compounds. No effects-based reference values were available for several organic compounds that were detected (see Table 3-5). These included the semivolatile organic compound bis(2-ethylhexyl)phthalate; the pesticides dacthal, heptachlor, malathion, methyl parathion, and parathion; the dioxin and furan congeners; and the organotin compounds that were detected in the reconnaissance survey sediment samples. The detection limits achieved for some of the pesticide samples were higher than the biological effects-based reference levels adopted for this study. These include the detection limits achieved for the pesticides DDT, dieldrin, and endrin. Most of the detection limits for DDT compounds (2 μg/kg with the exception of one sample with a DL of 20 μg/kg) were within the range of the effects-based reference values (1 to 3 μg/kg). The detection limits achieved for dieldrin and aldrin (2 μg/kg except for one sample with a DL of 20 μg/kg) were lower than the Ontario freshwater sediment guidelines (2 to 3 μg/kg), but they were much higher than the marine sediment ER-L levels of Long and Morgan (0.02 μg/kg) (see Table 3-5). The detection limits for PCBs were generally lower than the selected reference levels with the exception of one sample.

Measured sediment contaminant concentrations that were corrected for the sediment organic carbon content did not exceed the draft U.S. EPA freshwater sediment criteria in any sample (see Appendix C-3 through C-14 for the organic carbon corrected data). However, some of the sediment samples contained less than 0.2 percent carbon which is the lower limit for the valid use of these criteria (U.S. EPA 1991e,f,g,h,i).

Several PAH compounds and total PAHs (determined by summing the concentrations at each station of those PAH compounds that were detected) were measured at concentrations greater than effects concentrations at four stations: D2, D19, D22, and D24. The concentrations of the PCBs detected at station D19 exceeded both the ER-L and the Ontario freshwater sediment reference value (see Table 3-5). In at least one case for each pesticide, the reported detection limits exceeded the effects concentrations (see Table 3-5). Pesticides were measured at concentrations greater than their effects concentrations at 12 stations. No sediment quality reference values exist for the remaining compounds analyzed in the Columbia River sediments; therefore, these compounds were not ranked using this approach.

Overall, the concentrations of chemical substances exceeded sediment quality reference values at 23 stations. Stations with three or more chemicals at levels above reference concentrations occurred near urbanized or industrial areas, including Camas, St. Helens, Kalama, Longview, Ilwaco (Washington), and Astoria (Oregon). Station D6 in Grays Bay had four chemicals at concentrations above sediment quality reference levels.

3.6.3.3 Potential Areas of Concern. The stations that were identified as having sediments that were potentially anthropogenically influenced or that had chemical concentrations exceeding sediment quality reference values are summarized in Table 3-10. Because the dioxins and furans, PAHs, and PCBs generally consist of covariant groups of compounds, reflecting their common source, a single exceedance was assigned to those stations at which these compounds were found. Table 3-10 includes the actual numbers of individual compounds detected in each group, except for the PCBs, which were reported only as the single Aroclor representative.

Sediments collected at five stations (D15, E2^D, E3, E5, and E10^D) did not have any of the measured chemicals at concentrations that indicated potential anthropogenic influences. Stations D19 and D24 had the greatest numbers of different classes of compounds present at high concentrations. The stations with the greatest numbers of substances that indicated possible anthropogenic contributions also generally had the greatest numbers of substances that exceeded their effects-based reference values. The stations with the greatest numbers of elevations above naturally occurring concentrations and exceedances of effects levels included D1, D2, and D6 in the estuary; stations D16, D19, D22, E8, E9^D, and D24 in the reach between RM 58 (below Longview, WA) and 83 (downstream of St. Helens, OR); and station D35 (Camas Slough near RM 119). Station E9 was reclassified as a fine-grained station following the results of grain-size analysis, and sediments collected from this station were also noted to have an oily sheen (Tetra Tech 1991a). Comparatively high concentrations of dioxins and furans occurred at the stations downstream of St. Helens (station D24), across the river from Longview on the Oregon side of Lord Island (station D18), and Wauna, OR (station D10). Organotins were comparatively enriched at one station, D19 (RM 62 near Longview), which was also the one station at which PCBs were detected. PAHs were detected at five stations including station D32^E between Vancouver and Portland; stations D24 and E9^D, downstream from St. Helens; station E8 near Kalama, WA, and station D19 near Longview. Pesticides were distributed somewhat differently and were primarily found between Kalama and St. Helens (RM 76 to 86), with station E8 having the greatest number of pesticides detected.

TABLE 3-10. THE IDENTIFICATION OF AREAS OF CONCERN FOR SEDIMENT QUALITY BASED ON AREAS IDENTIFIED AS POTENTIALLY ENRICHED DUE TO ANTHROPOGENIC SOURCES AND EXCEEDANCES OF SEDIMENT QUALITY GUIDELINES[a]

(Page 1 of 3)

Station[b]	River Mile	Potentially Enriched Chemicals							Total # of Effects Exceedances
		Metals	Organic Compounds					Total # of Enrichments	
			Dioxins/Furans	Organotins	PAHs	PCBs	Pesticides		
D1	8	3						3	2
D2	2	4						4	3
D3	13	4						4	
D4	6	3						3	
D5[E]	21	2						2	1
D6	21	5						5	5
D7	22	5						5	1
D8	27	5						5	1
D9	34	2						2	3
D10	38	2	1(10)					3	0[c]
D11	29	3	1(1)					4	0[c]
D12	40	2					2	4	2
D13	43	2						2	
D14	42	2						2	
D15	50								
D16	58	3					2	5	3
D17	59	3					1	4	1
D18	62	2	1(9)					3	0[c]
D19	63	2		1	1(8)	1		5	5
D20	71	3	1(1)					4	1[c]

TABLE 3-10. THE IDENTIFICATION OF AREAS OF CONCERN FOR SEDIMENT QUALITY BASED ON AREAS IDENTIFIED AS POTENTIALLY ENRICHED DUE TO ANTHROPOGENIC SOURCES AND EXCEEDANCES OF SEDIMENT QUALITY GUIDELINES[a]
(Page 2 of 3)

Station[b]	River Mile	Potentially Enriched Chemicals								Total # of Effects Exceedances
		Metals	Organic Compounds					Total # of Enrichments		
			Dioxins/Furans	Organotins	PAHs	PCBs	Pesticides			
D21	70	3						3		1
D22	76	6					3	9		3
D23	80	2					3	5		
D24	85	2	1(8)		1(10)		5	8		3[c]
D25	88	3						3		
D26	92	2						2		
D27	94	1						1		
D28	99	4						4		
D29	101	3						3		
D30	103	4						4		
D31	106	2						2		
D32[E]	108	4			1(4)			5		1
D33	109	3						3		
D34[E]	112	3						3		
D35	118	5					4	9		5
D36	118	2						2		
D37	121	3						3		
D38[E]	124	4						4		
D39	128	2						2		
D40	142	3					2	5		1

TABLE 3-10. THE IDENTIFICATION OF AREAS OF CONCERN FOR SEDIMENT QUALITY BASED ON AREAS IDENTIFIED AS POTENTIALLY ENRICHED DUE TO ANTHROPOGENIC SOURCES AND EXCEEDANCES OF SEDIMENT QUALITY GUIDELINES[a]

(Page 3 of 3)

Station[b]	River Mile	Potentially Enriched Chemicals							Total # of Effects Exceedances
			Organic Compounds						
		Metals	Dioxins/Furans	Organotins	PAHs	PCBs	Pesticides	Total # of Enrichments	
E1	8	2						2	
E2^{D}	16								
E3	22								1
E4	30	2						2	2
E5	46								
E6^{D}	58	1						1	
E7	67	1						1	
E8	77	1			1(2)		6	8	4
E9^{D}	83	2			1(9)		3	6	2
E10^{D}	100								
E11^{D}	104	4						4	1
E12	114	1						1	
E13	126	1						1	
E14	137	2						2	

[a] A value of 1 was assigned to each metal and each group of organic compounds that was considered to be potentially enriched or exceeded reference concentrations. The actual number of individual compounds is indicated in parentheses.

[b] Station number prefixes "D" and "E" were assigned prior to sampling to stations expected to have fine-grained and coarse-grained sediments, respectively. Following sampling, some stations were reclassified. Based on the grain size analysis [>20% fines (<100 μm effective diameter)] was considered a fine-grained sediment station. Reclassified stations are identified by superscript "E" or "D".

[c] No effects screening levels for dioxins and furans were available.

3.7 DISCUSSION

The Columbia River receives both urban and industrial effluents that contribute inorganic (metals and other inorganic constituents), radionuclides, and organic substances to the river. Eight major municipal wastewater treatment facilities discharge directly to the lower Columbia River below Bonneville Dam (see Tetra Tech 1992c for a review of NPDES-permitted facilities that discharge directly to the lower Columbia River). Additionally, 24 industrial facilities including aluminum smelters, pulp and paper plants, wood products facilities, and chemical manufacturing facilities, discharge directly to the lower river within the study area. These discharges represent possible sources of metals and chlorinated organic compounds. Other sources above Bonneville Dam and along tributaries also contribute pollutants to the lower river. The operation of the Hanford plutonium production facility in Richland, WA, has been, and continues to be, a source of certain radionuclides to the river. The operation of the Trojan Nuclear Power Plant along the lower Columbia River has also been considered as a potential source of radionuclides to the environment. Nonpoint sources of pollution including stormwater runoff, seepage from septic tanks and landfills, and atmospheric deposition are additional sources of pollutants (both directly and indirectly) to the river. The sediments of the lower river and the estuary are the primary repository of these contaminants.

The results of the sediment study of the lower Columbia River reconnaissance survey are discussed in relation to historical data and available information on both point and nonpoint sources of the constituents measured in this study. In general, the discussion will focus on the problem chemicals identified.

3.7.1 Sediment Grain Size and Organic Carbon Content

Sediment grain size and sediment organic carbon content, although potential indicators of fine organic sediment input from pollution sources, were measured primarily as indicators of the relative character of the sedimentary environment (i.e., depositional vs. erosional). The sediment grain size and organic carbon content of the sediments also provide an indication of the potential of these collected sediments to adsorb the metal and organic contaminants which tend to bind to fine organic particles.

3.7.1.1 ***Sediment Grain Size.*** The physical character of the sediments collected during the reconnaissance survey ranged from samples that were predominantly coarse sand to samples that were over 90 percent silt. Although the reconnaissance survey was intended to characterize the general sediment quality of the river, an attempt was made to sample backwater areas that were expected to contain a high proportion of fine sediments. This attempt was relatively successful, but due to the limitations of the draft of the sampling vessel (4 ft) and low river stage, areas of finer sediments were not sampled.

Comparison with Historical Data and Identification of Potential Sources. The generally sandy character of lower Columbia River sediments observed in this study has been noted by several previous investigators (e.g., Hubbel and Glenn 1973; Sherwood et al. 1984; Johnson and Norton 1988). The trend of increasingly finer sediments towards the mouth of the estuary observed in this study was also noted by Hubbel and Glenn (1973) and Sherwood et al. (1984).

The sources of sediment in the lower Columbia River include natural geologic sources—due to land erosion, and erosion and scouring of the river—or anthropogenic sources resulting from land clearing, logging, urban runoff, and NPDES-permitted point source discharges. Whetten et al. (1969) summarized the textural and mineral characteristics of Columbia River sediments and quantified sediment transport relationships of the Columbia River. Whetten et al. (1969) concluded that Columbia River sediment is derived from two principal sources. The upstream sediments (above Bonneville Dam) are ultimately derived from the metamorphic, plutonic, and sedimentary rocks of the upper river basin, and the downstream sediment is derived from andesitic volcanic rocks and sediments of the lower river basin. The upstream sediment is generally fine-grained and is transported by the river primarily as suspended sediment. The volcanic sediments derived from the lower river basin are generally coarser and are transported primarily as bedload. The sediment particles in the river have undergone relatively little chemical weathering and the amount of sediment transported in a single high-flow period may exceed that which is transported in a single average year (Whetten et al. 1969). Whetten et al. (1969) also concluded that the primary sources of suspended sediment to the river were the Snake and Willamette rivers and that dam construction in the river basin had not affected the total annual discharge of sediment, but had altered the seasonal patterns of sediment transport and deposition.

Sherwood et al. (1984) reported the results of extensive studies of sediment, sediment bedforms, and sediment transport in the Columbia River estuary. Sherwood et al. (1984) noted the dynamic nature of sediment deposition and transport in the estuary due to diurnal and seasonal variation of tidal intrusion and seasonal variation of the flow of the Columbia River. They concluded that the increase in fine sediments towards the mouth of the river was likely due to the transport of fine shelf sediments into the estuary and evidence that seaward bedload transport of the relatively coarser sediments in the estuary did not occur. Sherwood et al. (1984) also concluded that deposition of fine-grained river sediments occurred primarily in protected peripheral bays and in channel bottoms of the mid- to upper-estuary, but that even in these areas the sediments did not contain clay-sized material. They concluded that sedimentation in the peripheral bays occurs during the quiescent period of the diurnal tidal cycle, neap tides, periods of high sediment supply, slack water, and calm weather; and that sedimentation in the channel bottoms of the mid- to upper-estuary is more closely related to the behavior of the turbidity maximum.

Anthropogenic sources of sediment also contribute to the overall sediment of the river. These sources include both NPDES-permitted point sources and nonpoint sources. Nonpoint sediment sources are primarily derived from agricultural, silvacultural, and urban lands during periods of rainfall runoff. These sediments may also be contaminated with metals and organic compounds. Much of these nonpoint sources of sediment likely enter the lower Columbia River through tributaries and from above Bonneville Dam (Tetra Tech 1992c). Point sources primarily contribute very fine organic sediments to the river. These sediments may then be transported downriver to the ocean or deposited in quiescent backwater areas. Although the absolute quantity of sediment discharged from point sources is relatively small, compared to tributary sediment inputs (Tetra Tech 1992c), these fine sediments are likely contaminated with hydrophobic organic pollutants and metals. The fine sediments derived from both point and nonpoint sources are, therefore, the primary transport mechanism of contaminants to and through the Columbia River. However, the relative importance of point and nonpoint pollutant sources is not known for a majority of the pollutants measured in this study (Tetra Tech 1992c).

Significance and Recommendations. In general these data suggest that the sediments of the main channel and backwater areas with water depths greater than 4 ft (during the low-water period) were representative of these areas of the river and are consistent with historical data. However, there is currently not adequate information to describe in quantitative terms the areal extent of various sediment types in the lower river [with the possible exception of data developed as part of recent investigations of the estuary (e.g., Sherwood et al. 1984; Simenstad et al. 1984)] or the areal extent of the location and extent of finer sediments that were not sampled during this survey. Furthermore, the environmental significance of the existence of potentially contaminated shallow backwater areas along the lower river is not presently know. Since these areas are likely feeding, spawning, and nursery areas for wildlife and species of commercial importance, these areas warrant further investigation. It is recommended that a preliminary investigation and location of areas of fine sediments in backwaters be followed by sampling of these areas for chemical analysis. Sampling of these areas should be conducted using shallow-draft vessels or land-based methods. Sampling of these areas would allow for a more complete assessment of the potential effect, on humans and wildlife, of sediment contaminant concentrations in the lower Columbia River.

3.7.1.2 Sediment Organic Carbon. Sediment organic carbon content measured during the survey was relatively low (less than 1.6 percent) at all but one station (D35 in Camas Slough), which had an organic carbon content of 4.1 percent. Although the relatively higher organic carbon content of the sediments in Camas Slough may be due to enhanced deposition in this backwater area, the slough was also the recipient, historically, of discharge from the former Crown-Zellerbach (Camas) mill (Lincoln and Foster 1943). Presently the area is used for log storage.

Comparison with Historical Data and Identification of Potential Sources. The relatively low TOC content of sediments sampled in this study has been noted in other studies (e.g., Hedges et al. 1984; Fuhrer 1986; Johnson and Norton 1988) (see Tetra Tech 1992a for a review of these studies). The maximum sediment TOC concentration reported by the studies reviewed in Tetra Tech (1992a) did not exceed 2 percent. Hedges et al. (1984) determined that the sediment organic matter of the Columbia River was generally dominated by nonwoody angiosperm material and, to a lesser extent, by woody gymnosperm tissue. It was suggested that the presence of relatively higher amounts of woody gymnosperm material in sediments offshore of the Columbia River mouth was due to the transport of woody gymnosperm debris through the Columbia River without deposition in the river during high flow periods (Hedges et al 1984). However, Fuhrer (1986) analyzed the sediment organic carbon content of sediment grain size fractions collected from Cathlamet Bay and determined that the coarse sediments contained the largest portion of particulate organic matter.

Point and nonpoint discharges of organic matter are additional sources of organic carbon to sediments of the Columbia River. Although their relative importance to natural sources of organic matter have not been determined, discharge of anthropogenically derived organic matter may be a significant source of sediment organic matter in localized areas of the river. However, the primary importance of anthropogenic discharges of organic matter is due to its association with metal and organic contaminants derived from these same sources.

Significance and Recommendations. The potential toxicity of non-polar, non-ionic organic compounds is related to the organic content of the sediments. Relatively higher sediment organic content allows for the absorption of organic compounds and the reduction of the toxicity potential of a given sediment contaminant level. The relatively low organic carbon content of the sediments collected in this survey indicates that, in general, the organic contaminant levels measured in this study may result in potentially greater toxicological effects. If most of this organic matter is not contained in the fine particulate fraction of the sediments, but is present primarily as coarse particulate matter, then the potential toxicity of a given amount of sediment contaminants could potentially be even greater. Based on the results of the present study, which indicates the presence of contaminants in sediments with relatively low concentrations of organic matter, future studies should determine the relative importance of sediment organic matter of the lower Columbia River in the control of the potential toxicity of sediment contaminants. Furthermore, future studies should also attempt to locate and sample sediments in backwater areas to determine if these sediments have higher sediment organic matter content. Studies should also determine the type of organic matter present, the effective size of the organic matter present, the contaminant concentrations, and the relationship between sediment organic carbon content and toxicity.

3.7.2 Metals

Metals were the most frequently detected substances in sediment samples from the study area. With the exception of beryllium, thallium, antimony, mercury, selenium, and silver, the metals analyzed were detected in nearly every sediment sample. The high detection frequency, which occurs at concentrations above the detection limits of conventional laboratory techniques, is due to the natural occurrence of many of these metals in Columbia River sediments. In most locations the degree to which the metals exceeded the predicted distribution of average concentrations was not great, indicating limited alteration of the sediment quality by anthropogenic influences in the areas sampled. However, some metals occurred at concentrations that exceeded the predicted distribution of background concentrations, indicating possible anthropogenic sources of these metals (see Table 3-9). Arsenic (1 station), cadmium (8 stations), copper (8 stations), iron (3 stations), nickel (1 station), silver (6 stations), and zinc (2 stations) were detected in at least one location at concentrations above levels (i.e., ER-Ls) that have been associated with adverse biological effects in other studies. These exceedances occurred at 13 stations, seven of which were located downstream of major urban and industrial discharges. It should be recognized that the limited nature of a reconnaissance survey does not ensure that any or all significantly contaminated areas have been identified; therefore, there may be locations of anthropogenic influence in localized areas that have not been identified.

The following discussion will relate the concentrations of metals measured in the reconnaissance survey that exceeded effects-based reference levels to historical data identified by Tetra Tech (1992a) and will discuss potential anthropogenic sources of these metals identified by Tetra Tech (1992c).

3.7.2.1 Comparison with Historical Data and Identification of Potential Sources.

Arsenic. Arsenic concentrations exceeded the effects-based reference value of 6 mg/kg (Ontario freshwater sediment guidelines) at one station (station D6 in Grays Bay) where the sediment arsenic concentration was 8.92 mg/kg. The Long and Morgan (1990) marine sediment ER-L of 33 mg/kg was not exceeded at any station in the estuary. Historical measurements of sediment arsenic concentrations, in sediments classified as silt, occasionally exceeded the 6 mg/kg reference level for arsenic (Tetra Tech 1992a). These exceedances include measurements made by the USACOE near Chinook, WA and near Tongue Point, OR (USACOE 1991) as well as stations analyzed by WDOE in Camas Slough (Johnson and Norton 1988).

Sources of arsenic include natural activities such as volcanic emissions, the weathering of soils and rocks that contain arsenic, and human activities that range from metal smelting, glass manufacturing, pesticide production and application, pharmaceuticals industry, metal alloy production, and the combustion of fossil fuels. Arsenic may also be present in phosphate-based detergents due to its close chemical association with phosphorus (Galvin et al. 1984). Point sources within the lower Columbia River that are required to monitor effluent discharge for arsenic include the cities of Gresham, Portland, and St. Helens (Tetra Tech 1992c). Estimated arsenic loading from permitted-point source discharges directly to the lower Columbia River for 1989 and 1990 were 14.1 and 15.4 lb/day, respectively (Tetra Tech 1992c). However, these estimates were based primarily on analyses that indicated that arsenic concentrations in the monitored effluents were below laboratory detection limits. Arsenic was detected in the city of Gresham effluent in 1990 (due to the achievement of lower detection limits) which resulted in an arsenic loading estimate of 2.4 lb/day for 1990 from this facility.

Cadmium. Cadmium concentrations exceeded the effects-based reference value of 0.6 mg/kg (Ontario freshwater sediment guidelines) at seven stations (stations D1, D2, D6, D9, D21, D22, and D35). The maximum reported concentration was 2.66 mg/kg at station D9 near Skamokawa, WA. The Long and Morgan (1990) ER-L for marine sediments of 5 mg/kg was not exceeded at any station in the estuary. Historical measurements of cadmium in sediments of the lower Columbia River classified as silt have occasionally exceeded the 2.66 mg/kg reference level for cadmium (1992a). These measurements include those made by the USACOE near Chinook, WA and Tongue Point (USACOE 1991), those made by Fuhrer (1986) in Baker Bay, and those in Camas Slough (Johnson and Norton 1988). Fuhrer (1986) noted that relatively elevated cadmium concentrations occurred in the navigation channel near the mouth of the Columbia River and that extractable cadmium concentrations were negatively correlated with percent silt and clay. No explanation for these observations could be provided.

Sources of cadmium include smelting operations, surface mine drainage, and phosphate fertilizer (May and McKinney 1981). Mining and smelting operations in the upper river basin have been cited as a major source of cadmium to the Columbia River (May and McKinney 1981). Additional sources of cadmium include fossil fuel burning and the natural weathering of cadmium-containing rocks and soils. Point sources within the lower Columbia River that are required to monitor effluent discharge for cadmium include the municipal wastewater treatment facilities of Portland, Gresham, and St. Helens, and the industrial facilities of Reynolds Metals Co. in Longview, and Kalama Chemical (Tetra Tech 1992c). Tetra Tech (1992c) identified data on effluent cadmium discharge for the municipal facilities in Portland and Gresham only; however, cadmium was typically undetected in the effluent of these sources.

Copper. Copper concentrations exceeded the effects-based reference value of 16 mg/kg (Ontario freshwater sediment guidelines) at seven stations (stations D1, D2, D12, D16, D20, D22, and D35). The maximum reported concentration was 23.59 mg/kg at station D2 near Ilwaco, WA. The Long and Morgan (1990) ER-L of 70 mg/kg for marine sediments was not exceeded at any station in the estuary. Historical measurements of copper in sediments classified as silt and very fine sand exceeded this reference value at almost all of the stations where copper was measured (Tetra Tech 1992a).

Sources of copper to the environment include inputs due to both natural (volcanic eruptions, soil and rock weathering) and human (copper smelting and mining operations, corrosion of domestic water systems, wood treatment, metal plating, agricultural chemical production and application, phosphate fertilizer production and application, waste incineration, and fossil fuel combustion) activities. Facilities discharging directly to the Columbia River that are required to monitor effluent copper concentrations include the Portland General Electric power plant in Clatskanie, OR, Weyerhaueser Paper Co. (Longview), Trojan Nuclear Power Plant, Kalama Chemical, and the municipal wastewater facilities of St. Helens, Portland, and Gresham (Tetra Tech 1992c). The Portland, Gresham, Portland General Electric (Beaver Generating Plant), and Weyerhaeuser (Longview) facilities typically reported undetectable levels of copper in their effluents. Kalama Chemical and the Trojan Nuclear Power facilities reported copper loadings averaging 0.11 and 0.03 lb/day in 1990 (Tetra Tech 1992c).

Iron. Iron concentrations exceeded the effects-based reference value of 20,000 mg/kg (i.e., 2 percent) (Ontario Freshwater Sediment Guidelines) at three stations (stations D2, D6, and D9). The maximum reported concentration was 24,408 mg/kg at station D9 near Skamokawa, WA. Long and Morgan (1990) did not report an ER-L for marine sediment iron concentrations. The Ontario freshwater sediment reference level has been exceeded in a number of historical measurements made of lower Columbia River sediments (Tetra Tech 1992a). These include a number of measurements made near Ilwaco and Chinook (USACOE 1991), Cathlamet Bay (Fuhrer and Horowitz 1989), and Camas Slough (Johnson and Norton 1988).

Sources of iron to the environment include natural weathering and erosion of soils and rocks in the drainage basin, and human-derived sources (for example, ore mining and smelting operations and corrosion of public water supply systems). Direct point source discharges to the lower Columbia River that are required to monitor effluent iron concentrations include the Beaver Generating Plant, Trojan Nuclear Power Plant, and the municipal wastewater facilities in Portland and Gresham (Tetra Tech 1992c).

Silver. Silver concentrations exceeded the effects-based reference value of 0.5 mg/kg (Ontario freshwater sediment guidelines) at six stations (stations D6, D7, D8, D9, E3, and E4). The Long and Morgan (1990) marine sediment ER-L for marine sediments of 1 mg/kg was exceeded at station D6 (Grays Bay) in the upper reach of the estuary. Sediment silver concentrations exceeded the freshwater sediment reference levels at six of the ten stations where silver was detected. Exceedances of the freshwater sediment silver reference level occurred at stations between RM 21 and 34. However, there are currently no known sources of silver in this reach of the river (Tetra Tech 1992c). It is possible that ash from the 1980 eruption of Mt. St. Helens (which entered the Columbia River through the Cowlitz River at RM 68) is enriched in silver, relative to sediments derived from the remaining drainage basins, and is deposited in this reach of the river. The possible significance of these catastrophic inputs of large amounts of sediment on the sediment budget of the estuary has been emphasized by Simenstad et al. (1984). The maximum concentration of 1.49 mg/kg was reported for station D6 in Grays Bay. No data on historical concentrations of silver were identified by Tetra Tech (1992a). However, Johnson and Norton (1988) did not detect silver above the detection limit of 0.6 mg/kg.

Potential sources of silver to Columbia River sediments include sources due to both natural (e.g., weathering of soils and rocks containing silver and volcanic eruptions) and human (e.g., ore smelting and mining, fossil fuel consumption, photographic industry, and cement manufacturing) activities. Facilities discharging directly to the lower Columbia River that are required to monitor effluent silver concentrations include the cities of Gresham, Portland, and St. Helens. The silver concentration in the effluents that were monitored in 1989 and 1990 were generally below the detection limits achieved by the analytical laboratories. Based on these limited data, the silver loading to the lower Columbia River from these facilities was probably less than 2.1 and 3.6 lb/day in 1989 and 1990, respectively (Tetra Tech 1992c).

Nickel. Nickel concentrations exceeded the effects-based reference value of 16 mg/kg (Ontario freshwater sediment guidelines) at one station (station D6 in Grays Bay) where the sediment nickel concentration was 20.1 mg/kg. The Long and Morgan (1990) marine sediment ER-L of 30 mg/kg was not exceeded at any station in the estuary. The Ontario freshwater sediment guidelines value was exceeded at a number of historical sampling locations in the lower river where sediments were classified as silt or very fine sand (Tetra Tech 1992a). These measurements were made near Chinook and Ilwaco (USACOE 1991), Astoria (Fuhrer and Rinella 1983; Fuhrer 1986), Tongue Point (Young et al. 1988), and Cathlamet Bay (Fuhrer and Horowitz 1989).

The potential sources of nickel to Columbia River sediments include sources due to both natural (e.g., weathering of soils and rocks containing nickel) and human (e.g., metal smelting and mining operations, metal plating industries, burning of fossil fuels, commercial fertilizer production and application) activities. Several NPDES-permitted point sources are required to monitor effluent discharges for nickel. These facilities include the cities of Gresham, Portland, and St. Helens, and the industrial facilities of

Weyerhaeuser (Longview), Reynolds Metals (Longview), Kalama Chemical, Reynolds Metals (Troutdale), and ALCOA (Vancouver) (Tetra Tech 1992c). Estimated point source loading of nickel, based on the available monitoring data, indicated that as much as 4.8 and 5.4 lb/day were discharged in 1989 and 1990, respectively. However, a portion of these estimates was based on calculations using reported detection limits (i.e., nickel was not detected in some effluents above the detection limit) (Tetra Tech 1992c).

Zinc. Zinc concentrations exceeded the effects-based reference level of 120 mg/kg [both the Long and Morgan (1990) marine sediment ER-L and the Ontario freshwater sediment guideline] at two stations (D22 near Kalama and D35 in Camas Slough). The maximum concentration reported was 161.3 mg/kg at the Camas Slough station. Historical measurements of sediment zinc concentrations have exceeded the reference value at several stations classified as silt and very fine sand by Tetra Tech (1992a). These include measurements made near Chinook (USACOE 1991; Fuhrer 1986), Baker Bay (Fuhrer and Rinella 1983; Fuhrer 1986), Tongue Point (Young et al. 1988), and Camas Slough (Johnson and Norton 1988).

Potential sources of sediment zinc include both natural (e.g., soil and rock weathering) and human (e.g., metal smelting and mining, metal plating, corrosion of domestic water supply systems, and production and erosion of automobile tires) sources. Permitted point sources that are required to monitor effluent concentrations of zinc include the municipal wastewater treatment facilities of Gresham, Portland, and St. Helens, and the industrial facilities of Kalama Chemical, Reynolds Metals (Troutdale), and ALCOA (Vancouver) (Tetra Tech 1992c). Detectable concentrations of zinc were reported in the effluents of Kalama Chemical (0.03 lb/day), Reynolds Metals (Troutdale) (0.03 lb/day), ALCOA (Vancouver) (0.17 lb/day), Portland (33.4 lb/day), and Gresham (6.8 lb/day) (Tetra Tech 1992c).

Metals That Did Not Exceed Reference Levels. No reference values were available to assess the sediment concentrations of aluminum, barium, beryllium, selenium, and thallium. Tetra Tech (1992a) identified no historical measurements in the lower Columbia River of sediment aluminum, barium, beryllium, selenium, or thallium for comparison with the results of the present study. However, thallium was not detected, in any sample collected for the reconnaissance survey, above the detection limits (which ranged from 10.3 to 26.8 mg/kg).

It was not possible to assess conclusively whether antimony exceeded the Long and Morgan (1990) marine sediment ER-L value of 2 mg/kg due to the relatively higher detection limits (4.3 to 11.1 mg/kg) achieved for this study. No historical measurements of sediment antimony concentrations were identified by Tetra Tech (1992a) for comparison with the results of the present study.

The sediment concentrations of chromium, lead, and mercury did not exceed either the Long and Morgan (1990) marine sediment ER-L values or the Ontario freshwater sediment guidelines (see Table 3-3). Based on the historical lower Columbia River sediment metals data summarized by Tetra Tech (1992a), historical measurements of sediment chromium concentration have been below the marine sediment ER-L of 80 mg/kg and the freshwater sediment guideline of 26 mg/kg. However, historical sediment measurements of lead and mercury have exceeded the reference values adopted for this study at a number of historical lower Columbia River sediment sampling locations. Historical measurements of sediment lead concentrations exceeded the freshwater sediment reference level of 31 mg/kg in Baker Bay (Fuhrer and Rinella 1983, Fuhrer 1986), near Vancouver (Johnson and Norton 1988), and Camas Slough (Johnson and Norton 1988). Historical measurements of sediment mercury concentration exceeded the marine sediment ER-L value of 0.15 mg/kg in sediments near Tongue Point (Young et al. 1988), and Parkers Landing (Young 1988). The value of 0.251 mg/kg of mercury reported for Parkers Landing (Young 1988) sediments also exceeded the freshwater reference value of 0.2 mg/kg. Sources of lead include fossil fuel combustion, natural mineral deposits, and surface mining and smelting operations (May and McKinney 1981). Point sources required to monitor effluent lead discharge include Weyerhaueser Paper Co. (Longview), Reynolds Metals (Longview), Kalama Chemical, and the municipal wastewater treatment facilities in St. Helens, Portland, and Gresham. Lead was typically undetected in the effluents monitored in 1989 and 1990 (Tetra Tech 1992c). Sources of mercury include natural mineral deposits and mining operations which occur near the mouth of the river (Fuhrer 1986) and in upper drainage areas of the Willamette River (May and McKinney 1981). Tetra Tech (1992c) identified a number of municipal wastewater treatment facilities that were required to monitor mercury concentrations in their effluent discharges to the lower Columbia River. These facilities included the cities of St. Helens, Portland, and Gresham. However, for 1989 and 1990 data were only available for the city of Gresham which typically reported that mercury concentrations were below laboratory detection limits. Based on these data, mercury discharged from the Gresham facility probably did not exceed 4.2 lb/day.

3.7.2.2 Significance and Recommendations. In general, the significance and recommendations for sediment metal concentrations measured in the reconnaissance survey are similar to those outlined in the water column section, Section 2.7.4.2. However, since sediments are generally the final repository of contaminants discharged to the river and integrate and record the history of pollutant input, the sediment data may be a better indicator of chronic metal pollution problems in the lower Columbia River. The sediment data also have the added advantage of being more easily quantified (i.e., detection limits are generally adequate to determine the quantity of metal present) and they are less sensitive to contamination in the field or laboratory (i.e., adequate data may be developed without the use of ultra-clean field and laboratory protocols).

Unfortunately, the sediment acid volatile sulfide (AVS) analyses performed for the reconnaissance survey were determined to be unusable. Generally, AVS is thought to be a significant factor in the mediation of the toxic effect of cationic (i.e., positively charged) metals in both marine and freshwater sediments (e.g., DiToro et al. 1990; Carlson et al. 1991). However, Ankley et al. (1993) have shown that metal to AVS ratios may not accurately predict metal toxicity in heavily contaminated freshwater sediments. Nevertheless, future measurements of sediment metal concentrations in the lower Columbia River should be accompanied by measurements of AVS.

Identification of specific sources of the metals detected in sediment samples collected during the reconnaissance survey was not possible due to the limited scope of the reconnaissance survey. However, indications that a number of stations may be enriched in several metals and that a number of metals exceed the effects-based reference values adopted for this study suggest potential for effects to biota inhabiting the lower Columbia River. Comparison with the historical data compiled by Tetra Tech (1992a) indicates that historical data are consistent with the results of the reconnaissance survey and also indicate exceedances of the effects-based reference values for several metals. The sediment sampling of the reconnaissance survey has identified problem areas and metals that may warrant further investigation (e.g., the metals cadmium, copper, and silver and stations D19 and D35).

Relevant questions for further research include the following:

- What are the major sources (point and nonpoint sources as well as background levels) of these metals to the river?

- What are the effects of these metals on the biota?
- Are the forms of the metals detected in this survey available to the biota?
- Are some metals and their various forms more available than others?
- Which is the most important pathway (water column or sediments) for metal contaminant exposure and accumulation?
- What are the residence times of these metals?
- How and in what forms are metals transported through the river system?
- What is the fate of the metals delivered to the river?

Answers to these questions are essential for identifying the most important sources of specific metals, and the acceptable limits of the input of these contaminants into the lower Columbia River system. An integrated monitoring program of both dissolved and total metals in the lower Columbia River, and the various point and nonpoint sources, should be performed on a seasonal basis to improve the understanding of the sources, forms, and fate of metals in the lower Columbia River. An assessment of chemical forms of the metals in various sediment types in the lower river, and the role of constituents such as AVS in controlling the toxic effects of these metals, would also aid in further assessing the relative effects of these metals on the biota of the river.

3.7.3 Radionuclides

Radionuclides have probably been the most extensively studied contaminant in the Columbia River. Extensive studies of radionuclides in water, sediment, and biota of the Columbia River began in the early 1940s as a result of the placement of the Hanford plutonium-production facility near the shore of the Columbia above RM 340 near Richland, WA (e.g., Robeck et al. 1954; Perkins et al. 1966; Forster 1972; Renfro et al. 1972; Haushild et al. 1973; Hubbel and Glenn 1973; Haushild et al. 1975; Johnson et al. 1977; Robertson and Fix 1977; Beasley et al. 1981; Beasley and Jennings 1984; Toombs et al. 1984; Jaquish and Mitchell 1988; Jaquish and Bryce 1989, 1990; Napier 1991; Portland General Electric Co. 1991; Woodruff and Hanf 1991, 1992). Of the seven long-lived radionuclides that were measured in sediments from the six reconnaissance survey stations selected for radioanalysis, only cesium-137 was consistently detected. Concentrations of the other radionuclides were at or below their respective detection limits with the exception of europium-152 and plutonium-239/240.

All of the sediment stations sampled for radionuclides were classified as fine-grained. In general, the chemistry of a particular radionuclide, for example chromium-51, is essentially the same as the chemistry of the non-radioactive isotope of chromium (i.e., chromium-52). Many of the long-lived radioactive elements have a strong affinity for fine sediments; therefore, fine sediments were the focus of this study. Perkins et al. (1966) studied the behavior of a number of radionuclides discharged from Hanford to the Columbia River and concluded that the radionuclides scandium-46, manganese-54, cobalt-58, cobalt-60, iron-59, zinc-65, and zirconium/niobium-95 were readily sorbed to particulate material and that chromium-51, rubidium-106, antimony-124, and barium-140 occurred primarily in dissolved form. Plutonium-239/240 is also considered to bind strongly to particulates; while cesium-137 is relatively more soluble (Noshkin et al. 1978). These chemical characteristics also affect the biological uptake and excretion of these elements.

3.7.3.1 Comparison with Historical Data and Identification of Potential Sources. Radionuclides occur naturally in the earth's crust and they also occur as a result of human activity. Anthropogenic sources of radionuclides include fallout from historical above-ground nuclear weapons testing; releases due to mining, refining, and purification of radionuclides; releases during disposal of radioactive medical wastes; and accidental releases during the use of radionuclides for the production of energy. Significant sources of radionuclides to the Columbia River include historical and present releases from the Hanford plutonium production facility, fallout from historical above-ground nuclear weapons testing (the U.S. and the former U.S.S.R. terminated above-ground testing in 1964, but the Chinese government continued above-ground testing until 1980), and radionuclide fallout from the April 1986 Chernobyl nuclear power plant accident. Although the Trojan Nuclear Power Plant was an additional potential source of radionuclides to the river (the plant has been shut-down indefinitely since 1991 and will not likely be restarted) since its initiation in 1976, environmental monitoring of this facility suggests that it has not been a significant source of radionuclides to the river (e.g., Beasley and Jennings 1984; Portland General Electric Co. 1991).

Beasley and Jennings (1984) report that as much as 300,000 Ci/yr were discharged in the once-through cooling water for the eight plutonium-production reactors at Hanford during the peak period of plutonium production in the mid-1960s. The Columbia River was called "...the most radioactive river in the United States" by Forster (1972). Although Hanford operations are likely the most significant source of radionuclides to the Columbia River, many of the neutron activation-product radionuclides that were discharged (formed by the neutron bombardment of the elements present in the intake cooling water) had relatively short half-lives. Over 60 different radionuclides have been detected in effluent from the Hanford reactors, and at least six of them were discharged at relatively high concentrations and are relatively long-lived [manganese-54 (half-life 314 days), zinc-65 (245 days), cobalt-60 (5.3 years), scandium-46 (84 days), antimony-124 (60 days), and chromium-51 (27.8 days)] (Forster 1972). Radionuclides with even longer half-lives were discharged in relatively low quantities [e.g., plutonium-239 (half-life 24,000 years) and cesium-137 (30.2 years)] (Beasley and Jennings 1984).

Beasely and Jennings (1984) estimated that about 20 to 25 percent of the plutonium-239/240 and 50 percent of the cesium-137 in sediments behind McNary Dam was derived from Hanford operations, and the remainder of these radionuclides were the result of atmospheric (i.e., above-ground nuclear weapons testing) sources (e.g., americium-241). However, the presence of cobalt-60 was attributed to operations at Hanford (Beasley and Jennings 1984). Robertson and Fix (1977) also estimated that in the mid-1970s, potassium-40 (a naturally occurring radionuclide) accounted for almost half of the total radioactivity of surface sediments behind McNary Dam.

The concentration of sediment radionuclides due to Hanford operations tends to decrease downriver as a result of radioactive decay, dispersion, and dilution with tributary sediments (Perkins et al. 1966; Glenn 1973; Haushild et al. 1975; Beasley and Jennings 1984). For example, Beasley et al. (1981) estimated that only about 4 percent of the plutonium-239/240 in Youngs Bay sediment (which was considered to be minimally influenced by sediment input from the Youngs, and Lewis and Clark rivers) was derived from Hanford operations. Following the termination of significant radionuclide input from the old once-through plutonium production reactors in 1971, sediment radionuclide concentrations have steadily declined due to radioactive decay, dispersion, transport, and burial of radionuclides by relatively uncontaminated sediments (Robertson and Fix 1977).

These historical observations are supported when relatively recent (1989) sediment radionuclide data from above (sediments behind Priest Rapids Dam at approximately RM 380) and below (sediments behind McNary Dam at approximately RM 280) the Hanford site are compared to the reconnaissance survey sediment data (Table 3-11). An increase in the radionuclide concentration of plutonium, europium, cobalt, and cesium is apparent downstream of Hanford in both the 1977 and 1989 data sets (see Table 3-11). However, the maximum concentrations measured in the reconnaissance survey are similar to, or less than, the reported maximum concentration in the sediments above Hanford, and these concentrations are all less than those reported for McNary Dam sediments below the Hanford site (see Table 3-11).

However, continued radionuclide releases from Hanford occur due to direct effluent discharges and the seepage of contaminated groundwater into the river (Woodruff and Hanf 1992). Environmental surveillance results indicate the discharge of measurable quantities of tritium, strontium-90, manganese-54, cobalt-60, rubidium-106, antimony-125, cesium-137, plutonium-238, and plutonium-239/240 from NPDES-permitted point sources (Woodruff and Hanf 1991). Contaminated springs and groundwater have also been identified which contain measurable quantities of tritium, strontium-90, technetium-99, and uranium (Woodruff and Hanf 1992).

Resuspension of deeper sediments in depositional areas, where relatively higher concentrations of several long-lived radionuclides still exist, is an additional source of radionuclides to the river water and sediments. For example, the peak concentration of plutonium-239/240 (0.086 pCi/g) in a sediment core raised from Youngs Bay in the 1970s occurred between the 19- and 20-cm sediment depth layers (Beasley et al. 1981).

3.7.3.2 Significance and Recommendations. Although there are established limits for the radionuclide concentration for drinking water (40 CFR 141), there are presently no standards established for sediments that could be used for comparison with the reconnaissance survey sediment radionuclide data. The damaging biological effect of radionuclides is due to the ionizing action of the emitted decay particles which cause the ionization of cellular chemicals. These ionized chemicals may then cause damage to cellular processes (somatic effects) or may cause damage to genetic material (genetic effects). Exposure of organisms to ionizing radiation may occur from exposure to external radiation or from radionuclides that have been incorporated into the organism's body through uptake across tissue membranes, or through

TABLE 3-11. COMPARISON OF RECONNAISSANCE SURVEY SEDIMENT RADIONUCLIDE RESULTS WITH RECENT AND HISTORICAL DATA FROM LOCATIONS ABOVE (PRIEST RAPIDS DAM) AND BELOW (MCNARY DAM) HANFORD OPERATONS.

Radionuclide	Radiologic Half-Life	Reconnaissance Survey	1989[a]		1977[b,c]	
			Priest Rapids	McNary	Priest Rapids	McNary
	Years	Maximum observed surficial concentration in pCi/g dry sediment.				
Americium-241	458	<0.006	-[d]	-[d]	0.002	0.002
Cesium-137	30	0.29	0.30	0.86	1.16	1.30
Cobalt-60	5.3	<0.05	0.01	0.44	<0.02	1.37
Europium-152	13	0.14	-[d]	1.11	<0.03[e]	1.00[e]
Europium-155	1.8	<0.08	0.09	0.10	-[d]	-[d]
Plutonium-238	86	<0.006	0.0003	0.002	<0.001	0.001
Plutonium-239/240	24,400/6,580	0.005	0.003	0.022	0.014	0.014

[a] Source: Jaquish and Bryce (1990).

[b] Source: Robertson and Fix (1977).

[c] Data converted from units of disintegrations per minute (dpm) to pCi by multiplying dpm by 0.45045.

[d] No data reported for this radionuclide.

[e] Measurement of Europium-152/154. Europium-154 has a half-life of 16 years.

the ingestion contaminated water, sediments, or prey items. Due to the affinity of radionuclides for sediments, bottom dwelling and feeding organisms may be exposed to the most radiation.

However, the radiation dose to humans and organisms due to exposure to radionuclides of natural and anthropogenic origin can be estimated if certain simplifying assumptions are made. Estimates of the radiation dose to humans, due to historical exposures to radionuclides of Hanford origin, is presently being conducted (Napier 1991, Ripple 1992). Radiation dose limits have been established by the U.S. Department of Energy (U.S. DOE) (Order 5400.5) for humans and wildlife for discharges from Hanford [see Appendix B, p. B.5, Woodruff and Hanf (1992)]. The routine public effective dose limit from all exposure pathways is 1.00 millisieverts/yr (100 mrem/yr), and the dose limit to native aquatic organisms exposed to liquid wastes is 10 milligrays/day (1 rad/day) (Woodruff and Hanf 1992). In 1992, the estimated total radiation dose to the maximally exposed individual (MEI) was 0.02 percent of the U.S. DOE dose limit. However, the fourth largest portion of the radiation exposure to the MEI was due to consumption of fish (containing primarily cesium-137) from the Columbia River (Woodruff and Hanf 1992). Dose estimates were also made for clams, fish, and waterfowl exposed to Columbia River water containing a mixture of the radionuclides reaching the river in 1991. The highest estimated dose was 3.0×10^{-5} milligrays/day (3.0×10^{-6} rad/day) for a fish-eating duck which is much less than the 10 milligray/day (1 rad/day) limit.

The potential environmental significance of the levels of radionuclides measured in surface sediments collected during the reconnaissance survey may be indicated by comparison to a recent ecological risk study of historical dumping of low-level radioactive waste off the Gulf of the Farallones National Marine Sanctuary (Tetra Tech 1993a). The maximum sediment concentrations measured within the dumpsite were 0.137 pCi/g of cesium-137 and 0.964 pCi/g of plutonium-239/240. The maximum concentration of cesium-137 measured in the Gulf of the Farallones dump-site is similar to the maximum value reported for this study (0.29 pCi/g), but the value reported for plutonium-239/240 was much higher (compared to 0.005 pCi/g measured in this study). Strontium-90 was also detected in sediments collected from the dumpsite at a maximum concentration of 0.023 pCi/g. The calculated dose to several organisms, due to exposure to the maximum levels of radionuclides measured at the dumpsite, was highest for a bottom-dwelling fish. It was estimated to receive a dose of 1.2×10^{-5} milligrays/day (1.2×10^{-6} rad/day) (Tetra Tech 1993a). This dose is also much lower than the U.S. DOE dose limit for aquatic organisms.

This discussion of radionuclide releases from Hanford does not attempt to summarize all of the environmental problems associated with Hanford (e.g., human health effects due to historical atmospheric releases of radioactive iodine). However, drinking water standards for radionuclides and gross alpha and beta radioactivity have not been exceeded in the Columbia River below Hanford in recent years (e.g., Jaquish and Bryce 1990; Woodruff and Hanf 1991; Becker and Gray 1992; Woodruff and Hanf 1992). Drinking water standards have been exceeded in groundwater and surface detention ponds of the Hanford site, but these sources are not used for potable water supplies (e.g., Woodruff and Hanf 1992).

3.7.4 Organic Compounds

Sediment samples collected during the reconnaissance survey were analyzed for semivolatile organic compounds, PCBs, pesticides, dioxin and furan compounds, and organotin compounds. Dioxins, furans, and organotins were the most frequently detected organic compounds in sediment samples collected during the reconnaissance survey. Several semivolatile organic compounds [PAHs and bis(2-ethylhexyl)phthalate], pesticides, and PCBs were detected at several of the stations sampled. Effects-based reference levels adopted for this study were exceeded by a number of the organic compounds detected in this study. These exceedances occurred for several PAHs, pesticides, and PCBs. However, sediment quality reference values were not available for several of the organic compounds that were detected in the study, including the semivolatile compounds bis(2-ethylhexyl)phthalate, several pesticides, dioxin and furan compounds, and organotin compounds. Based on these data potential areas of concern were identified which included stations D1, D2, and D6 (Grays Bay) in the estuary; stations D19, D22, E8, E9^{D}, and D24 between RM 62 (below Longview) and 83 (below St. Helens), and station D35 in Camas Slough. It should be recognized that the limited nature of a reconnaissance survey does not ensure that any or all significantly contaminated areas have been identified. There may be locations of anthropogenic influence in localized areas that have not been identified.

The following discussion will relate the concentrations of organic compounds measured in the reconnaissance survey to historical data identified by Tetra Tech (1992a) and will discuss potential anthropogenic sources of these organic compounds identified by Tetra Tech (1992c).

3.7.4.1 Comparison with Historical Data and Identification of Potential Sources.

Semivolatile Organic Compounds. The semivolatile organic compounds detected in the reconnaissance survey were limited to PAHs and the phthalate ester, bis(2-ethylhexyl)phthalate, which were detected at several locations throughout the river. The PAHs were detected at concentrations that exceeded available effects-based reference levels.

Bis(2-ethylhexyl)phthalate -- The phthalate ester bis(2-ethylhexyl)phthalate, which was detected at 18 stations at a maximum concentration of 790 μg/kg at station E10^D (below the confluence of the Willamette and Columbia rivers), is commonly used as a plasticizer and as a replacement for PCBs in dielectric fluids for electrical capacitors. It is present in many plastics (especially vinyls), paints, flexible tubing, plastic bags, and medical supplies. Potential sources of bis(2-ethylhexyl)phthalate include industrial and municipal effluents, landfill leachate, incineration of plastics, and nonpoint storm runoff from urban, industrial, and residential areas. A potential source of this compound is Kalama Chemical (at RM 74), which is required to monitor the effluent concentration of bis(2-ethylhexyl)phthalate (Tetra Tech 1992c).

No data on sediment concentrations of bis(2-ethylhexyl)phthalate in the lower Columbia River were identified by Tetra Tech (1992a). However, sediment concentrations of bis(2-ethylhexyl)phthalate concentrations were reported by Johnson and Norton (1988) for sediment samples collected at several port areas along the lower Columbia River. Although the analytical results reported by Johnson and Norton (1988) were qualified as estimates due to detection of bis(2-ethylhexyl)phthalate in the blank (at a concentration of 10 μg/kg or less), a concentration as high as 1,900 μg/kg was reported for a sample collected at the Kalama Chemical pier.

PAHs -- Polycyclic aromatic hydrocarbons (PAHs) were detected infrequently (a maximum of 5 of the 54 sediment sampling stations) in sediments throughout the lower Columbia River. PAHs were generally found in sediments near urban areas and may have been due to discharges of urban runoff from storm sewers. There are several possible sources of PAHs, including forest fires, combustion of fossil fuels, petroleum contamination, wood treatment facilities using creosote, and urban runoff (Hoffman et al. 1984; Menzie et al. 1992; Christensen and Zhang 1993). Most of the PAHs are ubiquitous in urban runoff and also have a substantial source from forest and range fires (Menzie et al. 1992). Hoffman et al. (1984) reported that urban runoff entering Narragansett Bay accounted for 71 percent of the total inputs for higher molecular weight PAHs and 36 percent of the total PAHs. Aluminum smelting also represents another source of PAHs (e.g., Näf et al. 1992). PAHs were most frequently detected at the highest concentrations at station D19, immediately downstream of the aluminum smelter in Longview, a potential source of these organic compounds. The three aluminum smelters that discharge directly to the lower Columbia River (located at RMs 63 in Longview, 103 in Vancouver, and 120 in Troutdale) are required to monitor the effluent concentration of the PAH benzo(a)pyrene. However, atmospheric discharge of PAHs from these facilities may also be a significant, but indirect, source of PAHs to the river.

Historical measurements of the sediment concentrations of PAHs in lower Columbia River sediments have revealed detectable concentrations of total and individual PAHs at a number of locations (Tetra Tech 1992a). Total PAH concentrations have been reported for Chinook (USACOE 1991) (maximum of 552 μg/kg), Tongue Point (Young et al. 1988) (maximum of 1510 μg/kg), Longview (Johnson and Norton 1988) (maximum concentration of 19,000 μg/kg), and St. Helens (USACOE 1991) (maximum concentration of 979 μg/kg). Although many specific PAH compounds were typically below the reported laboratory detection limits, several PAHs were detected at a number of locations in the lower river (Tetra Tech 1992a). The PAH compounds benzo(a)anthracene (159 μg/kg), benzo(b)fluoranthene (127 μg/kg), benzo(k)fluoranthene (134 μg/kg), benzo(g,h,i)perylene (173 μg/kg), benzo(a)pyrene (223 μg/kg), chrysene (76 μg/kg), phenanthrene (72 μg/kg), and pyrene (260 μg/kg) were detected in sediments collected from Cathlamet Bay (Fuhrer and Horowitz 1989). Although many of the sediment concentrations of specific PAH compounds reported by Johnson and Norton (1988) were qualified as estimates due to blank contamination, concentrations reported for samples collected below Reynolds Metals in Longview were relatively high and often exceeded the Ontario effects-based reference value of 2,000 μg/kg used in this study. The highest concentrations were reported for fluoranthene (2,100 μg/kg), pyrene (2,500 μg/kg), benz(a)anthracene (2,200 μg/kg), chrysene (4,100 μg/kg), benzo(b)fluoranthene (1,800 μg/kg), benzo(k)fluoranthene (910 μg/kg), benzo(a)pyrene (1,500 μg/kg), indeno(1,2,3-cd)pyrene (920 μg/kg), and benzo(g,h,i)perylene (1,100 μg/kg) (Johnson and Norton 1988).

Pesticides and PCBs. Pesticides were detected throughout the river and included DDT compounds, heptachlor, aldrin, dieldrin, mirex, dacthal, methyl parathion, parathion, malathion, endrin, and lindane compounds (i.e., alpha-, delta-, and gamma-BHC). The occurrence of pesticide residues in the sediments may be due to agricultural usage or pesticide-handling facilities in the Columbia River basin. Most of the chlorinated pesticides are no longer used in the United States, and their presence in the sediments may therefore represent residual concentrations from past usage rather from recent applications. This residual, however, may be present over large areas of the Columbia River basin above Bonneville Dam and may continue to act as a source to the lower river. No source could be identified to explain the particular distribution of high concentrations of pesticides near station E8, although a chemical manufacturer of fertilizers (Chevron Chemical Co.) is located near this site. As suggested earlier in the discussion, it is recommended that the identification of the pesticides be confirmed through additional studies.

Historical measurements of pesticides in lower Columbia River sediments indicated the presence of several pesticides, including DDT compounds, aldrin, chlordane, and endrin aldehyde (Tetra Tech 1992a). DDT compounds were detected in Oregon Slough, including DDD (3.6 μg/kg) and DDE (2.6 μg/kg), but DDT was not detected (DL=1.0 μg/kg) (USACOE 1991). DDT compounds were also reported at relatively high levels in sediments collected from the Columbia River 1 mile above the confluence with the Willamette River (U.S. EPA unpublished STORET data). The concentrations of DDD, DDE, and DDT reported in STORET were 68, 22, and 103 μg/kg, respectively. Aldrin was detected in sediments collected from Baker Bay at a concentration of 1.5 μg/kg (Fuhrer and Rinella 1983). Chlordane has been detected in sediments collected near Chinook (4 μg/kg) and in Baker Bay (2 μg/kg) (Fuhrer and Rinella 1983). Endrin aldehyde was also detected near Chinook at a maximum concentration of 310 μg/kg (USACOE 1991).

Although the laboratory detection limits were occasionally rather high, analyses for the pesticides dieldrin, endrin, endosulfan compounds, heptachlor, heptachlor epoxide, methoxychlor, mirex, lindane and isomers (alpha, beta, delta, and gamma), perthane, silvex, toxaphene, 2,4-D, 2,4,5-T, and 2,4-DP indicated that these pesticides were generally below the laboratory detection limits achieved in these studies (Tetra Tech 1992a).

PCBs (as Aroclor 1254) were only detected at station D19 below Longview (85 μg/kg). PCBs were used in many locations and processes in the past and hence have been found historically in almost all urban, and many industrial discharges. PCBs have been used as insulators and lubricants in transformers, capacitors, and other electrical equipment. Although the manufacture and importation of PCBs has been prohibited in the United States, transformers manufactured or imported prior to the ban are still in use and continue to be a potential source of these compounds. PCBs are also slowly degraded in the environment and are known to bioaccumulate. Therefore, it is likely that PCBs are present in depositional areas near many urban areas, near former PCB production facilities, and near areas that contain power transformers.

Johnson and Norton (1988) reported detectable concentrations of PCBs (quantified as Aroclor 1254, the same PCBs that were detected at station D19 in this study) at a sampling location below Reynolds Metals in Longview (73 μg/kg) and below the ALCOA aluminum facility in Vancouver (58 μg/kg). PCBs have been detected at a number of other locations in the lower Columbia River at concentrations ranging from 2 μg/kg (total PCBs) in Cathlamet Bay (Fuhrer and Horowitz 1989) to 30 μg/kg (total PCBs) in Baker Bay (Fuhrer and Rinella 1983).

Dioxins and Furans. Of the organic chemicals detected in sediments from the study area, the polychlorinated dibenzodioxins (PCDDs) and the polychlorinated dibenzofurans (PCDFs) were the most frequently detected compounds. These compounds were detected in every sample collected, indicating that they are widespread in the river. Entry of PCDDs and PCDFs into the environment has been associated with chlorophenol production, wood-treating facilities, aerial application of phenoxy herbicides (2,4-D and 2,4,5-T) (i.e., the contaminant of concern in agent orange), effluent discharge from chlorine-bleach kraft pulp mills and chlorinated municipal sewage treatment plants, and from combustion processes including fires (Czuczwa and Hites 1984). Macdonald et al. (1992) determined that the predominant source of octachlorodibenzo-*p*-dioxin (OCDD) in sediments collected from Howe Sound, British Columbia was the atmosphere and that the predominant source of 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF) was bleached kraft pulp and paper mill effluent discharges. Comparatively high concentrations of PCDDs and PCDFs occurred at stations downstream of the Multnomah Channel, and the cities of St. Helens and Longview. Each of these locations is associated with pulp mill discharges, which are known sources of PCDDs and PCDFs. Currently, only the four bleach kraft pulp and paper mills that discharge directly to the lower Columbia River (including the city of St. Helens that receives and treats treated pulp mill wastewater) and the wastewater treatment plant serving the city of Portland are required to monitor and report the effluent concentrations of dioxins and furans in their effluent (Tetra Tech 1991c).

Historical measurements of sediment dioxin and furan concentrations have recently been conducted (1990), exclusively in locations near the five pulp and paper mill sources of these compounds (i.e., Wauna, Longview, St. Helens, and Camas) (Tetra Tech 1992a). The highest concentrations of dioxins and furans were measured at collection sites near Wauna and Longview. The dioxin 2,3,7,8-TCDD was not detected above the laboratory detection limits, which ranged from 0.38 to 5.4 pg/g, at any of the stations sampled. The highest concentration of 2,3,7,8-TCDF (1.1 pg/g) was measured at a station near Wauna (RM 39.7) below the James River pulp and paper mill. The highest concentration of OCDD (220 pg/g) was measured upstream of the James River pulp and paper mill at RM 43.2. These results are comparable to those of the reconnaissance survey which generally reported the detection of 2,3,7,8-TCDD at concentrations below the concentration of 0.35 pg/g; 2,3,7,8-TCDF at concentrations ranging from 0.06 to 2.94 pg/g; and OCDD at concentrations ranging from 6.76 to 1,480 pg/g.

Organotin Compounds. The detection of organotins, used as biocides in antifouling coatings for boats, ships, and submerged structures, in sediments from 7 of 10 stations analyzed for these compounds reflects the proximity of these stations to marinas and facilities associated with boat painting and repair. No historical measurements of butyltin compounds in sediments of the lower Columbia River were identified by Tetra Tech (1992a) for comparison with these data. The sediment study of lower Columbia River port areas conducted by the WDOE did not include analyses of sediment organotin levels (Johnson and Norton 1988). Sediment organotin studies conducted in other areas have shown that the levels of butyltin compounds are directly related to boating and shipping activity, with the highest levels typically measured in marinas, berthing and mooring areas, and ship yards (e.g., Dowson et al. 1992; Espourteille et al. 1993). The highest concentrations measured in these studies ranged from 3,935 μg/kg of tributyltin in sediments collected from a marina in an estuary in the United Kingdom (Dowson et al. 1992) and 4,000 μg/kg of tributyltin in marina sediments from Hampton Roads in Chesapeake Bay (Espourteille et al. 1993). The highest concentrations of organotin compounds measured in this study occurred between Portland and Longview, a reach of the river that receives heavy use by recreational boaters and commercial shipping traffic. The second highest concentration measured in the present study 28 μg/kg of ethyl tributyltin which was measured at station D19 below Longview. The highest concentration of 100 μg/kg of triethyl butyltin was also measured at this station. A number of marinas and drydocking facilities are located in Portland, Vancouver, and Longview and may be sources of organotins in the study area.

Measurements of butyltin compounds in the tissues of bivalve mollusks (*Mytilis edulis*) collected from the North and South jetties at the mouth of the Columbia River have been made since 1988, as part of NOAAs National Status and Trends Mussel Watch Project (Uhler et al. 1993). Concentrations of tributyltin in bivalve tissues ranged from 0.26 to 0.49 $\mu g/g$ (as dry weight). The highest total butyltin levels (tri-, di-, and monobutyltin) were measured at the North Jetty in 1988-1989 (1.26 $\mu g/g$) and at the South Jetty in 1989-1990 (0.57 $\mu g/g$). Of the 24 West Coast sites for which data were available for 1988-1989, the reported total butyltin concentration of 1.26 $\mu g/g$ reported for the North Jetty was exceeded at six sites. The highest concentration reported for 1988-1989 was 4.98 $\mu g/g$ from Squalicum Marina Jetty located in Bellingham Bay. Of the 41 West Coast sites for which data were available for 1989-1990, the concentration of 0.57 $\mu g/g$ reported for the South Jetty was exceeded at nine sampling sites. The highest concentration reported in 1989-1990 was 9.05 $\mu g/g$ from Keehi Lagoon located in Honolulu Harbor.

3.7.4.2 Significance and Recommendations. In general, the sediment organic compound concentration data gathered as part of the reconnaissance survey was superior to that of the water column sampling results due to the detection and quantification of a larger number of organic contaminants. This is due to the combination of the relatively higher concentrations of these contaminants in sediments and the ability of the analytical laboratory to more easily achieve detection limits low enough to quantify a larger number of the compounds present in the sediments. The compound bis(2-ethylhexyl)phthalate was the only contaminant that was detected in both water and sediments. The following is a discussion of the significance of the particular organic compounds detected in sediments collected for the reconnaissance survey. General recommendations similar to those made for the results of the water column survey (Section 2.7.5.1) will then be made.

Bis(2-ethylhexyl)phthalate — Although bis(2-ethylhexyl)phthalate is thought to occur as a laboratory contaminant, sediment concentrations at several location exceeded the concentration that could reasonably be attributed to blank contamination. This compound was also reported as detected in two water samples collected during the reconnaissance survey. This compound appears to be distributed throughout the lower river, but without an effects-based reference level it is not possible to determine the potential effect of this compound on humans and wildlife. However, the concentrations at the two water column stations where bis(2-ethylhexyl)phthalate was detected (station W26 and W37) exceeded the chronic marine and freshwater criteria for the protection of aquatic organisms.

PAHs — Based on the reconnaissance survey data, PAHs appear to be distributed throughout the river. Based on the available effects-based reference levels used in this study, effects to aquatic biota due to exposure to sediments at several locations may adversely affect aquatic biota, especially fine-grained sediment locations directly below aluminum smelters.

PCBs — PCBs (Aroclor 1254) were detected at one station, station D19. PCBs have been detected in this same area during a previous sediment investigation conducted by WDOE (Johnson and Norton 1988). The concentration reported also exceeded the effects-based reference levels adopted for this study; therefore, sediment contamination by PCBs in sediments of the lower Columbia River warrant further study.

Dioxins and Furans — Although no effects-based reference levels were available for dioxins and furans measured in this study, it should be mentioned that the Columbia River has recently been identified as water quality limited due to the prediction that water column dioxin (2,3,7,8-TCDD) concentrations exceed the water column criteria for the consumption of contaminated fish and water (0.013 pg/L) and the finding that Columbia River fish tissue levels of 2,3,7,8-TCDD exceeded the human cancer risk factor of an increase of one additional cancer for a population of 1 million people for consumption of Columbia River fish (U.S. EPA 1991c,d). This prediction was based on modeling inputs of 2,3,7,8-TCDD to the Columbia River from chlorine-bleached pulp and paper mill effluents to the mainstem of the river and on analysis of the dioxin levels in fish tissue samples collected from the river (U.S. EPA 1991c,d). Eleven chlorine-bleaching pulp mills currently discharge to the Columbia River system. These mills are located in Canada (1), Idaho (1), Washington (4), and Oregon (3). Five major pulp and paper facilities discharge chlorine-bleach process effluent directly to the lower Columbia River below Bonneville Dam (Tetra Tech 1992c). The U.S. EPA has developed a total maximum daily load (TMDL) which will regulate the discharge of dioxin from U.S. pulp and paper mills in the Columbia River basin to reduce the level of 2,3,7,8-TCDD below the water quality standard (U.S. EPA 1991c,d). Further investigations are being conducted by U.S. EPA Region X and the states of Oregon and Washington to provide additional information for the refinement of the TMDL and to monitor the effect of the regulatory actions that have been implemented.

Organotin Compounds — Organotin compounds, especially tributyltin, are highly toxic. Although effects-levels for butyltin concentrations in sediments are not available, effects on the sexual development of mud snails (*Ilyanassa obsoleta*) have been observed at water concentrations as low as 0.020 μg/L (Bryan et al. 1989). An estimate of the acceptable daily human intake (ADI) of tributyltin for an adult of 3.2 μg/kg of body weight has been suggested (Schweinfurth and Gunzel 1987). Although the sediment organotin concentrations measured in this study are generally much lower than concentrations reported for highly contaminated areas investigated in other studies, further study of organotin compounds in the lower Columbia River may be warranted. However, organotin use has been restricted following the Organotin Antifouling Paint Control Act of 1988 [see Huggett et al. (1992) for a review of TBT legislation and risk assessment]; therefore, the present levels of these compounds are likely to decline (albeit slowly) over time. Although the preliminary results of tissue analyses of bivalve mollusks as part of NOAAs National Status and Trends program indicates that butyltin levels are decreasing in some areas, in some cases increases were also noted (Uhler et al. 1993). However, Uhler et al. (1993) suggested that if tributyltin inputs are reduced, environmental levels are expected to decline over a period of one to five years.

Overall Significance and Recommendations. The importance of historical discharges from both point and nonpoint sources is most evident for the sediment organic data. The organotins and many of the pesticides detected have been banned or their use has been restricted, yet they have persisted and are still detectable in sediments of the lower Columbia River. Furthermore, the sediment concentrations of these pesticides often exceed the effects-based reference levels adopted for this study. It also appears that some of these compounds may have a significant atmospheric source (e.g., PAHs, OCDD).

In general, recommendations for further sediment studies reflect the recommendations provided in the water column section (Section 2.7.5.1). Relevant questions for further research include the following:

- What are the major sources (point and nonpoint sources) of organic compounds to the river?
- What are the effects of these organic compounds on the biota?
- Are the forms of the organic compounds in the water column available to the biota?

- Are some organic compounds and their various forms more available than others?

- Which is the most important pathway (water column or sediments) for organic contaminant exposure and accumulation?

- What are the residence times of these organic compounds?

- How and in what forms are organic compounds transported through the river system?

- What is the fate of the organic compounds delivered to the river?

Answers to these questions are essential for identifying the most important sources of specific organic compounds, and the acceptable limits of the input of these contaminants, in the lower Columbia River system. An integrated monitoring program of organic contaminants in the lower Columbia River, and the various point and nonpoint sources should be performed on a seasonal basis to improve the understanding of the sources, forms, and fate of organic contaminants in the lower Columbia River.

3.7.5 Areas of Concern

At present it is difficult to identify areas of concern within the lower Columbia River using sediment contaminant concentrations as the basis for selection of impaired sites. Although sediment quality guidelines are in the process of being developed and adopted by state and federal regulatory agencies, there are currently no accepted criteria or guidelines for application to the freshwater sediments of the lower Columbia River. Furthermore, the guidelines adopted for application in this study included only a limited number of metals and organic compounds. Specific compounds for which no sediment concentration guidelines were available included dioxins, furans, and organotin compounds. The evaluation was further hampered by the laboratory detection limits achieved in this study. Although the detection limits achieved by the contract laboratories were generally typical of the conventional laboratory methods used, several of the detection limits were similar to or above the reference guideline concentrations adopted for this study. This was particularly true for the pesticides analyzed in this study. However, with the above qualifications several potential problem areas of the greatest concern may be identified based on the reconnaissance survey sediment data. The stations identified below are those with the highest number of potentially elevated metals concentrations, detections of organic contaminants, and the highest number of exceedances of the effects-based reference values (see Table 3-10).

- **Station D6 located in Grays Bay at RM 21.** Sediment concentrations of five metals (arsenic, cadmium, iron, nickel, silver) were potentially elevated due to anthropogenic sources, and the sediment concentrations of all five of these metals exceeded the effects-based reference values adopted for this study.

- **Station D16 in Coal Creek Slough at RM 58.** Sediment concentrations of three metals (aluminum, arsenic, mercury) were potentially elevated due to anthropogenic sources, and two pesticides of anthropogenic origin were detected in the sediments. The sediment concentrations of three of these constituents (copper, 4,4'-DDE, delta-BHC) exceeded the effects-based reference values adopted for this study.

- **Station D19 located below Longview at RM 63.** Sediment concentrations of two metals (aluminum and copper) were potentially elevated due to anthropogenic sources; and one organotin compound, eight PAHs, and one PCB compound, all of anthropogenic origin, were detected in the sediments. The sediment concentrations of five of these constituents [benzo(a)anthracene, chrysene, pyrene, total PAHs, and PCB (Aroclor 1254)] exceeded the effects-based reference values adopted for this study.

- **Station D22 located above Kalama at RM 76.** Sediment concentrations of six metals (aluminum, cadmium, copper, lead, mercury, and zinc) were potentially elevated due to anthropogenic sources, and three pesticides (heptachlor, alpha-BHC, methyl parathion) of anthropogenic origin were detected in the sediments. The sediment concentrations of three of these constituents (cadmium, copper, zinc) exceeded the effects-based reference values adopted for this study.

- **Station E8 located above Sandy Island at RM 77.** The sediment concentration of one metal (arsenic) was potentially elevated due to anthropogenic sources, and two PAHs and six pesticides of anthropogenic origin were detected in the sediments. The sediment concentrations of three of these constituents (4,4'-DDT; dieldrin; endrin) exceeded the effects-based reference values adopted for this study.

- **Station E9^{D} located approximately 2 RMs below the city of St. Helens, OR at RM 83.** The sediment concentrations of two metals (aluminum, mercury) were potentially elevated due to anthropogenic sources, and nine PAHs and three pesticides of anthropogenic origin were detected in the sediments. The sediment concentrations of two of these constituents (4,4'-DDT and aldrin) exceeded the effects-based reference values adopted for this study.

- **Station D24 located in the St. Helens Marina at RM 85.** The sediment concentrations of two metals (aluminum and mercury) were potentially elevated due to anthropogenic sources, and eight dioxin and furan compounds, ten PAHs, and five pesticides of anthropogenic origin were detected in the sediments. The sediment concentrations of three of these constituents (pyrene; total PAHs; 4,4'-DDE) exceeded the effects-based reference values adopted for this study.

- **Station D35 located in Camas Slough at RM 118.** The sediment concentrations of five metals (arsenic, cadmium, copper, mercury, zinc) were potentially elevated due to anthropogenic sources, and four pesticides of anthropogenic origin were detected in the sediments. The sediment concentrations of five of these constituents (cadmium, copper, zinc, 4,4'-DDE, alpha-BHC) exceeded the effects-based reference values adopted for this study.

3.8 SUMMARY

Of the locations sampled during the survey, the reach from RM 58 (the area below Longview) to RM 80 (the area of St. Helens) appeared to be unique in both the number of substances detected and the number of substances that exceeded naturally occurring concentrations and effects-based reference values. These concentrations may reflect the fact that the area downstream of station D25 consisted of relatively finer sediments than the reach between the Willamette River and station D25. The occurrence of finer sediments below station D25 could indicate a depositional area for both local inputs and for inputs from the large Portland/Vancouver metropolitan area. Station E8 was particularly interesting because of the number of chlorinated pesticides detected in these sediments, although this site was relatively coarse-grained and hence would not be expected to accumulate these compounds as readily as the finer sediments upstream and downstream of this station. Station $E9^D$ (reclassified as a fine-grained station), which was upriver from station E8, also contained a number of pesticides and PAHs. At Station $E9^D$, an oil sheen was visible during sample collection. Station D19 below Longview also had a somewhat unique group of compounds that may reflect local inputs from shore-based industries and municipal development.

4.0 TISSUE BIOACCUMULATION

4.1 INTRODUCTION

The concentration of anthropogenic chemicals in aquatic organisms is of great environmental concern. First, there is concern among federal and state agencies and the public about the potential human health risks from consuming chemically contaminated fish and shellfish. A 1989 survey of 50 states and the District of Columbia showed that 37 states reported having waterbodies under some type of advisory restricting fish or shellfish consumption due to elevated tissue levels of pesticides, PCBs, or metals (Reinert et al. 1991). Second, there is concern about the potential for adverse impacts to wildlife populations resulting from the consumption of prey containing chemical contaminants. Henny et al. (1981) found elevated levels of PCBs and organophosphorus pesticides in mink (*Mustela vison*) and otters (*Lutra canadensis*) collected along the lower Columbia river and suggested that population declines of these species might be attributed to reproductive failure due to the consumption of PCB-contaminated fish. Impairment of reproductive success of predatory birds, such as the bald eagle (*Haliaetus leucocephalus*) and osprey (*Pandion haliaetus*), due to the biomagnification of organochlorine pesticides has been documented in many areas of the United States (McGarigal et al. 1991). Within the lower Columbia River Basin, the U.S. Fish and Wildlife Service has detected dioxin in the eggs of bald eagles nesting near the river (U.S. Fish and Wildlife Service 1991, unpublished data). Finally, there is concern that physiological or behavioral responses of aquatic species may be impaired by the exposure and accumulation of toxic chemicals in tissues.

The two primary objectives of the tissue component of the reconnaissance survey were to:

- Characterize the distribution and levels of contaminants of concern in selected indicator organisms

- Collect tissue contaminant data that could be used to support future preliminary assessments of ecological risks and potential risks to human health from the consumption of fish.

Five species were selected for analysis in this study: crayfish *(Pacifastacus leniusculus)*, common carp (*Cyprinus carpio*), largescale sucker (*Catostomus macrocheilus*), peamouth (*Mylocheilus caurinus*), and white sturgeon *(Acipenser transmontanus)*. They were selected because their feeding characteristics, fat content, and/or longevity suggested *a priori* that they might have higher contaminant levels than other aquatic species. Other factors considered as part of the selection process were the mobility, or presumed ranges, of the organisms and whether or not they were preyed upon by key wildlife species or humans.

Crayfish are omnivorous scavengers that feed on vegetation, detritus, and fresh or decomposed carrion (Wetzel 1975; Barnes 1987; Mitchell and Smock 1991). Adults generally remain hidden in burrows, or beneath stones or other debris in the daytime and generally move about and feed between dusk and dawn (Pennak 1978). Crayfish can be an important component of the diet of predatory fish (Mitchell and Smock 1991) and are harvested commercially and recreationally from the lower Columbia river for human consumption. A total of 22,011 pounds of crayfish were harvested commercially during 1991 from waters of the three Oregon counties that adjoin the lower Columbia River (i.e., Clatsop, Columbia, and Multnomah counties) (Lukas, J., 11 May 1993, personal communication). Crayfish were selected as an indicator organism because they are a food source for aquatic and terrestrial wildlife; they are harvested from the lower Columbia river for human consumption; they are bottom-dwelling organisms; and they are assumed to have relatively limited ranges.

Common carp, a species of minnow native to Asia, were introduced to North America (possibly as early as 1831) because of their suitability for pond culture and their use as a food fish (Scott and Crossman 1973). The first introduction of this fish to the Pacific Northwest occurred in 1882; the lower Columbia River was populated by carp by 1894 (Wydoski and Whitney 1979). Carp are omnivorous and consume plant and animal tissue and may selectively feed on bottom ooze and detritus. Animal prey items include aquatic insects, crustaceans, annelids, and molluscs (Scott and Crossman 1973). Carp are preyed upon by predaceous fish and birds (Scott and Crossman 1973; Watson et al. 1991) and may also be consumed by humans. Carp are thought to be fairly long-lived; an upper limit of 20 years has been suggested as the normal life span of a North American carp (Scott and Crossman 1973). Wydoski and Whitney (1979) report that the oldest recorded specimen collected from natural waters was 15 years old. Carp were selected as an indicator organism primarily because they are a bottom-feeding fish with a relatively high lipid content and they have been documented to readily bioaccumulate hydrophobic organic pollutants (Schmitt et al. 1990).

The largescale sucker is a bottom fish native to the Pacific Northwest. Spawning occurs during April and May in shallow water with a gravel or sand bottom. The adhesive eggs are broadcast and settle to the bottom (Wydoski and Whitney 1979). The small fry feed pelagically on small zooplankton and then become bottom dwellers as they grow and change their diet to aquatic insect larvae and plant material (Wydoski and Whitney 1979). Larger individuals feed on a variety of bottom organisms including crustaceans, aquatic insect larvae, earthworms, snails, and detritus (Wydoski and Whitney 1979). Largescale sucker are preyed upon by predaceous fish and birds (Scott and Crossman 1973; Watson et al. 1991) and may also be consumed by humans. The largescale sucker may live as long as 11 years and reach a length of 24 inches (9.4 cm) and a weight of 7 pounds (3.2 kg) (Wydoski and Whitney 1979). Largescale sucker were selected as an indicator organism primarily because they are a bottom-feeding fish which, unlike carp, could be captured throughout the study area.

Peamouth are a species of chub that are native to rivers and lakes of northwestern North America. They spawn in gravel-covered areas of shallow water in May and early June. The eggs are broadcast on the bottom where they adhere to the substrate and hatch in 7 to 8 days (Wydoski and Whitney 1979). The fish prefer weedy shallows in spring, summer, and fall, although it may seek deeper water in winter (Scott and Crossman 1973, Wydoski and Whitney 1979). Peamouth are tolerant of brackish water and can therefore be captured in the estuarine portion of the lower Columbia River. Young fish feed on zooplankton, while older fish feed both pelagically and on the bottom on a variety of plant and animal matter which includes plankton, aquatic and terrestrial insects, snails, and occasionally small fish such as sculpins (Wydoski and Whitney 1979). The shallow water spawning habits of this fish make it particularly susceptible to predation by fish-eating birds and mammals (Scott and Crossman 1973). Watson et al. (1991) reported that peamouth, along with other fish from the Columbia River, including largescale sucker, common carp, and American shad comprised over 60 percent of the diet of bald eagle nestlings along the lower Columbia River estuary. The peamouth may live 13 years or longer and reach 14 inches (5.5 cm) in length (Wydoski and Whitney 1979). The extent to which peamouth are presently consumed by humans along the river is not known; however, historically this fish was served in hotels of the Columbia River Basin (Wydoski and Whitney 1979). Peamouth were selected primarily because their diet and feeding habits differ from carp. They occur throughout the study area, are an important component of the diet of bald eagles, other wildlife, and game species of fish, and they have relatively high lipid contents.

The white sturgeon is the largest North American sturgeon and is native to the Pacific Northwest. The movements of these fish in freshwater is not well understood, although in the Columbia River they appear to travel upstream in late summer and fall to exploit dying salmon runs and downstream in spring and early summer to exploit smelt runs in Pacific coastal rivers (Haynes et al. 1978). The fish seem to prefer free-flowing habitats and tend to occur shallower in the water column during periods of maximum activity and movement in summer and deeper during minimum activity in winter (Hayes et al. 1978). Spawning occurs in the Columbia River from May through July and females may contain over a million eggs (Wydoski and Whitney 1979). The white sturgeon is primarily a bottom feeder. The food of smaller sturgeons is primarily chironomids and to a lesser degree crustaceans, molluscs, and aquatic insect larvae (Scott and Crossman 1973). Stomach content analysis performed on white sturgeon collected at RM 131 in the lower Columbia River indicated that fish less than 350 mm long (fork length) fed primarily on *Corophium salmonis*, but eggs of eulachon (*Thaleichthys pacificus*) and mysid shrimp (*Neomysis mercedis*) were also important during certain months (McCabe and Hinton 1990b). Relatively larger sturgeon (351 to 725 mm fork length) fed on eulachon eggs and *Corophium* in May and June, the asian clam *Corbicula fluminea* during May through August, and *Corophium* and chironomid larvae during September and October (McCabe and Hinton 1990b). Larger specimens are primarily predaceous and feed on fish and crayfish (Scott and Crossman 1973). This species is long-lived, with one fish collected from the Columbia River determined to be 82 years old (Wydoski and Whitney 1979). Scott and Crossman (1973) suggest that larger specimens may be over 100 years old. White sturgeon were selected for analysis because they are long-lived, and therefore have the potential to accumulate high levels of tissue contaminants, and because they are harvested commercially and recreationally from the lower Columbia River for human consumption. In 1991, the recreational and commercial catch of sturgeon on the lower Columbia River was 20,730 and 3,784 fish, respectively (Melcher and King 1992; Washington Department of Fisheries and Oregon Department of Fish and Wildlife 1992).

4.2 SAMPLING LOCATIONS

Crayfish, carp, peamouth, largescale sucker and white sturgeon were collected during the reconnaissance survey for analysis of tissue chemical burdens. Crayfish and largescale sucker were collected at 18 locations, and carp and peamouth at 12 locations along the lower Columbia River. Approximate fish and crayfish collection areas are shown in Figures 1-1 through 1-4 in Section 1.2. Collection dates and geographic coordinates for the collection areas are given in Tables 4-1 and 4-2.

Crayfish, carp, largescale sucker, and peamouth were collected near sediment sampling locations designated as fine-grained stations, with the exception of the samples collected near sediment sampling station D38 (near Reed Island) which was reclassified as a coarse-grained sediment station (see Section 3.6.1.2). [Note: This station will be identified as D38^E in the following text.] Crayfish were collected close to sediment sampling sites. However, to obtain adequate numbers of fish for analyses, collections of carp, peamouth and largescale sucker occurred approximately within a 1-mile range of the sediment sampling stations. Crayfish and fish collection locations have been given the same station designations as the sediment stations due to the proximity of these areas. Table 4-3 shows the stations and species that were analyzed for tissue chemistry.

Commercially caught white sturgeon from each of the four major river segments were obtained from fish processors located along the lower Columbia River. A total of 17 sturgeon were collected between RM 15 and 136 (see Table 4-4). The approximate river mile location for sturgeon capture is shown in Table 4-4.

The following general considerations were used to choose sampling locations for crayfish, carp, peamouth, and largescale sucker:

- Achieving broad-scale coverage to gain an overall characterization of tissue chemical burdens in the lower Columbia River;
- Obtaining data on tissue chemical burdens in biota inhabiting wildlife refuges, areas around known point source discharges, and putative reference areas;
- Assessing tissue chemical burdens of relatively immobile species in relation to chemical contamination in the surrounding sediments;

TABLE 4-1. LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY: LOCATIONS AND TIME OF CRAYFISH SAMPLING

(Page 1 of 2)

Station	River Mile	Latitude/Longitude	Date/Time Traps Deployed	Date/Time Traps Retrieved	Number of Crayfish Retained for Analysis
D6	23.0	46-16-02.1N 123-40-25.8W	9-30-91 1300	10-1-91 1005	31
D8	27.7	46-13-38.8N 123-34-35.6W	9-29-91 1650	9-30-91 1200	31
D10	38.0	46-12-35.5N 123-26-35.1W	9-29-91 1600	9-30-91 1100	31
D12	38.5	46-12-20.9N 123-23-25.2W	9-29-91 1500	9-30-91 1000	10
D15	50.5	46-09-21.3N 123-13-56.6W	9-28-91 1400	9-28-91 1720	9
			9-28-91 1720	9-29-91 1320	23
D16	57.5	46-11-15.3N 123-05-28.1W	9-28-91 1330	9-28-91 1700	5
			9-28-91 1715	9-29-91 1240	26
D19	63.0	46-08-17.3N 123-00-28.5W	9-28-91 1245	9-29-91 1130	30
D20	71.5	46-03-28.4N 122-52-16.1W	9-30-91 1830	10-1-91 1230	21
D22	75.0	46-00-34.8N 122-50-55.6W	9-27-91 1700	9-28-91 1130	8
			9-28-91 1150	9-29-91 1025	10
D23	79.5	45-57-20.1N 122-48-15.8W	9-27-91 1650	9-28-91 1050	12
D24	85.5	45-52-22.5N 122-47-54.9W	9-27-91 1600	9-28-91 1000	0
			9-28-91 1030	9-29-91 0730	1
			9-29-91 0800	9-30-91 1700	30
D26	92.5	45-46-52.5N 122-46-09.3W	9-26-91 1845	9-27-91 1735	32
D28	98.5	46-41-39.4N 122-45-55.2W	9-25-91 1720	9-26-91 1920	24
D29	102.5	45-38-57.9N 122-44-42.1W	9-25-91 1650	9-26-91 2015	30

TABLE 4-1. LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY: LOCATIONS AND TIME OF CRAYFISH SAMPLING

(Page 2 of 2)

Station	River Mile	Latitude/Longitude	Date/Time Traps Deployed	Date/Time Traps Retrieved	Number of Crayfish Retained for Analysis
D31	107	45-36-14.2N 122-40-18.3W	9-24-91 1730	9-25-91 1450	12
D35	118.0	45-34-36.7N 122-26-48.2W	9-24-91 1630	9-25-91 1400	61
D38	125.0	45-33-23.7N 122-20-00.4W	9-24-91 1400	9-25-91 1200	2
			9-25-91 1300	9-26-91 0900	30
D40	141.0	45-37-27.9N 122-01-09.8W	9-24-91 1200	9-25-91 0930	5
			9-25-91 0845	9-25-91 1830	2
			9-26-91 0800	9-27-91 1030	2

TABLE 4-2. LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY: LOCATIONS AND DATE OF FISH SAMPLING

(Page 1 of 2)

Station	River Mile	Station Coordinates	Fish Caught	Date
D40	141.5	45-37-20.5N 122-01-13.7W	5 carp[a] 8 sucker[a]	14 Oct 91
D38	125.5	45-33-32.5N 122-19-03.6W	5 carp[a] 6 sucker[a]	15 Oct 91
D35	118.5	45-34-28.4N 122-26-23.9 W	5 carp[a] 1 peamouth 5 sucker[a]	15 Oct 91
D31	107.5	45-36-33.8N 122-40-33.2W	5 carp[a] 5 sucker[a]	17 Oct 91
D29	101.0	45-40-07.0N 122-44-54.7W	5 carp[a] 2 peamouth 5 sucker[a]	16 Oct 91- 17 Oct 91
D28	98.0	45-42-15.7N 122-45-35.3W	5 carp[a] 5 peamouth[a] 6 sucker[a]	17 Oct 91
D26	92.5	45-46-52.5N 122-46-09.3W	5 carp[a] 5 sucker[a]	19 Oct 91 19 Nov 91
D24	85.5	45-52-22.5N 122-47-54.9 W	5 carp[a] 5 peamouth[a] 5 sucker[a]	19 Oct 91
D23	79.5	45-57-20.1N 122-48-15.8W	5 carp 5 peamouth[a] 5 sucker[a]	20 Oct 91
D22	75.0	46-00-34.8N 122-50-55.6W	3 carp 5 sucker[a]	21 Oct 91 19 Nov 91
D20	71.1	122-52-02.6 N 46-03-39.3 W	5 peamouth[a]	19 Nov 91
D21	71.0	122-53-29.2 N 46-03-43.6 W	5 sucker[a]	21 Oct 91
D19	67.0	46-08-17.3N 123-00-28.5W	2 carp 7 peamouth[a] 5 sucker[a]	21 Oct 91- 23 Oct 91, 27 Oct 91
D16	57.5	46-11-15.3N 123-05-28.1W	8 peamouth[a] 5 sucker[a]	23 Oct 91, 27 Oct 91
D15	49.5	46-08-21.3N 123-13-56.6W	7 peamouth[a] 5 sucker[a]	23 Oct 91, 27 Oct 91
D12	38.0	46-12-20.9N 123-23-25.2W	5 peamouth[a] 1 carp 5 sucker[a]	24 Oct 91- 25 Oct 91
D10	38.0	46-12-35.5N 123-26-35.1W	5 peamouth[a] 5 sucker[a]	25 Oct 91

TABLE 4-2. LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY: LOCATIONS AND DATE OF FISH SAMPLING
(Page 2 of 2)

Station	River Mile	Station Coordinates	Fish Caught	Date
D8	20.0	46-13-38.8N 123-34-35.6W	5 sucker[a]	27 Oct 91
D6	22.5	46-18-02.0N 123-43-16.4W	5 sucker[a]	26 Oct 91
D4	5	46-15-58.86 N 123-58-15.66 W	none	26 Oct 91- 27 Oct 91
D3	15.5	46-09-56.0N 123-48-59.2W	9 peamouth[a]	26 Oct 91

[a] Five of these fish were analyzed.

TABLE 4-3. SAMPLING STATIONS FROM WHICH CAPTURED BIOTA WERE ANALYZED FOR TISSUE CHEMISTRY[a]

Station	Crayfish	Carp	Largescale Sucker	Peamouth
D1				
D2				
D3				X
D4				
D5				
D6	X		X	
D7				
D8	X		X	
D9				
D10	X		X	X
D11				
D12	X		X	X
D13				
D14				
D15	X		X	X
D16	X		X	X
D17				
D18				
D19	X		X	X
D20	X		X	
D21				X
D22	X		X	
D23	X	X	X	X
D24	X	X	X	X
D25				
D26	X	X	X	
D27				
D28	X	X	X	X
D29	X	X	X	
D30				
D31	X	X	X	
D32				
D33				
D34				
D35	X	X	X	
D36				
D37				
D38	X	X	X	
D39				
D40	X	X	X	

[a] White sturgeon tissue (filets) were obtained from commercial fish processors located along the lower Columbia River.

TABLE 4-4. LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY: WHITE STURGEON COLLECTION AREAS AND TISSUE CHEMICALS ANALYZED
(Page 1 of 2)

Sample No.	River Segment	Approx. River Mile	Location Caught	Tissue Chemicals Analyzed	Date Caught	Date Collected	Processor	Sex
ST-1-2-D	1B	18.5	Tongue Point, Oregon	Metals, semivolatiles, pesticides/PCBs, dioxins/furans	10/10/91	10/11/91	Bornstein, Astoria	Male
ST-1-3-D	1C	27	Caboth Drift (Woody Island Channel)	Metals, semivolatiles, pesticides/PCBs, dioxins/furans	10/1/91	10/3/91	Fishhawk Fisheries, Astoria	ND
ST-1-4	1A/1B	15	Estuary, below Tongue Point	Metals, semivolatiles, pesticides/PCBs	10/15/91	10/16/91	Bornstein, Astoria	Female
ST-1-5	1B	21	Frankfort, WA (mouth of Deep River)	Metals, semivolatiles, pesticides/PCBs	10/16/91	10/18/91	Pac. Coast Seafood, Astoria	ND
ST-1-5(dup)	1B	21	Frankfort, WA (mouth of Deep River)	Metals, semivolatiles, pesticides/PCBs	10/16/91	10/18/91	Pac. Coast Seafood, Astoria	ND
ST-1-6	1B	20	Deep River, WA	Semivolatiles, pesticides/PCBs	10/20/91	10/21/91	Pac. Coast Seafood, Astoria	ND
ST-2-1-D	2B	49	Wallace Island, OR	Metals, semivolatiles, pesticides/PCBs, dioxins/furans	10/10/91	10/11/91	Bornstein, Astoria	Male
ST-2-2-D	2C	67	Rainier, OR	Metals, semivolatiles, pesticides/PCBs, dioxins/furans	10/20/91	10/21/91	Fishhawk Fisheries, Astoria	Male
ST-2-3	2B	49	Wallace Island, OR	Metals, semivolatiles, pesticides/PCBs	10/21/91	10/22/91	Bornstein, Astoria	ND
ST-2-4	2B	49	Wallace Island, OR	Metals, semivolatiles, pesticides/PCBs	10/21/91	10/22/91	Bornstein, Astoria	ND

TABLE 4-4. LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY: WHITE STURGEON COLLECTION AREAS AND TISSUE CHEMICALS ANALYZED
(Page 2 of 2)

Sample No.	River Segment	Approx. River Mile	Location Caught	Tissue Chemicals Analyzed	Date Caught	Date Collected	Processor	Sex
ST-3-1-D	3A	75	Kalama Drift, WA	Metals, semivolatiles, pesticides/PCBs, dioxins/ furans	10/23/91	10/23/91	King Fish Trading Co., The Dalles	ND
ST-3-3-D	3A	75	Kalama Drift, WA	Metals, semivolatiles, pesticides/PCBs, dioxins/ furans	10/23/91	10/23/91	King Fish Trading Co., The Dalles	ND
ST-3-4	3A	75	Kalama Drift, WA	Metals, semivolatiles, pesticides/PCBs	10/25/91	10/26/91	King Fish Trading Co., The Dalles	ND
ST-3-6	3A	80	Martin Bluff (River Mile 80), WA	Metals, semivolatiles, pesticides/PCBs	10/29/91	10/30/91	S&S Seafood, Portland	ND
ST-4-1-D	4B	127	Warrendale, OR (downstream from Rooster Rock)	Metals, semivolatiles, pesticides/PCBs, dioxins/ furans	10/2/91	10/4/91	S&S Seafood, Portland	ND
ST-4-2	4B	136	Multnomah Falls, OR	Metals, semivolatiles, pesticides/PCBs	10/10/91	10/11/91	Fishhawk Fisheries, Astoria	ND
ST-4-3-D	4A	115	East of I-205 Bridge (north side of Government Island)	Metals, semivolatiles, pesticides/PCBs, dioxins/ furans	9/29/91	9/30/91	S&S Seafood, Portland	ND
ST-4-4	4A	103	Alcoa Al (downstream from Hayden Island)	Metals, semivolatiles, pesticides/PCBs	9/29/91	9/30/91	S&S Seafood, Portland	ND

- Preventing duplication of effort in areas where recent tissue bioaccumulation studies had been conducted by the Oregon Department of Environmental Quality (ODEQ);
- Taking into account the known distributions of the various target species in the study area.

More extensive details on the rationale for choosing sampling locations for each species are provided in Section 6.4 of the final sampling plan (Tetra Tech 1991c).

4.3 SAMPLING METHODS

The sampling methods employed for the collection of the crayfish and fish species are described in detail in Tetra Tech (1991a) and are briefly summarized below.

4.3.1 Crayfish

Crayfish were collected at 18 stations between September 24 and October 1, 1991, using crayfish traps baited with cat food. The dates and duration of trap deployment, and the number of crayfish retained for analysis from each station are shown in Table 4-1. Crayfish were removed from the traps and frozen on dry ice in the field. Each crayfish was weighed individually, wrapped in aluminum foil, and kept frozen on dry ice until delivery to the laboratory for tissue analysis.

4.3.2 Carp, Peamouth, and Largescale Sucker

Carp, peamouth, and largescale sucker were collected between October 14 and November 19, 1991, using a combination of electrofishing and gill-netting methods. Although the original intent was to collect carp (primarily a bottom feeder) and peamouth (primarily a pelagic feeder), these target species were not always found at all the pre-selected sampling locations. After further discussion with Bi-State Program members, largescale sucker (also a bottom feeder) was collected as an alternate species; it was available at all the sampling locations, with the exception of the estuary stations D3 and D4 (Table 4-2).

All captured fish were weighed, measured for length, wrapped in aluminum foil, and frozen on dry ice until delivery to the laboratory for tissue chemical analysis. Details of the fishing operation are provided in Section 4.2 of the Cruise Report (Tetra Tech 1991a).

4.3.3 White Sturgeon

Twenty white sturgeon were obtained from five fish-processing facilities located along the lower Columbia River. The processors obtained the sturgeon from fish buyers who, in turn, received the fish from commercial fishermen. The sturgeon were delivered to the buyer between 6 to 18 hours after capture and were assumed to have been stored on ice after being caught.

Most of the 20 sturgeon were individually weighed and measured for length before being cut into smaller filets (filets did not include internal organs or fat) by the processor. One filet from each fish was placed in a glass jar or double wrapped in aluminum foil, assigned a sample number, and kept frozen until delivery to the laboratory for tissue analysis. A second filet was also collected from one fish to serve as a duplicate for analysis.

4.4 LABORATORY METHODS

All tissue analyses were performed by contract laboratories approved by the Bi-State Program. Whole-body tissue chemical burdens were analyzed for station composite samples of five specimens of crayfish, carp, peamouth, and/or largescale sucker. For sturgeon, only the filet (i.e., no internal organs or fat) of separate individuals was analyzed following removal of exposed surface tissue. All tissue results were reported on a concentration-per-wet-tissue-weight basis.

Tissue metal burdens were analyzed by Precision Analytics Inc., of Pullman, WA. Dioxin and furan levels were analyzed by Keystone/NEA Environmental Resources, Inc., of Portland, OR. All other chemicals of concern (see Table 1-1) were analyzed by Alden Laboratories of Seattle, WA.

Tissue dioxin and furan levels were measured according to U.S. EPA Methods 8290 for extraction and cleanup, and Method 1613 for analysis. Tissue levels of metals and other chemicals of concern were also measured using U.S. EPA-approved methods (see Tetra Tech 1991b).

An extensive QA/QC review of the tissue chemistry data was performed according to the data validation guidance provided in U.S. EPA (1988a,b). QA/QC reviews of the data included assessments of sample holding times, initial and continuing calibration, blank results, interference check samples, matrix spikes, surrogate spikes and laboratory replicates. Some of the data were qualified based on this review. Results of the QA/QC reviews are summarized briefly below, and the complete review is provided under separate cover in the QA memoranda in Appendix A.

4.5 RESULTS

4.5.1 Species Size/Age Data

4.5.1.1 Crayfish. Wet weights of individual crayfish collected between RM 23 and RM 141 ranged from 2.7 to 132.4 g (Figure 4-1). The mean weight of individuals included in the composite samples analyzed ranged from 27.7 to 69.83 g (see Figure 4-1). Age considerations are important when evaluating tissue concentrations of bioaccumulating chemicals because older organisms will potentially have had a longer exposure period. Data relating crayfish weight and age are not available for *Pacifastacus leniusculus* in the lower Columbia River. However, rough estimates of age can be obtained using data collected for this species in the Sacramento-San Joaquin Delta in California (McGriff 1983).

Table 4-5 shows the estimated age of different crayfish weight ranges. The mean weights of composite samples analyzed correspond to ages ranging from 2-3 to greater than 4 years, with most of the mean composite weights falling within the 3-4 year age group. Crayfish age-weight or age-length relationships vary with sex, and environmental conditions (e.g., McGriff 1983; Mitchell and Smock 1991). Thus, the actual ages of crayfish collected in the lower Columbia River may differ from the estimates provided in Table 4-5.

4.5.1.2 Carp. Wet weights of individual carp collected at nine stations between RM 79 and RM 141 are presented in Table 4-3. The mean weight of individuals included in the composite samples analyzed ranged from 587 to 2860 g (see Figure 4-1). Individual lengths of fish ranged from 24 to 55 cm, with mean lengths of individuals included in composite samples ranging from 31 to 45 cm (Figure 4-2).

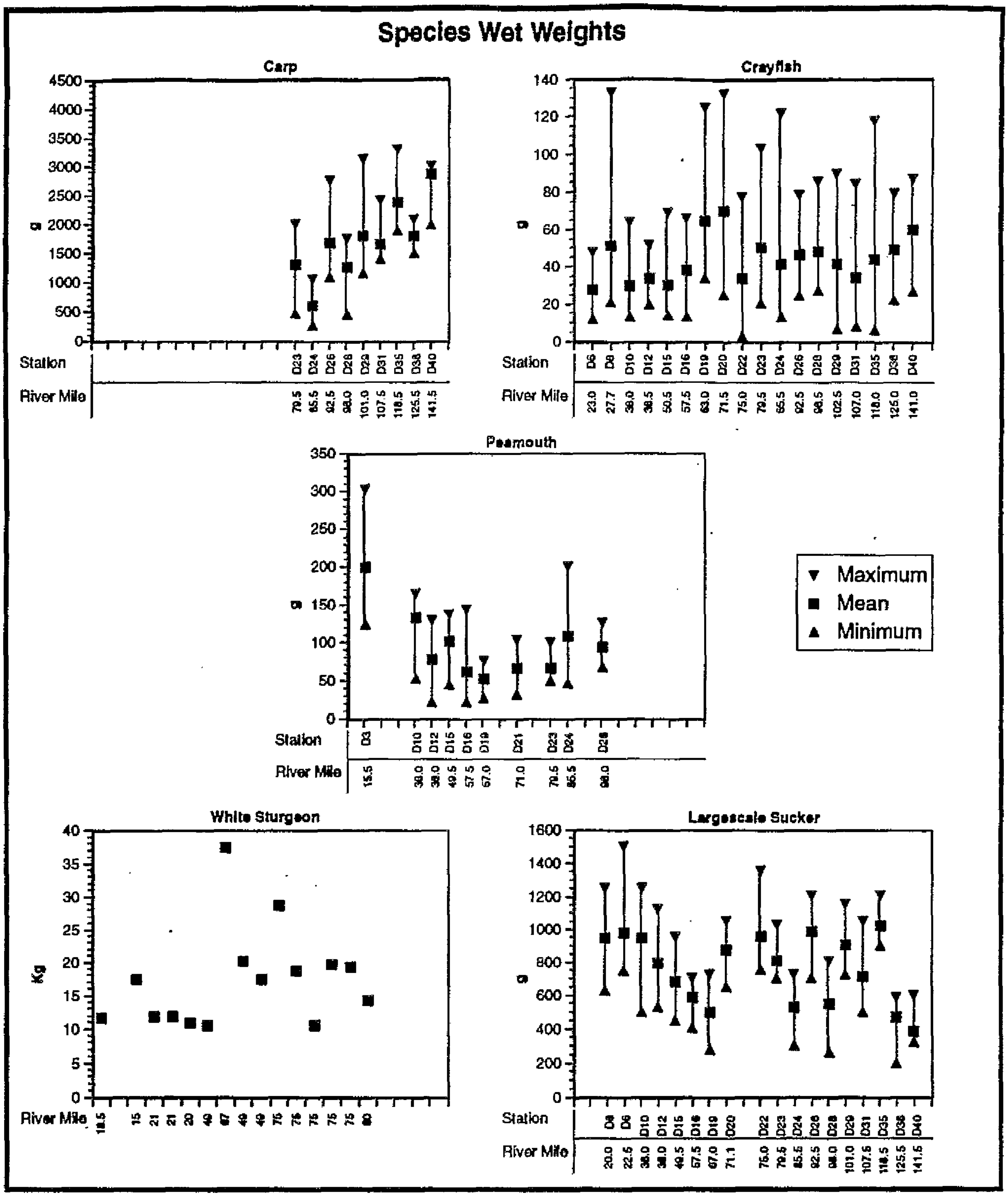


Figure 4-1. Minimum, Maximum, and Mean Wet Weights of Species Collected in the Lower Columbia River

TABLE 4-5. ESTIMATED RELATIONSHIP BETWEEN WHOLE-BODY WET WEIGHT AND AGE FOR THE CRAYFISH *PACIFASTACUS LENIUSCULUS*

Estimated Age (yrs)	Crayfish Weight (g)
<1	<8
1-2	8-15
2-3	15-31
3-4	31-48
>4	>48

Source: McGriff (1983).

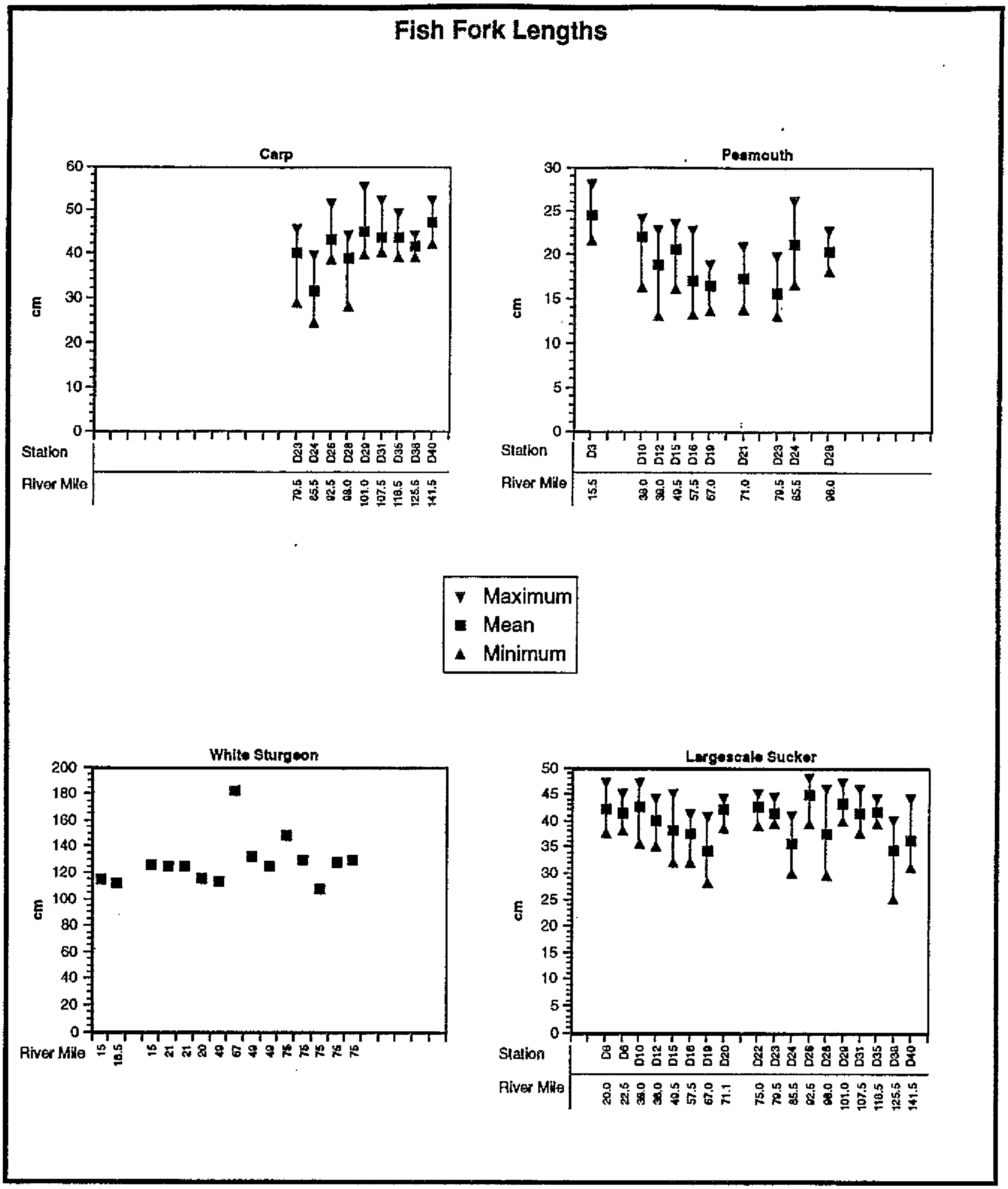


Figure 4-2. Minimum, Maximum, and Mean Fork Lengths of Fish Species Collected in the Lower Columbia River

Age estimates are not available for the carp collected from the lower Columbia River. Length-age relationships for *Cyprinus carpio* from other locations in the U.S. are quite variable, and suggest that the fish collected could range in age from less than 1 to 11 years (Wydoski and Whitney 1979). Ages corresponding to the mean composite fork lengths range from less than 1 to 8 years.

4.5.1.3 Largescale sucker. Largescale sucker were collected at 18 stations between RM 20 and RM 141 (Table 4-3). Wet weights of individuals collected within the study area ranged from 197 to 1,500 g. The mean weight of individuals included in the composite samples analyzed ranged from 378 to 1,020 g (see Figure 4-1). Individual fork lengths of fish ranged from 25 cm to 48 cm, with fork mean lengths of individuals included in composite samples ranging from 34 to 45 cm (see Figure 4-2).

Age estimates are not available for the largescale sucker collected from the lower Columbia River. Length-age relationships for *Catostomus macrocheilus* in British Columbia and Montana (Wydoski and Whitney 1979) suggest that the size of fish collected could range in age from 4 to greater than 10 years. Ages corresponding to the mean composite fork lengths range from 5 to greater than 10 years.

4.5.1.4 Peamouth. Wet weights of individual peamouth collected at ten stations between RM 15 and RM 98 (Table 4-3). The mean weight of individuals included in the composite samples analyzed ranged from 60 g to 199 g (see Figure 4-1). Individual fork lengths of fish ranged from 13 cm to 28 cm, with mean fork lengths of individuals included in composite samples ranging from 15 to 24 cm (see Figure 4-2).

Age estimates are not available for the peamouth collected from the lower Columbia River. Length-age relationships for *Mylocheilus caurinus* in Washington and Montana lakes (Wydowski and Whitney 1979) suggest that the fish collected could range in age from 1 to 9 years. Ages corresponding to the mean composite lengths range from approximately 2 to 7 years.

4.5.1.5 White Sturgeon. Eighteen white sturgeon caught as incidental catch by salmon gill-net fisherman were analyzed for tissue contaminants. These fish were collected at sites between approximately RM 15 and RM 136 (Table 4-4). Wet weights of individuals collected ranged from 10.4 to 37.2 kg (see Figure 4-1). Fork lengths of these fish ranged from 107 to 182 cm (see Figure 4-2). Based on length-age data for white sturgeon collected in the lower Columbia River between 1980 to 1983 (Hess 1984), the fish collected had a mean age from 7 to 20 years.

4.5.2 Tissue Metal Concentrations

4.5.2.1 Summary of Quality Assurance/Quality Control. A total of 73 tissue samples were analyzed for 11 metals. Seventeen samples were analyzed for white sturgeon, 18 for largescale suckers, 20 for crayfish, 10 for peamouth, and 8 for carp. All of the tissue samples were field samples, with the exception of sample ST-1-5-dup, which was a field duplicate of sample ST-1-5, and samples D15d and D26d, which were laboratory duplicates of crayfish samples D15 and D26, respectively. Metals analyzed by ICP/AES (antimony, barium, copper, nickel, silver, and zinc) and ICP/MS (lead) were unsupported by calibration or check standard data. Calibration and check standard data are necessary to verify the accuracy of the analytical results. Because these data were not provided by the analytical laboratory, all values for tissue concentrations of metals were qualified as estimates. Among the trace metals analyzed in tissue, only data for cadmium, arsenic, and selenium were not qualified as estimates. For mercury, all of the largescale sucker and peamouth values, as well as three of the carp values, were qualified as estimates because of holding time exceedances. Copper was detected in the one method blank performed with the tissue samples. All positive values less than 30 mg/kg were qualified as undetected because of possible blank contamination. DLs reported by the laboratory for antimony, barium, copper, nickel, silver, zinc, and selenium exceeded the DLs specified in the QA/QC plan for at least some of the samples (Tetra Tech 1991b). The tissue metals data are considered acceptable for use in this report, with the above qualifications.

Analytical results, including surrogate and matrix spike recoveries and blind laboratory and field replicate samples, are presented under separate cover in the QA memorandum in Appendix A-3.

4.5.2.2 ***Results.*** Whole-body composite samples of crayfish, carp, largescale sucker, peamouth, and filets of individual white sturgeon were analyzed for 11 metals (Table 1-1). Metal concentrations (mg/kg wet weight) measured for each species are presented in Appendices D1-1, D2-1, D3-1, D4-1, and D5-1. Table 4-6 shows the metals that were detected in tissue samples, the number of samples for each species with concentrations above laboratory detection limits, and the range of concentrations measured. Data for each metal are presented in the following sections.

TABLE 4-6. CHEMICALS DETECTED[b] IN FIVE SPECIES COLLECTED IN THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY
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Chemical	Units	Crayfish[c]	Carp[c]	Peamouth[c]	Largescale Sucker[c]	White Sturgeon[d]
METALS						
Antimony	mg/kg	a	a	a	a	a
Arsenic	mg/kg	a	a	a	a	<0.26 - 1.86 (7/16)
Barium	mg/kg	0.6 - 3.5 (20/20)	1.3 - 3.4 (8/8)	1.9 - 4.2 (10/10)	1.1 - 5.4 (18/18)	a
Cadmium	mg/kg	0.02 - 0.13 (20/20)	0.03 - 0.35 (8/8)	0.02 - 0.08 (10/10)	0.02 - 0.06 (18/18)	<0.01 - 0.04 (2/17)
Copper	mg/kg	17.94 - 46.40 (20/20)	1.20 - 1.82 (8/8)	0.90 - 27.81 (10/10)	0.70 - 1.23 (18/18)	<0.43 - 0.50 (2/17)
Lead	mg/kg	0.01 - 0.05 (15/20)	0.02 - 0.23 (8/8)	0.05 - 1.35 (10/10)	<0.02 - 0.86 (14/18)	0.01 - 1.12 (16/17)
Mercury	mg/kg	<0.012 - 0.078 (17/20)	0.056 - 0.166 (8/8)	0.054 - 0.230 (10/10)	0.022 - 0.137 (18/18)	<0.012 - 0.521 (14/17)
Nickel	mg/kg	<0.43 - 1.23 (3/20)	<0.70 - 17.29 (3/8)	<0.72 - 3.42 (2/10)	<0.59 - 1.36 (3/18)	<0.46 - 0.59 (1/17)
Selenium	mg/kg	a	a	a	a	a
Silver	mg/kg	<0.16 - 1.54 (16/20)	a	a	a	<0.12 - 0.23 (1/17)
Zinc	mg/kg	20.2 - 38.8 (20/20)	78.5 - 133.7 (8/8)	22.7 - 44.2 (10/10)	17.3 - 98.0 (18/18)	<1.8 - 16.0 (15/17)
PHENOLIC COMPOUNDS						
Phenol	µg/kg	a	<100 - 5000 (1/9)	a	a	a
2-Chlorophenol	µg/kg	a	<100 - 4200 (1/9)	a	a	a

TABLE 4-6. CHEMICALS DETECTED[b] IN FIVE SPECIES COLLECTED IN THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

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Chemical	Units	Crayfish[c]	Carp[c]	Peamouth[c]	Largescale Sucker[c]	White Sturgeon[d]
4-Chloro-3-methylphenol	µg/kg	a	<200 - 5600 (1/9)	a	a	a
4-Nitrophenol	µg/kg	a	<1000 - 4000 (1/9)	a	a	a
NITROAROMATICS						
2,4-Dinitrotoluene	µg/kg	a	<100 - 1000 (1/9)	a	a	a
NITROSAMINES						
N-nitroso-di-n-propylamine	µg/kg	a	<100 - 2900 (1/9)	a	a	a
POLYNUCLEAR AROMATIC HYDROCARBONS						
Acenaphthene	µg/kg	a	<100 - 3800 (1/9)	a	a	a
Naphthalene	µg/kg	a	<100 - 220 (1/9)	a	a	a
2-Methylnaphthalene	µg/kg	a	<100 - 230 (2/9)	a	<100 - 140 (1/18)	a
Pyrene	µg/kg	a	<100 - 5200 (1/9)	a	a	a
CHLORINATED BENZENES						
1,4-Dichlorobenzene	µg/kg	a	<100 - 1800 (1/9)	a	a	a
1,2,4-Trichlorobenzene	µg/kg	a	<200 - 3100 (1/9)	a	a	a

TABLE 4-6. CHEMICALS DETECTED[b] IN FIVE SPECIES COLLECTED IN THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

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Chemical	Units	Crayfish[c]	Carp[c]	Peamouth[c]	Largescale Sucker[c]	White Sturgeon[d]
PHTHALATE ESTERS						
Di-n-butylphthalate	µg/kg	< 100 - 110 (1/18)	< 100-160 (2/9)	a	a	< 100 - 190 (5/18)
Bis-2-(ethylhexyl)phthalate	µg/kg	< 100 - 3100 (13/18)	< 100 - 1500 (3/9)	< 100 - 770 (9/10)	< 100 - 1100 (8/18)	< 100 - 1,500 (10/18)
Butylbenzylphthalate	µg/kg	a	a	a	a	< 100 - 990 (1/18)
PESTICIDES						
o,p'-DDE	µg/kg	a	<3 - 17 (3/9)	<3 - 47 (1/10)	<3 - 42 (9/18)	<3 - 14 (1/18)
o,p'-DDD	µg/kg	a	<3 - 3.3 (1/9)	<3 - 49 (1/10)	<3 - 29 (6/18)	<3 - 9.1 (2/18)
o,p'-DDT	µg/kg	<3 - 3 (1/18)	<3 - 6.9 (1/9)	a	a	<3 - 30 (1/18)
4,4'-DDE	µg/kg	<3 - 17 (16/18)	<3 - 91 (7/9)	<3 - 480 (7/10)	<3 - <70 (1/18)	<3 - 51 (15/18)
4,4'-DDD	µg/kg	<3 - 9.9 (2/18)	<3 - 23 (6/9)	<3 - 72 (3/10)	<5 - 30 (16/18)	<3 - 11 (3/18)
4,4'-DDT	µg/kg	<3 - 3 (1/18)	<3 - 11 (5/9)	a	<3 - 16 (14/18)	<3 - 16 (8/18)
Heptachlor	µg/kg	<3 - 4.5 (1/18)	a	a	a	a
Aldrin	µg/kg	a	<3 - 9.6 (1/9)	<3 - 42 (3/10)	<3 - 5.6 (3/18)	a
Dieldrin	µg/kg	<3 - 6.6 (1/18)	<3 - 5.6 (2/9)	<3 - 35 (2/10)	<3 - 4.5 (1/18)	<3 - 12 (5/18)
Mirex	µg/kg	a	<3 - 8.8 (1/9)	a	a	a

TABLE 4-6. CHEMICALS DETECTED[b] IN FIVE SPECIES COLLECTED IN THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

(Page 4 of 6)

Chemical	Units	Crayfish[c]	Carp[c]	Peamouth[c]	Largescale Sucker[c]	White Sturgeon[d]
Dacthal	µg/kg	a	a	<3 - 13 (1/10)	a	a
Dicofol	µg/kg	a	a	a	a	a
Methyl parathion	µg/kg	<3 - 38 (3/18)	a	a	a	<3 - 22 (3/18)
Parathion	µg/kg	a	a	<3 - 26 (1/10)	<3 - 15 (3/18)	a
Malathion	µg/kg	a	a	<3 - 110 (2/10)	a	a
Toxaphene	µg/kg	a	a	a	a	a
Isophorone	µg/kg	<100 - 430 (7/18)	a	a	a	a
Endosulfan I	µg/kg	a	a	<3 - 85 (3/10)	<3 - 3.3 (1/18)	<3 - 4.9 (1/18)
Endosulfan II	µg/kg	<3 - 7.6 (1/18)	a	a	a	a
Endosulfan sulfate	µg/kg	<3 - 3 (1/18)	a	a	<3 - 3.5 (1/18)	<3 - 5.5 (1/18)
Endrin	µg/kg	a	<3 - 3.9 (1/9)	a	<3 - 12 (2/18)	<3 - 5.1 (2/18)
Endrin aldehyde	µg/kg	a	a	<3 - 40 (1/10)	<3 - 4.2 (1/18)	<3 - 8.4 (2/18)
Methoxychlor	µg/kg	<30 - 34 (2/18)	a	a	<30 - 65 (1/18)	<30 - 180 (3/18)
alpha-BHC	µg/kg	a	a	a	<3 - 3.7 (2/18)	a
beta-BHC	µg/kg	<3 - 5.6 (2/18)	a	<3 - 150 (2/10)	<3 - 4.1 (1/18)	a

TABLE 4-6. CHEMICALS DETECTED[b] IN FIVE SPECIES COLLECTED IN THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY

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Chemical	Units	Crayfish[c]	Carp[c]	Peamouth[c]	Largescale Sucker[c]	White Sturgeon[d]
delta-BHC	µg/kg	a	a	a	a	a
gamma-BHC	µg/kg	a	<3 - 3.5 (1/9)	<3 - 14 (1/10)	<3 - 7.7 (3/18)	a
PCBs						
Aroclor 1016	µg/kg	a	a	a	a	a
Aroclor 1221	µg/kg	a	a	a	a	a
Aroclor 1232	µg/kg	a	a	a	a	a
Aroclor 1242	µg/kg	a	a	<50 - 99 (2/10)	a	a
Aroclor 1248	µg/kg	a	a	a	a	a
Aroclor 1254	µg/kg	a	<50 - 270 (5/9)	a	<50 - 380 (17/18)	<50 - 500 (4/18)
Aroclor 1260	µg/kg	a	<50 - 110 (4/9)	80 - 520 (10/10)	<50 - 130 (1/18)	a
Dioxins and Furans[e]						
2,3,7,8-TCDD	pg/g	0.27 - 0.86 (12/12)	1.28 - 2.10 (5/5)	1.44 - 4.41 (7/7)	0.49 - 1.56 (12/12)	<0.59 - 1.66 (1/8)
1,2,3,7,8-PeCDD	pg/g	<0.09 - 0.48 (1/12)	0.84 - 1.89 (5/5)	0.31 - 2.04 (7/7)	0.40 - 1.10 (12/12)	a
1,2,3,4,7,8-HxCDD	pg/g	<0.08 - 0.39 (3/12)	0.26 - 1.45 (5/5)	0.11 - 0.87 (7/7)	0.13 - 0.53 (12/12)	a
1,2,3,6,7,8-HxCDD	pg/g	<0.07 - 0.89 (5/12)	0.73 - 4.82 (5/5)	0.31 - 1.16 (7/7)	0.18 - 1.42 (12/12)	a
1,2,3,7,8,9-HxCDD	pg/g	<0.07 - 0.76 (3/12)	<0.36 - 0.50 (4/5)	0.12 - <0.47 (6/7)	0.11 - 0.92 (12/12)	a
1,2,3,4,6,7,8-HpCDD	pg/g	<0.32 - 5.21 (11/12)	1.59 - 9.81 (5/5)	0.24 - 2.81 (7/7)	1.04 - 4.36 (12/12)	0.35 - <1.25 (2/8)

TABLE 4-6. CHEMICALS DETECTED[b] IN FIVE SPECIES COLLECTED IN THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY
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Chemical	Units	Crayfish[c]	Carp[c]	Peamouth[c]	Largescale Sucker[c]	White Sturgeon[d]
OCDD	pg/g	1.62 - 79.10 (12/12)	2.71 - 30.6 (5/5)	3.62 - 18.1 (7/7)	0.79 - 21.3 (12/12)	<0.61 - 3.61 (7/8)
2,3,7,8-TCDF	pg/g	4.10 - 12.40 (12/12)	4.37 - 12.2 (5/5)	22.2 - 58.8 (7/7)	2.46 - 11.4 (12/12)	1.54 - 22.8 (8/8)
1,2,3,7,8-PeCDF	pg/g	0.11 - 1.02 (8/12	0.21 - 0.76 (5/5)	0.24 - 0.86 (7/7)	0.14 - 0.49 (12/12)	<0.25 - 0.73 (1/8)
2,3,4,7,8-PeCDF	pg/g	0.20 - 3.05 (12/12)	0.46 - 1.37 (5/5)	0.55 - 2.46 (7/7)	0.31 - 1.21 (12/12)	<0.21-0.49 (1/8)
1,2,3,4,7,8-HxCDF	pg/g	<0.07 - 0.36 (4/12)	0.12 - 0.66 (5/5)	<0.11 - 0.56 (5/7)	0.08 - 0.45 (12/12)	a
1,2,3,6,7,8-HxCDF	pg/g	<0.06 - 0.32 (4/12)	0.09 - 0.57 (5/5)	<0.10 - 0.44 (5/7)	0.09 - 0.36 (12/12)	a
2,3,4,6,7,8-HxCDF	pg/g	<0.32 - 7.26 (11/12)	0.26 - 5.70 (5/5)	0.23 - <1.61 (5/7)	0.40 - 2.77 (12/12)	a
1,2,3,7,8,9-HxCDF	pg/g	<0.05 - 0.23 (2/12)	0.05 - <0.34 (1/5)	a	0.09 - 0.33 (12/12)	a
1,2,3,4,6,7,8-HpCDF	pg/g	<0.09 - 0.7 (7/12)	0.18 - 1.31 (5/5)	<0.17 - 0.74 (6/7)	0.23 - 1.79 (12/12)	a
1,2,3,4,7,8,9-HpCDF	pg/g	<0.07 - 0.19 (1/12)	0.12 - <0.56 (1/5)	<0.08 - 0.18 (4/7)	0.06 - 0.43 (12/12)	a
OCDF	pg/g	<0.18 - 1.24 (6/12)	<0.29 - 2.45 (3/5)	<1.18 - 2.03 (6/7)	0.30 - 10.60 (12/12)	a

[a] Chemical was not detected in any sample.

[b] The first number is the number of times the compound was detected. The second number is the number of stations at which samples were collected.

[c] Analysis conducted on composite sample of five whole-body specimens from each station.

[d] Analysis conducted on single filet sample from an individual white sturgeon at each location.

[e] Detected values include estimated values below the Lower Method Calibration Limit.

Antimony. Antimony tissue concentrations were qualified as estimates because QA/QC data on method calibration and analysis of standards of known concentration were not supplied by the analytical laboratory. Antimony was not detected in any of the tissue samples analyzed. Laboratory detection limits for this metal ranged from 0.20 to 4.05 mg/kg wet weight (Table 4-7).

Arsenic. Arsenic was detected above the laboratory detection limits only in tissue samples of white sturgeon filets (Figure 4-3). The maximum arsenic concentration in white sturgeon was 1.86 mg/kg wet weight (see Table 4-6). Detection limits for tissue analyses ranged from 0.24 to 0.64 mg/kg wet weight (see Table 4-7).

Table 4-8 shows the locations of the five highest arsenic tissue samples measured within the study area. These samples were for white sturgeon which had arsenic concentrations ranging from 0.27 to 1.86 mg/kg wet weight. These fish were collected near Multnomah Falls, OR (RM 137), Rainier, OR (RM 67), Wallace Island (RM 49), and near Astoria (RM 15).

Barium. Barium was detected in all tissue samples of crayfish, carp, peamouth, and largescale sucker (Table 4-6). Barium was not detected in white sturgeon samples. Laboratory detection limits for barium analysis in sturgeon ranged from 0.5 to 0.8 mg/kg (Table 4-7). Median concentrations (mg/kg) of barium were 2.7, 2.4, 2.4, and 1.5 for largescale sucker, carp, peamouth, and crayfish, respectively (Figure 4-4). Concentrations corresponding to the lowest ten percent of measured values for each species were 1.9, 1.3, 1.2, 0.6, and 0.1 for peamouth, carp, largescale sucker, and crayfish, respectively (see Figure 4-4). Ninety percent of the samples had concentrations below 3.6, 3.3, 3.2, and 2.5 for largescale sucker, carp, peamouth, and crayfish, respectively (see Figure 4-4).

Table 4-8 shows the species and locations where the five highest barium concentrations were measured. Four of the five highest barium tissue concentrations were measured for largescale sucker collected between RM 79.5 and RM 141. Tissue concentrations ranged from 3.6 to 5.4 mg/kg. Peamouth collected at RM 50.5 near the mouth of the Clatskanie River had the second highest barium concentration of 4.2 mg/kg.

TABLE 4-7. DETECTION LIMITS REPORTED FOR CHEMICALS NOT DETECTED IN ANY TISSUE SAMPLES FOR ONE OR MORE OF THE FIVE SPECIES COLLECTED IN THE LOWER COLUMBIA RIVER

(Page 1 of 6)

Chemical	Units	Crayfish[b]	Carp[b]	Peamouth[b]	Largescale Sucker[b]	White Sturgeon[c]
METALS						
Antimony	mg/kg	0.31 - 4.05	0.30 - 0.48	0.31 - 0.37	0.25 - 3.38	0.20 - 2.40
Arsenic	mg/kg	0.24-0.54	0.40-0.64	0.41-0.49	0.34-0.52	a
Barium	mg/kg	a	a	a	a	0.5 - 0.8
Selenium	mg/kg	0.40-0.64	0.24-0.54	0.41-0.49	0.33-0.52	0.26-0.55
Silver	mg/kg	a	0.18 - 0.29	0.19 - 0.21	0.15 - 0.24	a
PHENOLIC COMPOUNDS						
Phenol	μg/kg	100	a	100 - 200	100	100
Pentachlorophenol	μg/kg	1000	1000	1000 - 2000	1000	1000
2-Chlorophenol	μg/kg	100	a	100 - 200	100	100
2,4-Dichlorophenol	μg/kg	200	200	200 - 400	200	200
2,4-Dinitrophenol	μg/kg	1000	1000	1000 - 2000	1000	1000
2-Nitrophenol	μg/kg	200	200	200 - 400	200	200
4-Nitrophenol	μg/kg	1000	a	1000 - 2000	1000	1000
4-Chloro-3-methylphenol	μg/kg	200	a	200 - 400	200	200
2,4,6-Trichlorophenol	μg/kg	200	200	200 - 400	200	200
HALOGENATED ETHERS						
bis(2-chloroethyl) ether	μg/kg	100	100	100 - 200	100	100
bis(2-chloroethyoxy) methane	μg/kg	100	100	100 - 200	100	100
bis(2-chloroisopropyl) ether	μg/kg	100	100	100 - 200	100	100
4-Bromophenyl phenyl ether	μg/kg	200	200	200 - 400	200	200
4-Chlorophenyl phenyl ether	μg/kg	100	100	100 - 200	100	100

TABLE 4-7. DETECTION LIMITS REPORTED FOR CHEMICALS NOT DETECTED IN ANY TISSUE SAMPLES FOR ONE OR MORE OF THE FIVE SPECIES COLLECTED IN THE LOWER COLUMBIA RIVER

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Chemical	Units	Crayfish[b]	Carp[b]	Peamouth[b]	Largescale Sucker[b]	White Sturgeon[c]
NITROAROMATICS						
2,4-Dinitrotoluene	µg/kg	100	a	100 - 200	100	100
2,6-Dinitrotoluene	µg/kg	100	100	100 - 200	100	100
Nitrobenzene	µg/kg	100	100	100 - 200	100	100
NITROSAMINES						
N-nitroso-di-n-propylamine	µg/kg	100	a	100 - 200	100	100
N-nitrosodiphenylamine	µg/kg	100	100	100 - 200	100	100
CHLORINATED NAPHTHALENE						
2-Chloronaphthalene	µg/kg	100	100	100 - 200	100	100
POLYNUCLEAR AROMATIC HYDROCARBONS						
Acenaphthene	µg/kg	100	a	100 - 200	100	100
Acenaphthylene	µg/kg	100	100	100 - 200	100	100
Anthracene	µg/kg	100	100	100 - 200	100	100
Benzo(a)anthracene	µg/kg	100	100	100 - 200	100	100
Benzo(b)fluoranthene	µg/kg	200	200	200 - 400	200	200
Benzo(k)fluoranthene	µg/kg	200	200	200 - 400	200	200
Benzo(a)pyrene	µg/kg	200	200	200 - 400	200	200
Benzo(g,h,i)perylene	µg/kg	200	200	200 - 400	200	200
Chrysene	µg/kg	100	100	100 - 200	100	100
Dibenzo(a,h)anthracene	µg/kg	200	200	200 - 400	200	200
Fluoranthene	µg/kg	100	100	100 - 200	100	100
Fluorene	µg/kg	100	100	100 - 200	100	100
Indeno(1,2,3-c,d)pyrene	µg/kg	200	200	200 - 400	200	200
Naphthalene	µg/kg	100	a	100 - 200	100	100

TABLE 4-7. DETECTION LIMITS REPORTED FOR CHEMICALS NOT DETECTED IN ANY TISSUE SAMPLES FOR ONE OR MORE OF THE FIVE SPECIES COLLECTED IN THE LOWER COLUMBIA RIVER

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Chemical	Units	Crayfish[b]	Carp[b]	Peamouth[b]	Largescale Sucker[b]	White Sturgeon[c]
2-Methylnaphthalene	µg/kg	100	a	100 - 200	a	100
Phenanthrene	µg/kg	100	100	100 - 200	100	100
Pyrene	µg/kg	100	a	100 -200	100	100
CHLORINATED BENZENES						
1,3-Dichlorobenzene	µg/kg	100	100	100 - 200	100	100
1,2-Dichlorobenzene	µg/kg	100	100	100 - 200	100	100
1,4-Dichlorobenzene	µg/kg	100	a	100 - 200	100	100
1,2,4-Trichlorobenzene	µg/kg	200	a	200 - 400	200	200
Hexachlorobenzene	µg/kg	200	200	200 - 400	200	200
Hexachlorobutadiene	µg/kg	100	100	100 - 200	100	100
Hexachloroethane	µg/kg	200	200	200 - 400	200	200
Hexachlorocyclopentadiene	µg/kg	500	500	500 - 1000	500	500
BENZIDINES						
3,3-Dichlorodibenzidine	µg/kg	1000	1000	1000 - 2000	1000	1000
PHTHALATE ESTERS						
Dimethylphthalate	µg/kg	100	100	100 - 200	100	100
Diethylphthalate	µg/kg	200	200	200 - 400	200	200
Di-n-butylphthalate	µg/kg	a	a	100 - 200	100	a
Butylbenzylphthalate	µg/kg	100	100	100 - 200	100	a
Di-n-octylphthalate	µg/kg	200	200	200 - 400	200	200
PESTICIDES						
o,p'-DDE	µg/kg	3	a	a	a	a
o,p'-DDD	µg/kg	3	a	a	a	a
o,p'-DDT	µg/kg	a	a	3 - 25	3 - 15	a

TABLE 4-7. DETECTION LIMITS REPORTED FOR CHEMICALS NOT DETECTED IN ANY TISSUE SAMPLES FOR ONE OR MORE OF THE FIVE SPECIES COLLECTED IN THE LOWER COLUMBIA RIVER

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Chemical	Units	Crayfish[b]	Carp[b]	Peamouth[b]	Largescale Sucker[b]	White Sturgeon[c]
4,4'-DDE	µg/kg	a	a	a	a	a
4,4'-DDD	µg/kg	a	a	a	a	a
4,4'-DDT	µg/kg	a	a	3 - 25	a	a
Heptachlor	µg/kg	a	3	3 - 25	3	3
Heptachlor epoxide	µg/kg	3	3 - 4	3 - 25	3	3
alpha-chlordane	µg/kg	3	3	3 - 25	3	3
Aldrin	µg/kg	3	a	a	a	3
Mirex	µg/kg	3	a	3 - 25	3	3
Dacthal	µg/kg	3	3 - 4	a	3	3
Dicofol	µg/kg	30	30	30 - 250	30	30
Methyl parathion	µg/kg	a	3 - 10	3 - 25	3 - 16	a
Parathion	µg/kg	3	3	a	a	3
Malathion	µg/kg	3	3 - 6	a	3	3
Toxaphene	µg/kg	150	150	150 - 1500	150	150
Isophorone	µg/kg	a	100	100 - 200	100	100
Endosulfan I	µg/kg	3	3	a	a	a
Endosulfan II	µg/kg	a	3	3 - 25	3	3 - 5
Endosulfan sulfate	µg/kg	a	3	3 - 25	a	a
Endrin	µg/kg	3 - 4	a	3 - 25	a	a
Endrin aldehyde	µg/kg	3	3 - 5	a	a	a
Methoxychlor	µg/kg	a	30	30 - 250	a	a
alpha-BHC	µg/kg	3	3	3 - 25	a	3
beta-BHC	µg/kg	a	3	a	a	3

TABLE 4-7. DETECTION LIMITS REPORTED FOR CHEMICALS NOT DETECTED IN ANY TISSUE SAMPLES FOR ONE OR MORE OF THE FIVE SPECIES COLLECTED IN THE LOWER COLUMBIA RIVER

(Page 5 of 6)

Chemical	Units	Crayfish[b]	Carp[b]	Peamouth[b]	Largescale Sucker[b]	White Sturgeon[c]
delta-BHC	µg/kg	3	3	3 - 40	3	3
gamma-BHC	µg/kg	3	a	a	a	3 - 4
PCBs						
Aroclor 1016	µg/kg	50	50	50	50	50
Aroclor 1221	µg/kg	50	50	50	50	50
Aroclor 1232	µg/kg	50	50	50	50	50
Aroclor 1242	µg/kg	50	50	a	50	50
Aroclor 1248	µg/kg	50	50	50	50	50
Aroclor 1254	µg/kg	50	a	50	a	a
Aroclor 1260	µg/kg	50	a	a	a	50
Dioxins and Furans						
1,2,3,7,8-PeCDD	pg/g	a	a	a	a	0.57 - 2.50
1,2,3,4,7,8-HxCDD	pg/g	a	a	a	a	0.18 - 0.50
1,2,3,6,7,8-HxCDD	pg/g	a	a	a	a	0.17 - 0.38
1,2,3,7,8,9-HxCDD	pg/g	a	a	a	a	0.19 - 0.42
1,2,3,4,7,8-HxCDF	pg/g	a	a	a	a	0.31 - 1.30
1,2,3,6,7,8-HxCDF	pg/g	a	a	a	a	0.31 - 1.10
2,3,4,6,7,8-HxCDF	pg/g	a	a	a	a	0.35 - 4.81
1,2,3,7,8,9-HxCDF	pg/g	a	a	0.08 - 1.38	a	0.41 - 2.04
1,2,3,4,6,7,8-HpCDF	pg/g	a	a	a	a	0.20 - 0.84
1,2,3,4,7,8,9-HpCDF	pg/g	a	a	a	a	0.26 - 1.00
OCDF	pg/g	a	a	a	a	0.29 - 0.93

TABLE 4-7. DETECTION LIMITS REPORTED FOR CHEMICALS NOT DETECTED IN ANY TISSUE SAMPLES FOR ONE OR MORE OF THE FIVE SPECIES COLLECTED IN THE LOWER COLUMBIA RIVER
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Chemical	Units	Crayfish[b]	Carp[b]	Peamouth[b]	Largescale Sucker[b]	White Sturgeon[c]

[a] Chemical was detected in at least one sample for this species.

[b] Analysis conducted on composite sample of five whole-body specimens from each station.

[c] Analysis conducted on single filet sample from an individual white sturgeon at each location.

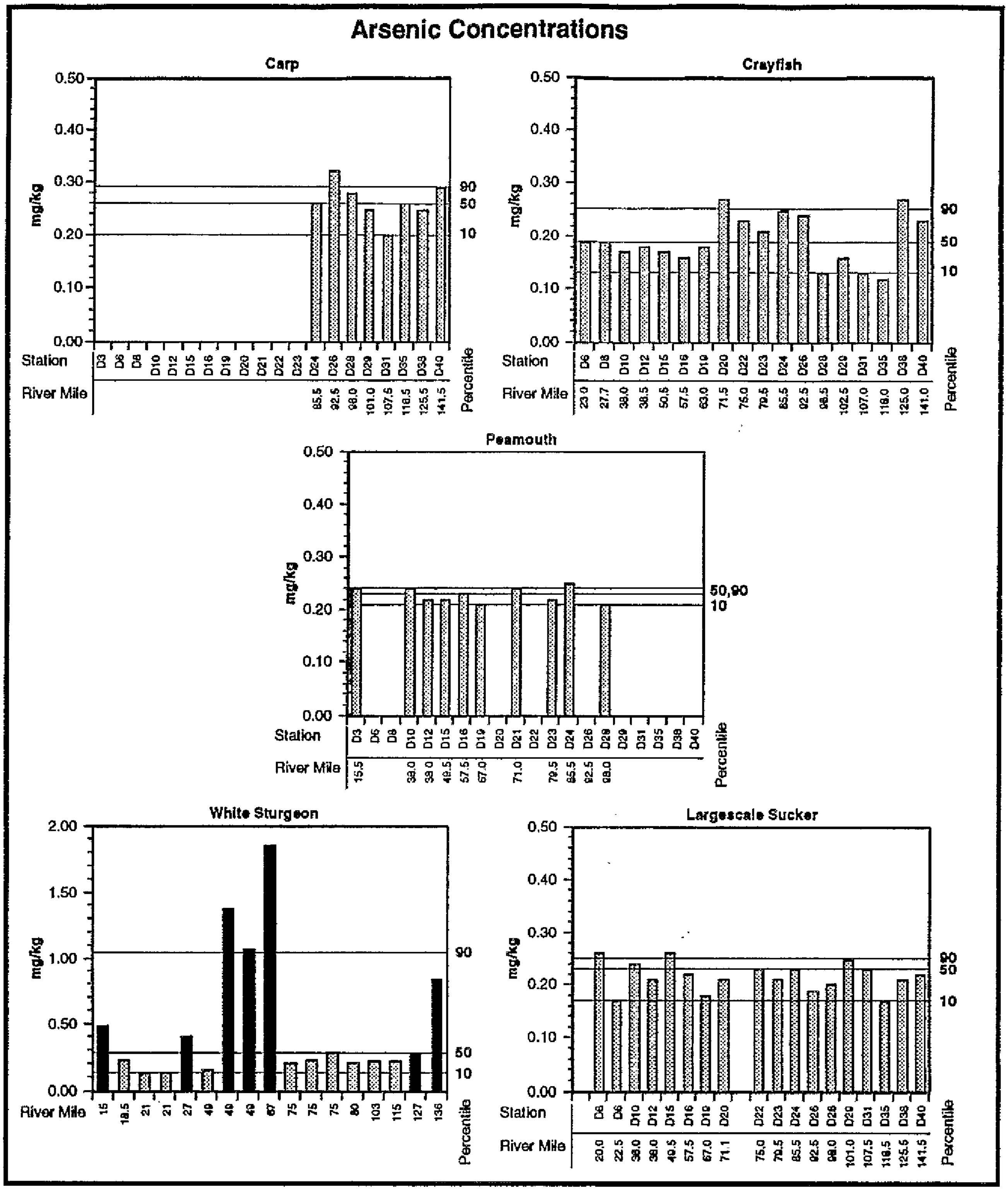

Figure 4-3. Arsenic concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

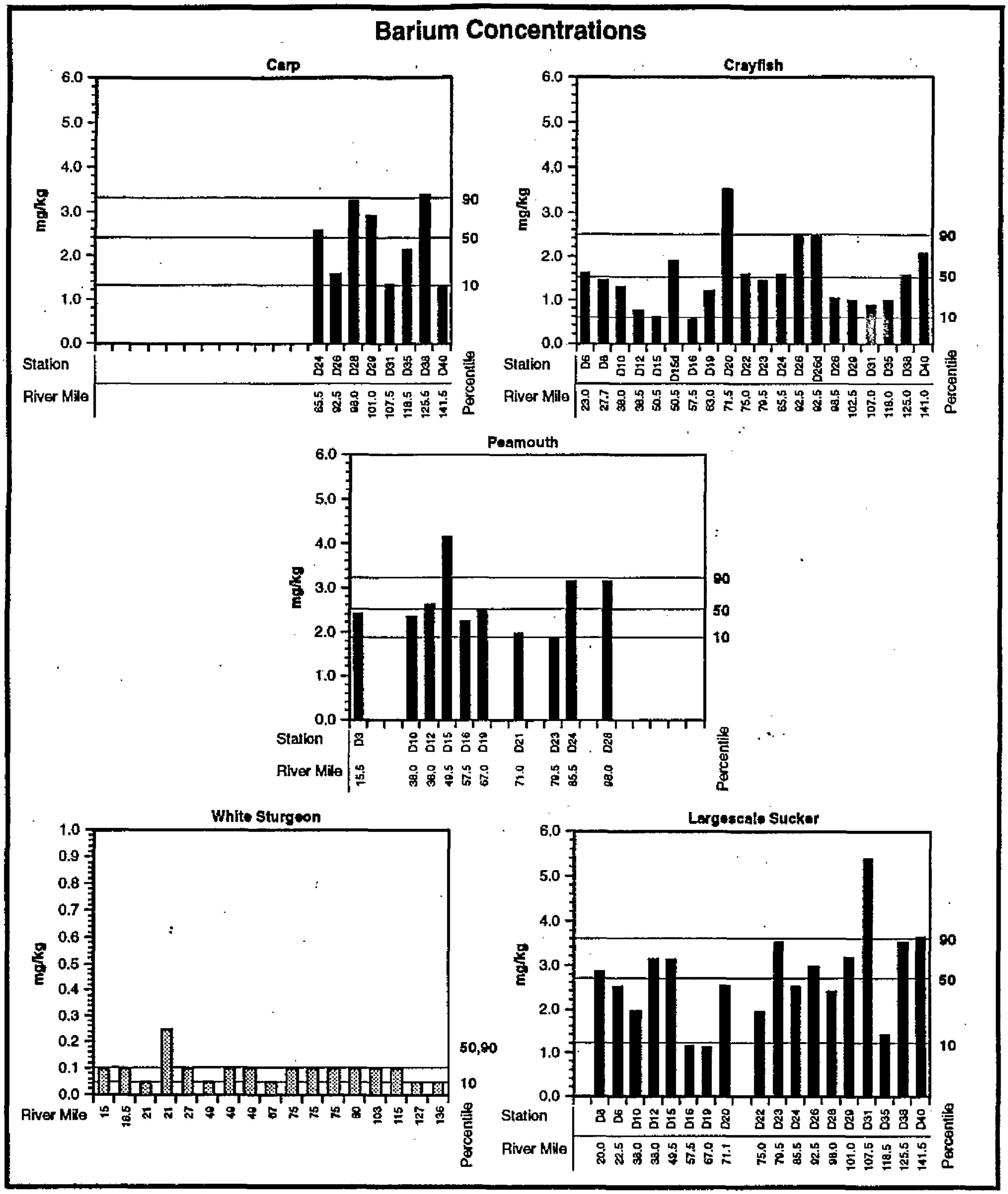

Figure 4-4. Barium concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

TABLE 4-8. LOCATIONS OF MAXIMUM MEASURED TRACE METAL CONCENTRATIONS IN TISSUE SAMPLES (mg/kg wet weight).
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Compound	Maximum Concentrations	Station Designation	Type of Fish	Sample Type	Location (River Mile)	Comment
Arsenic	1.86	RM67	White sturgeon	ST[a]	67	Off Rainier, OR, across from mouth of Cowlitz R.
	1.38	RM49	White sturgeon	ST	49	Wallace Island
	1.07	RM49[c]	White sturgeon	ST	49	Wallace Island
	0.84	RM136	White sturgeon	ST	136	Upstream of Skamania Island
	0.49	RM15	White sturgeon	ST	15	Near Port of Astoria, OR
Barium	5.4	D31	Largescale sucker	WB[b]	107.0	Hayden Island, N. Portland Harbor, above Interstate 5 bridge
	4.2	D15	Peamouth	WB	50.5	Wallace Slough near mouth of the Clatskanie R.
	3.7	D40	Largescale sucker	WB	141.0	Beacon Rock State Park, below Bonneville Dam
	3.6	D38	Largescale sucker	WB	125.0	Reed Island, upstream of Washougal, WA
	3.6	D23	Largescale sucker	WB	79.5	Burke Slough near Martin Island
Cadmium	0.35	D26	Carp	WB	92.5	Upstream of Bachelor Point, Bachelor Is. Slough
	0.29	D38	Carp	WB	125.0	Reed Island, upstream of Washougal, WA
	0.13	D15	Crayfish	WB	50.5	Wallace Slough near mouth of the Clatskanie R.
	0.12	D40	Crayfish	WB	141.0	Beacon Rock State Park, below Bonneville Dam
	0.12	D40	Carp	WB	141.0	Beacon Rock State Park, below Bonneville Dam
Copper	46.40	D26	Crayfish	WB	92.5	Upstream of Bachelor Point, Bachelor Is. Slough
	44.73	D26[c]	Crayfish	WB	92.5	Upstream of Bachelor Point, Bachelor Is. Slough
	41.39	D10	Crayfish	WB	38.0	Clifton Channel, along upstream end of Tenasillahe Is.
	38.05	D19	Crayfish	WB	63.0	Downstream of Longview, WA
	37.99	D31	Crayfish	WB	107.0	Hayden Island, N. Portland Harbor, above Interstate 5 bridge
	37.33	D6	Crayfish	WB	23.0	Grays Bay near Altoona, WA
Lead	1.35	D15	Peamouth	WB	50.5	Wallace Slough near mouth of the Clatskanie R.
	1.12	RM75	White sturgeon	ST	75	Downstream of Kalama, WA
	0.86	D22	Largescale sucker	WB	75.0	Vicinity of Port of Kalama
	0.41	D38	Largescale sucker	WB	125.0	Reed Island, upstream of Washougal, WA
	0.34	D24	Peamouth	WB	85.5	Adjacent to St. Helens, OR marina, downstream of Multanomah Channel mouth

TABLE 4-8. LOCATIONS OF MAXIMUM MEASURED TRACE METAL CONCENTRATIONS IN TISSUE SAMPLES (mg/kg wet weight).

(Page 2 of 3)

Compound	Maximum Concentrations	Station Designation	Type of Fish	Sample Type	Location (River Mile)	Comment
Mercury	0.347	RM75	White sturgeon	ST	75	Downstream of Kalama, WA
	0.230	D3	Peamouth	WB	15.5	Near Port of Astoria, OR
	0.212	D24	Peamouth	WB	85.5	Adjacent to St. Helens, OR marina below Multnomah Channel mouth
	0.166	D26	Carp	WB	92.5	Upstream of Bachelor Point, entrance to Bachelor Is. Slough
	0.146	D31	Carp	WB	107.0	Hayden Island, Portland Harbor, above Interstate 5 bridge
Nickel	17.29	D38	Carp	WB	125.0	Reed Island, upstream of Washougal, WA
	3.42	D24	Peamouth	WB	85.5	Adjacent to St. Helens, OR marina, below Multnomah Channel mouth
	1.97	D15	Peamouth	WB	50.5	Wallace Slough near mouth of the Clatskanie R.
	1.85	D28	Carp	WB	98.5	3 mi downstream of Willamette R. mouth
	1.36	D28	Largescale sucker	WB	98.5	3 mi downstream of Willamette R. mouth
Selenium	ND					
	ND					
	ND					
	ND					
	ND					
Silver	1.54	D20	Crayfish[d]	WB	71.5	Carrolls Channel, upstream of mouth of Cowlitz R.
	1.37	D40	Crayfish	WB	141.0	Beacon Rock State Park, below Bonneville Dam
	1.17	D8	Crayfish	WB	27.7	Marsh Island, Lewis and Clark Nat. Wildlife Refuge
	1.13	D15[c]	Crayfish	WB	50.5	Wallace Slough near mouth of the Clatskanie R.
	1.11	D38	Crayfish	WB	125.0	Reed Island, upstream of Washougal
Zinc	133.7	D28	Carp	WB	98.5	3 mi downstream of Willamette R. mouth
	112.0	D26	Carp	WB	92.5	Upstream of Bachelor Point, Bachelor Is. Slough
	109.6	D38	Carp	WB	125.0	Reed Island, upstream of Washougal, WA
	109.5	D35	Carp	WB	118.0	Mouth of Camas Slough
	100.0	D31	Carp	WB	107.0	Hayden Island, N. Portland Harbor, above Interstate 5 bridge

TABLE 4-8. LOCATIONS OF MAXIMUM MEASURED TRACE METAL CONCENTRATIONS IN TISSUE SAMPLES (mg/kg wet weight).

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[a] Filet samples of white sturgeon were analyzed. White sturgeon samples were not collected at the same stations as the other species, but at a number of approximate river mile locations. Therefore, the station designation for these samples is for river mile only.

[b] Whole-body tissue samples were analyzed for crayfish, carp, largescale sucker, and peamouth.

[c] Indicates a replicate sample analysis.

[d] Silver was not detected in other species.

ND = Not detected above the laboratory detection limit.

Cadmium. Cadmium was detected in all tissue samples of crayfish, carp, peamouth, and largescale sucker and in 13 percent of the white sturgeon samples analyzed. Median concentrations (mg/kg) of cadmium were 0.11, 0.08, 0.04, 0.03, and 0.02 for carp, crayfish, largescale sucker, peamouth, and white sturgeon, respectively (Figure 4-5). Cadmium concentrations corresponding to the lowest ten percent of measured values for these species were similar, ranging from 0.02 to 0.03 mg/kg (see Figure 4-5). Ninety percent of the samples had concentrations below 0.29, 0.11, 0.07, 0.05, and 0.03 for carp, crayfish, peamouth, largescale sucker, and white sturgeon, respectively (see Figure 4-5).

Table 4-8 shows the species and locations where the five highest cadmium concentrations were measured. Three of these concentrations were measured for carp collected upstream of RM 92.5 (approximately 8 miles upstream of St. Helens, OR) to RM 141 below Bonneville dam. Crayfish collected at RM 50.5 near the mouth of the Clatskanie River and RM 141 below Bonneville dam had the third and fourth highest tissue concentrations of cadmium (0.12 and 0.13 mg/kg).

Copper. Copper was detected in all tissue samples of crayfish, carp, peamouth, and largescale sucker and in 2 of 16 white sturgeon samples analyzed (Table 4-6). Median concentrations (mg/kg) of copper were 28.88, 1.62, 1.47, 1.01, and 0.33 for crayfish, peamouth, carp, largescale sucker, and white sturgeon, respectively (Figure 4-6). Copper concentrations corresponding to the lowest ten percent of measured values for species other than crayfish ranged from 0.24 to 1.22 mg/kg (see Figure 4-6). The ten percentile concentration for crayfish was 16 to 83 times higher than the fish species (19.93 mg/kg). Ninety percent of the samples had concentrations below 41.39, 8.54, 1.68, 1.18, and 0.45 for crayfish, peamouth, carp, largescale sucker, and white sturgeon, respectively (see Figure 4-6).

Table 4-8 shows the locations and species where the five highest copper concentrations were measured. All five highest copper tissue concentrations were measured for crayfish. Collection locations for these samples were dispersed throughout the study area from RM 38 in the Clifton Channel just below Puget Island to RM 107 on the south side of Hayden Island just upstream of the Interstate 5 bridge.

Lead. Lead was detected in all tissue samples of carp and peamouth, 94 percent of the white sturgeon samples, 75 percent of the crayfish samples, and 78 percent of the largescale sucker samples analyzed (Table 4-6). Median concentrations (mg/kg) of lead were 0.15, 0.14, 0.10, 0.02, and 0.02 for carp, largescale sucker, peamouth, white sturgeon, and crayfish, respectively (Figure 4-7). Lead con-

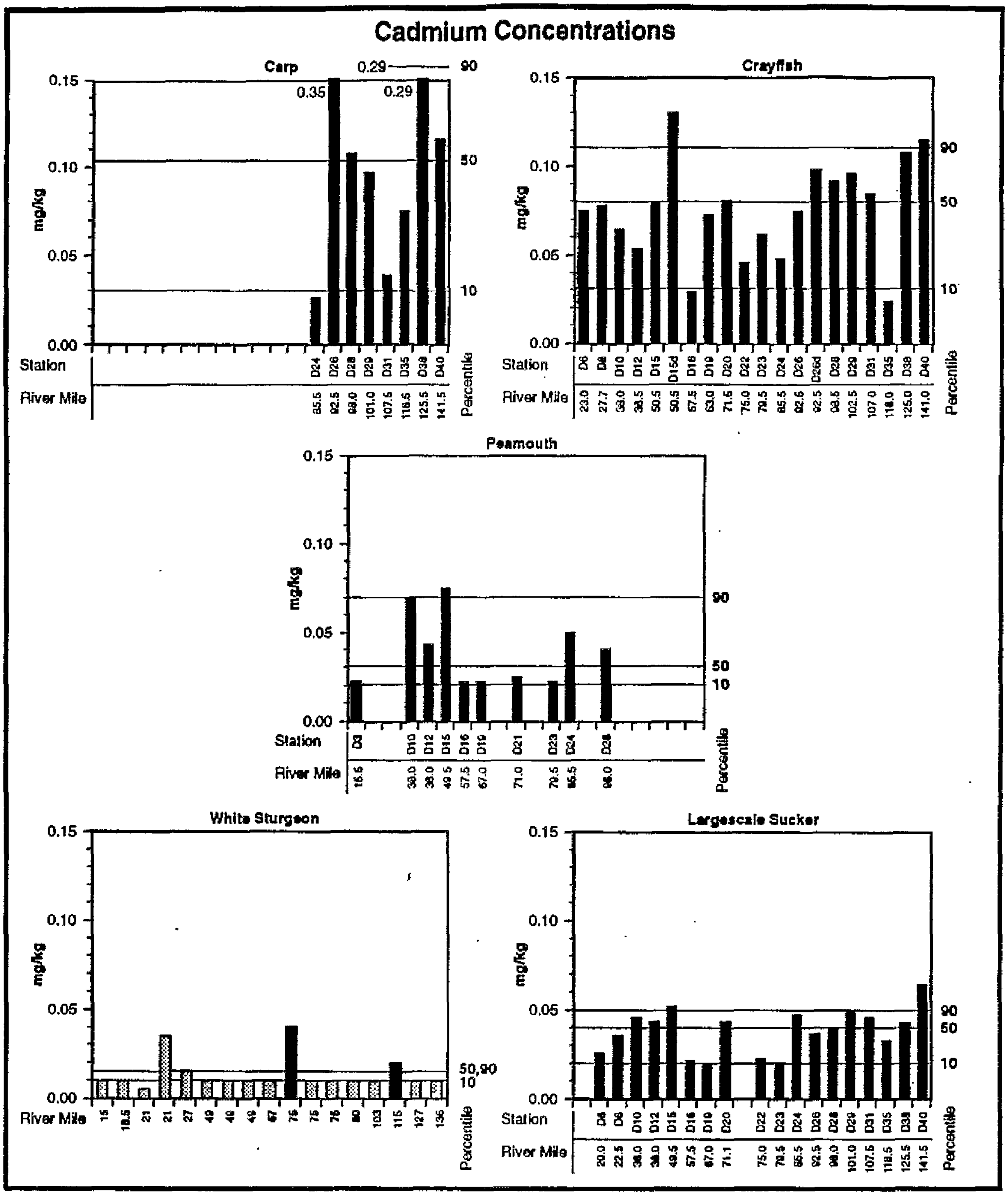


Figure 4-5. Cadmium concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

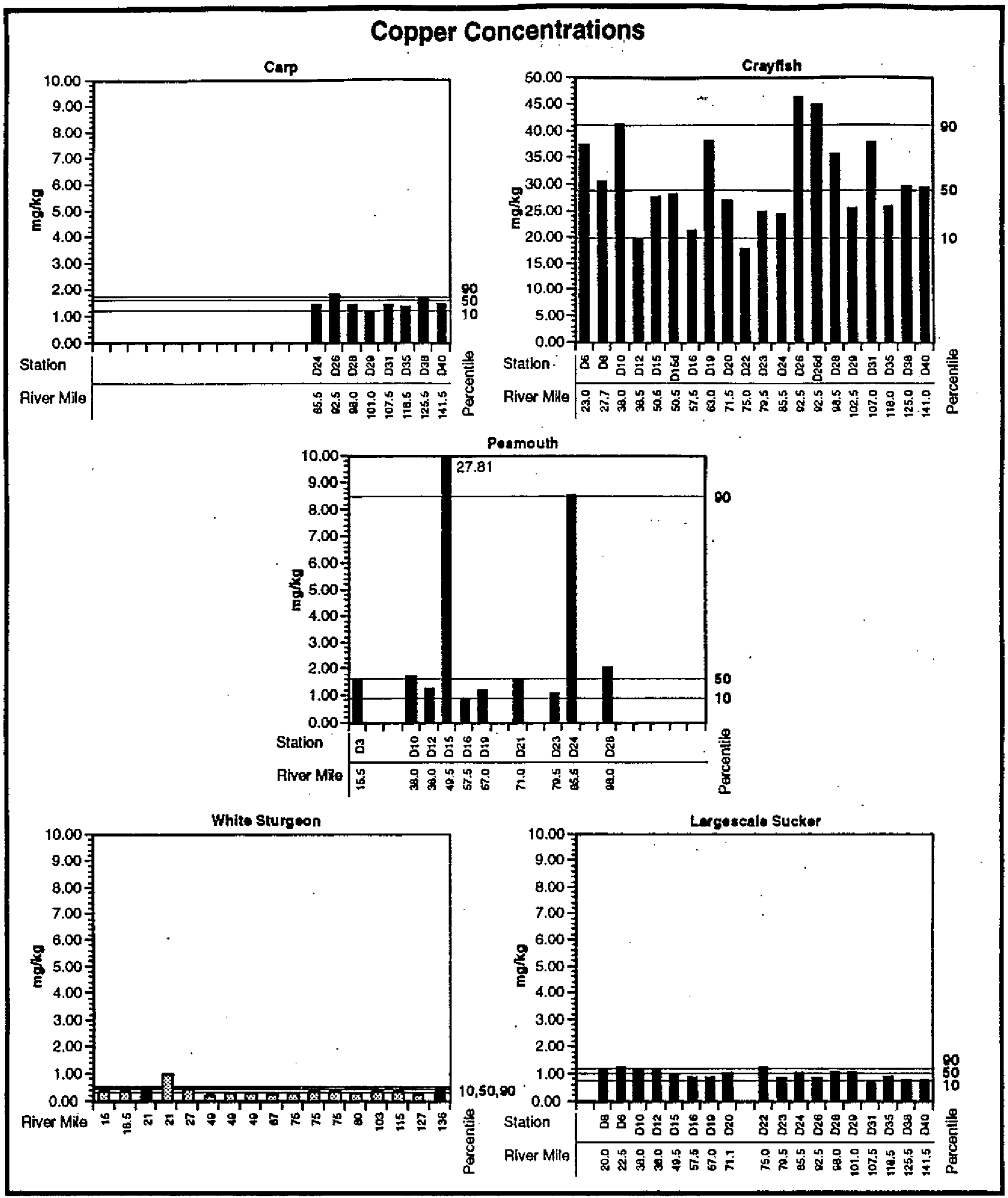


Figure 4-6. Copper concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

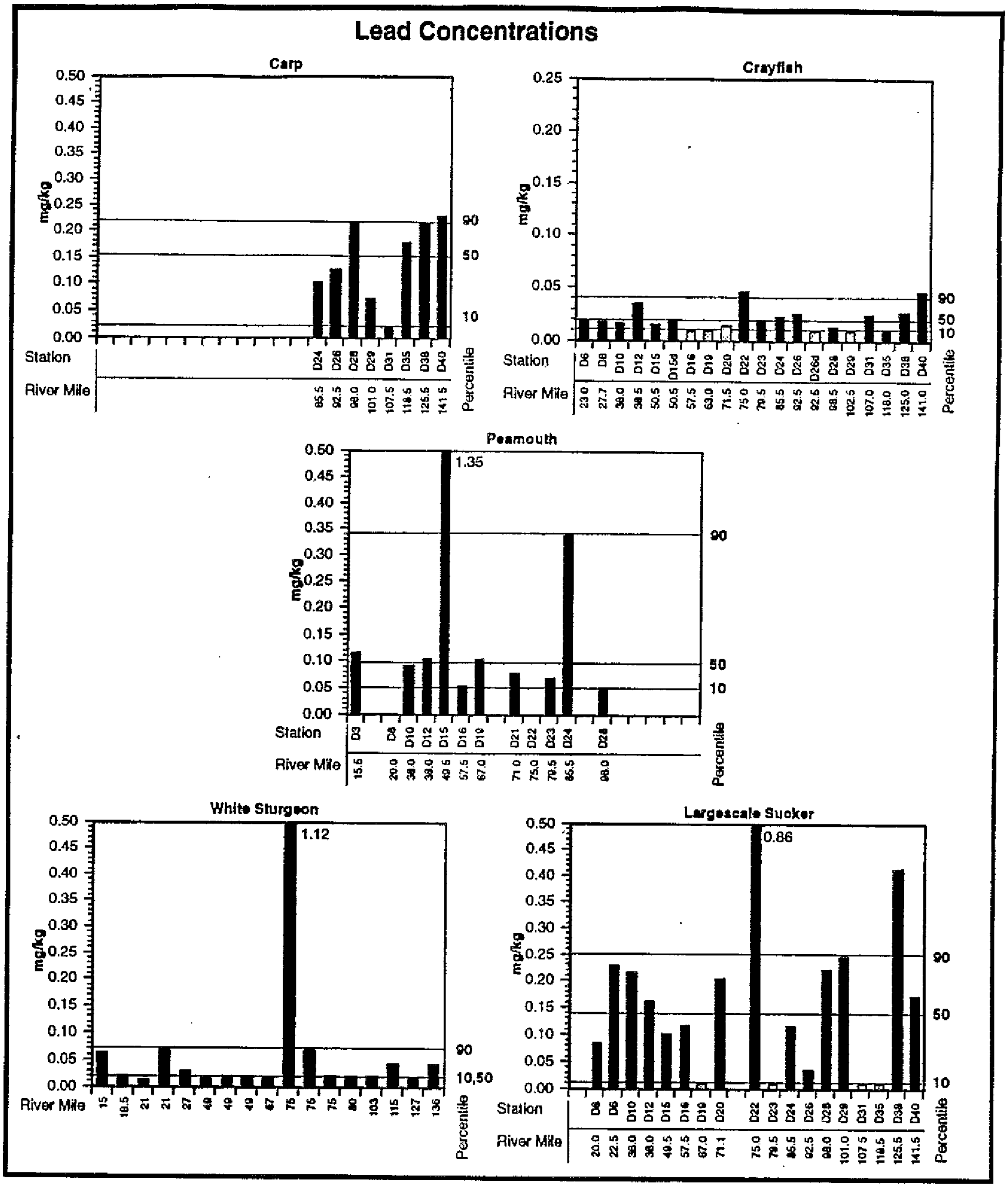


Figure 4-7. Lead concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

centrations corresponding to the lowest ten percent of measured values for these species were similar ranging from 0.01 to 0.02 mg/kg. Ninety percent of the samples had concentrations below 0.34, 0.25, 0.22, 0.07, and 0.04 for peamouth, largescale sucker, carp, white sturgeon, and crayfish, respectively (see Figure 4-7).

Table 4-8 shows the species and locations of the five highest lead concentrations measured in the lower Columbia River. All samples were collected between RM 50.5 and RM 125 and had lead concentrations in tissue ranging from 0.34 to 1.35 mg/kg. The highest and fifth highest lead concentrations were measured in peamouth collected in the Wallace Slough near the mouth of the Clatskanie River (RM 50.5) and adjacent to the St. Helens, OR marina below the mouth of the Multnomah channel, respectively (see Figure 4-7). The second and third highest lead tissue concentrations were measured in white sturgeon and largescale sucker caught near Kalama, WA. The fourth highest lead concentration was measured in largescale sucker caught near Reed Island, upstream of Washougal, WA.

Mercury. Mercury was detected in all tissue samples of carp, peamouth, and largescale sucker, 85 percent of the crayfish samples, and 88 percent of the white sturgeon samples analyzed (Table 4-6). Median concentrations (mg/kg) of mercury were 0.097, 0.0955, 0.071, 0.068, and 0.007 for carp, peamouth, largescale sucker, white sturgeon, and crayfish, respectively (Figure 4-8). Mercury concentrations corresponding to the lowest 10 percent of measured values ranged from 0.006 to 0.056 mg/kg. Ninety percent of the samples had concentrations below 0.212, 0.146, 0.131, 0.127 and 0.006 for peamouth, carp, largescale sucker, white sturgeon, and crayfish, respectively (see Figure 4-8).

Table 4-8 shows the species and locations of the five highest mercury concentrations measured in the lower Columbia River. Tissue concentrations of these samples ranged from 0.146 to 0.347 mg/kg. Four of these samples were collected in the 32-mile stretch of river between Kalama (RM 75) and Portland (RM 107). The highest mercury tissue concentrations were measured in white sturgeon caught downstream of Kalama. Peamouth caught near Astoria (RM 15.5) and St. Helens, OR (RM 85.5) had the second and third highest mercury tissue concentrations measured in the lower Columbia River. Carp collected near the upstream Bachelor Slough channel (RM 92.5) and in North Portland Harbor along Hayden Island (RM 107) had the fourth and fifth highest mercury tissue concentrations, respectively.

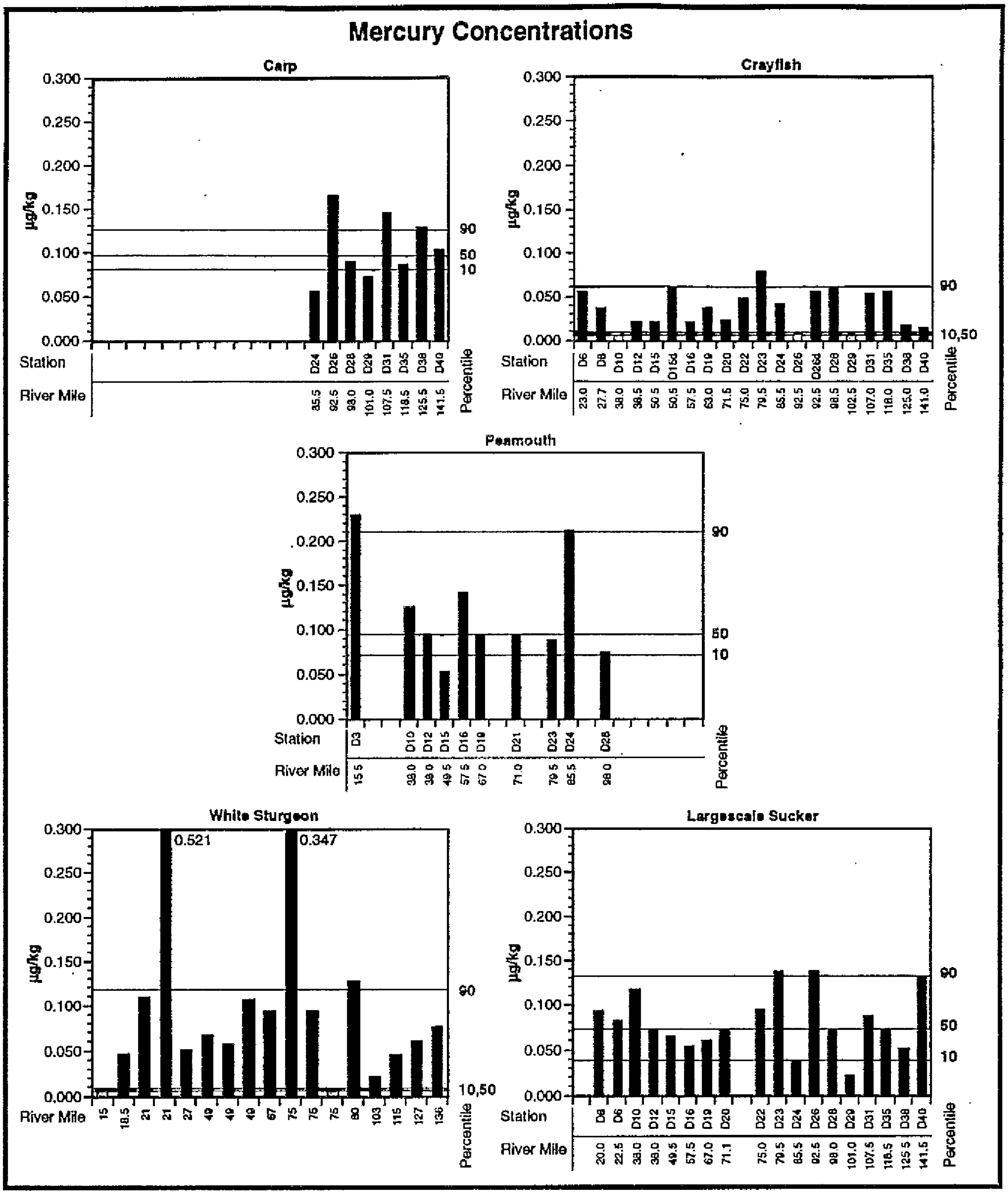


Figure 4-8. Mercury concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

Nickel. Nickel was detected in relatively few of the tissue samples analyzed (Figure 4-9). Concentrations above laboratory detection limits were measured in 15, 38, 20, 17, and 6 percent of the crayfish, carp, peamouth, largescale sucker, and white sturgeon samples, respectively (Table 4-6). Nickel was detected in fish and crayfish tissue samples collected from the 74-mile stretch of river between Wallace Slough (RM 50.5) and Reed Island (RM 125) (see Figure 4-9).

Table 4-8 shows the species and locations of the five highest nickel concentrations measured in the lower Columbia River. Tissue concentrations of these samples ranged from 1.36 to 17.29 mg/kg. The highest nickel tissue concentration was measured for carp collected near Reed Island, which is upstream from Washougal. The second and third highest nickel concentrations were measured in peamouth caught near St. Helens (RM 85.5) and Wallace Slough near the mouth of the Clatskanie River (RM 50.5), respectively. The fourth and fifth highest nickel concentrations were measured in carp and largescale sucker collected downstream of the mouth of the Willamette River (RM 98.5).

Selenium. Selenium was not detected above the reported laboratory detection limits in any sample. The detection limits ranged from 0.24 to 0.64 mg/kg wet weight (see Table 4-7).

Silver. Silver was detected in 80 percent of the crayfish samples and only one white sturgeon sample. Laboratory detection limits for silver analysis for carp, peamouth, and largescale sucker ranged from 0.15 to 0.29 mg/kg (Table 4-7). The 10, 50, and 90 percentile tissue concentrations of silver for crayfish samples were 0.17, 0.70, and 1.17 mg/kg, respectively (Figure 4-10).

Table 4-8 shows the locations of the five highest silver tissue concentrations measured in the lower Columbia River. These concentrations were all measured in crayfish and ranged from 1.11 to 1.54 mg/kg. The collection locations of these samples covered almost the entire study area from RM 27.7 to RM 141. The highest silver concentration was measured for crayfish collected from Carrolls Channel, just upstream from where this channel empties into the Cowlitz River. Similar to that observed for other metals, elevated levels of silver were also measured for tissue samples collected near Beacon Rock State Park below Bonneville Dam, Wallace Slough near the mouth of the Clatskanie River, and Reed Island upstream of Washougal.

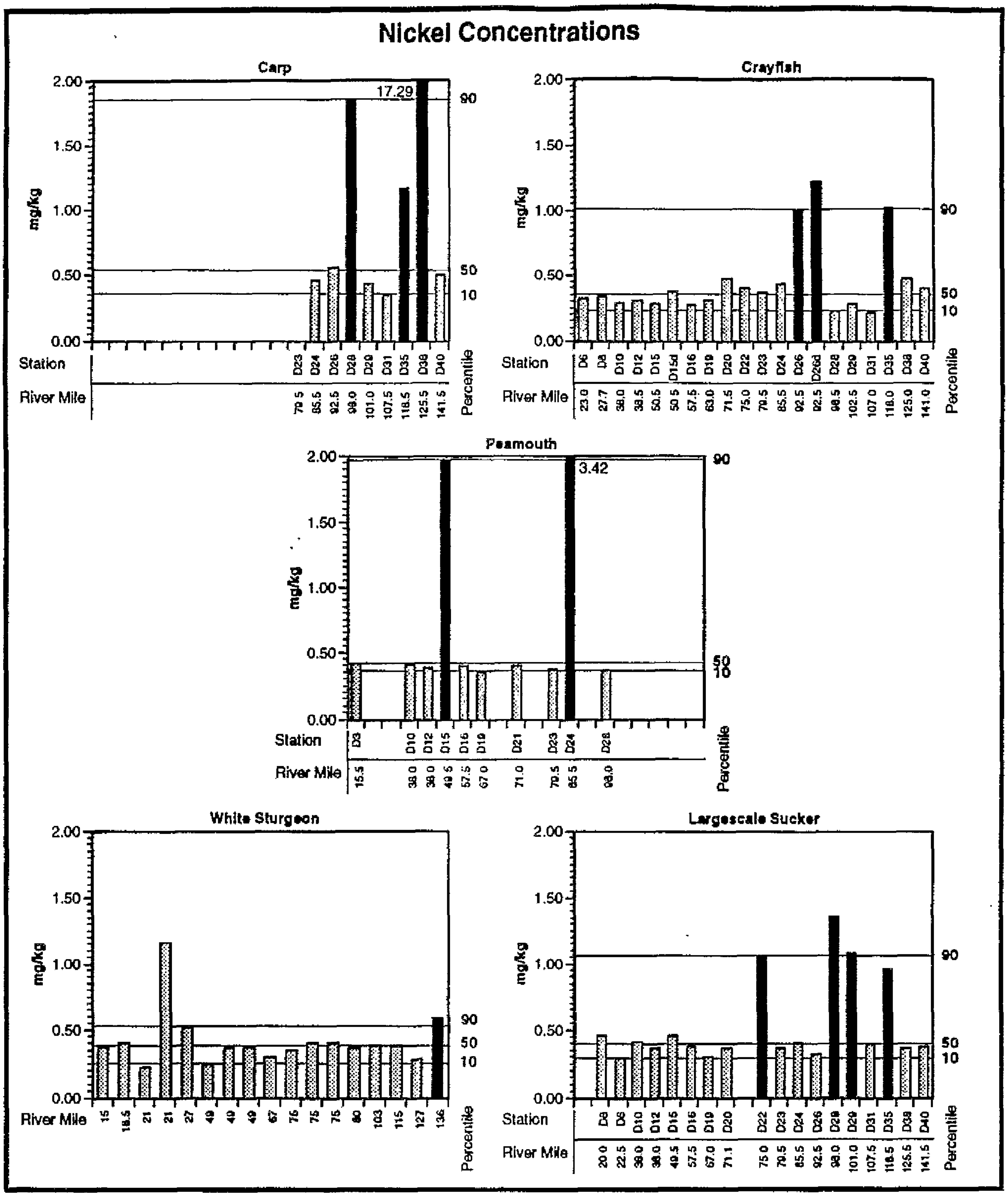


Figure 4-9. Nickel concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

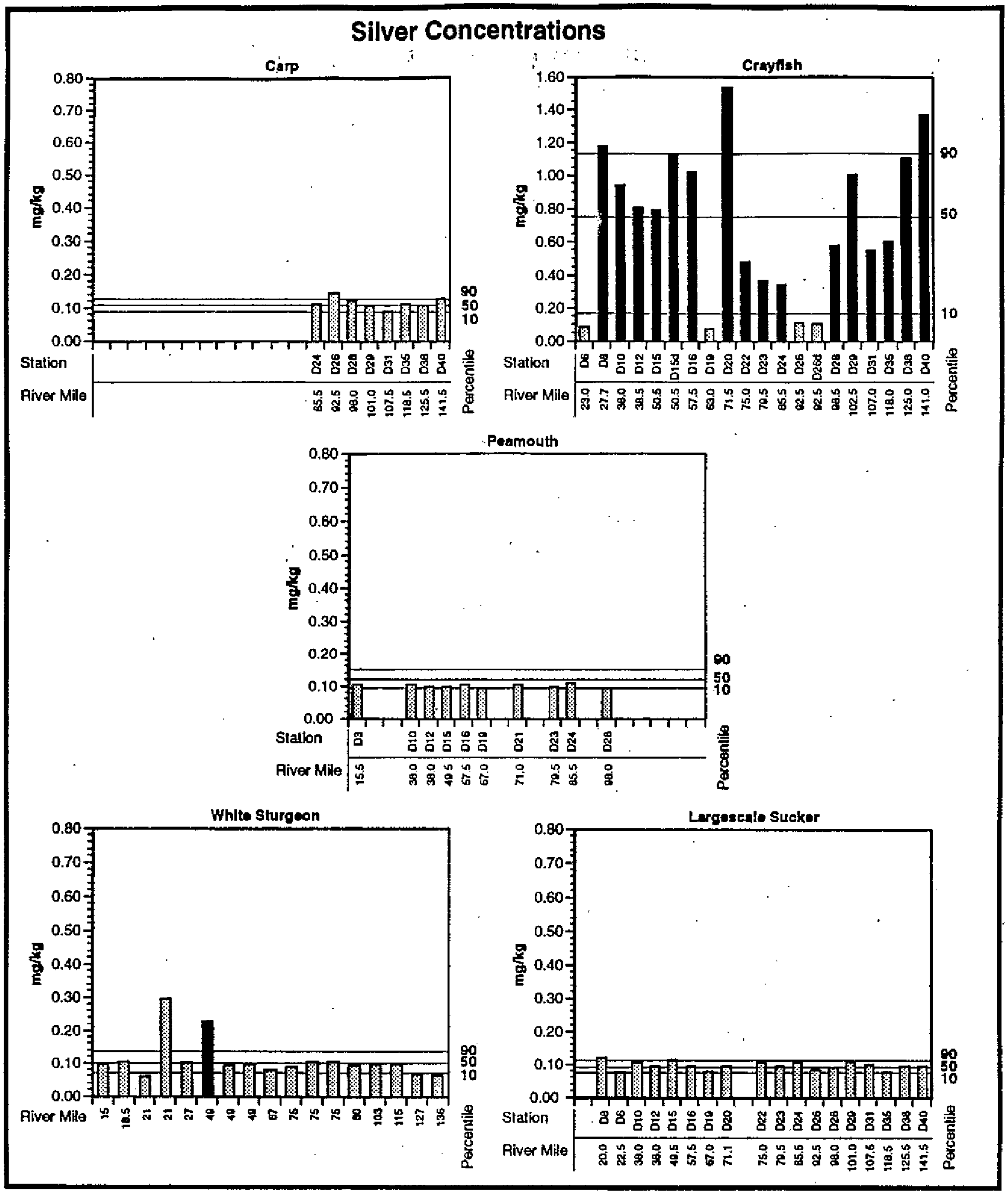


Figure 4-10. Silver concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

Zinc. Zinc was detected in all tissue samples of crayfish, carp, peamouth, largescale sucker, and all but two white sturgeon samples (Table 4-6). Median concentrations (mg/kg) of zinc were 104.75, 28.95, 26.3, 21.90, and 4.00 for carp, peamouth, crayfish, largescale sucker, and white sturgeon, respectively (Figure 4-11). Zinc concentrations corresponding to the lowest ten percent of measured values were 78.50, 22.70, 21.00, 18.0, and 2.3 for carp, peamouth, crayfish, largescale sucker, and white sturgeon, respectively (see Figure 4-11). Ninety percent of the samples had concentrations below 112.00, 33.70, 31.50, 28.60, and 5.70 for carp, crayfish, peamouth, largescale sucker, and white sturgeon, respectively (see Figure 4-11).

Carp samples had the five highest zinc tissue concentrations measured in the lower Columbia River (Table 4-8). Zinc concentrations in these carp samples ranged from 100 to 133.7 mg/kg. All of these fish were collected within a 32-mile stretch of the river from Bachelor Point, downstream of the Willamette River mouth (RM 92.5), to Reed Island, just upstream of Washougal (RM 125).

4.5.3 Tissue Semivolatile Organic Chemical Concentrations

4.5.3.1 Summary of Quality Assurance/Quality Control Results. A total of 73 tissue samples were analyzed for 52 semivolatile organic compounds. Eighteen samples were analyzed from white sturgeon, largescale suckers, and crayfish; ten samples were analyzed from peamouth; and nine samples were analyzed from carp. All of the tissue samples were unique field samples with the exception of sample ST-1-5-dup, which was a field duplicate of sample ST-1-5. The semivolatile organic data were considered acceptable for use in this report, although all compounds from several samples were qualified as estimates. All semivolatile data from samples ST-4-1-D and ST-2-2-D (both sturgeon samples) were qualified as estimates because surrogate recoveries were outside the acceptable control limits. Blank contamination by two phthalate esters [bis(2-ethylhexyl)phthalate and di-n-butyl phthalate] was noted in one of the eight analytical blanks. All positive values (above the DL) for these two compounds, in the 14 samples associated with this blank, were qualified as undetected. The large majority of the semivolatile organics data has been qualified as undetected. The reported DLs (40-1900 μg/kg) were less than or equal to those established in the QA/QC plan (Tetra Tech 1991b).

Analytical results, including surrogate and matrix spike recoveries and blind laboratory and field replicate samples, are presented under separate cover in the QA memorandum in Appendix A-4.

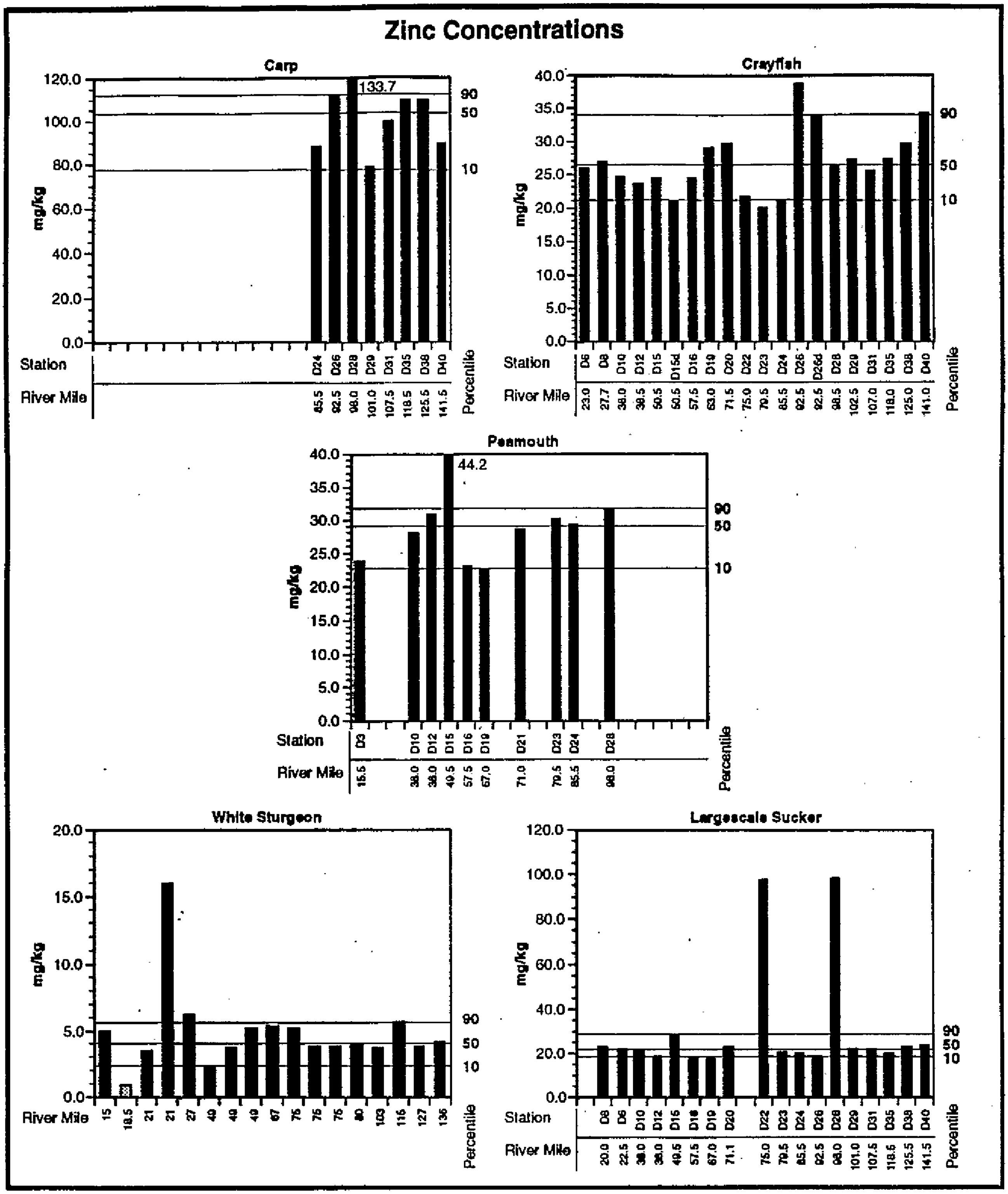


Figure 4-11. Zinc concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

4.5.3.2 Results. Whole-body composite samples of crayfish, carp, largescale sucker, peamouth, and filets of individual white sturgeon were analyzed for 52 semivolatile organic compounds (Table 1-1). Table 4-6 shows the compounds detected in at least one tissue sample, the number of samples for each species with concentrations above laboratory detection limits, and the range of concentrations measured. Table 4-7 shows laboratory detection limits for those compounds not detected in any samples for each species. Data for each category of semivolatile compounds are presented in the following sections.

Phenolic Compounds. Tissue samples were analyzed for nine phenolic compounds (Table 1-1). None of these compounds was detected in crayfish, peamouth, largescale sucker, or white sturgeon samples. Detection limits varied for the different chemicals, but limits were usually in the range of 100-200 μg/kg or 1,000-2,000 μg/kg (Table 4-7).

Four of the nine phenolic compounds were detected in one carp sample collected at station D29 located at RM 101. This station was located just downstream from the mouth of the Willamette River on the Washington side of the Columbia River. Phenolic compounds were not detected for the other eight carp samples analyzed. The detected compounds were phenol (5,000 μg/kg), 2-chlorophenol (4,200 μg/kg), 4-chloro-3-methylphenol (5,600 μg/kg), and 4-nitrophenol (4,000 μg/kg). Phenol, 2-chlorophenol, and 4-chlorophenol are all chemical intermediates used in the production of other chemicals for a wide number of industries. 4-Chloro-3-methylphenol is used as a topical antiseptic and disinfectant.

Halogenated Ethers. Tissue samples were analyzed for five halogenated ether compounds (Table 1-1). None of these compounds was detected in any of the five species sampled. Laboratory detection limits for all halogenated ethers, except 4-bromophenyl phenyl ether, ranged from 100 to 200 μg/kg. Detection limits for 4-Bromophenyl phenyl ether ranged from 200 to 400 μg/kg (Table 4-7).

Nitroaromatic Compounds. Tissue samples were analyzed for three nitroaromatic compounds (Table 1-1). None of these compounds was detected in crayfish, peamouth, largescale sucker, or white sturgeon. Detection limits for these chemicals ranged from 100 to 200 μg/kg (Table 4-7).

One of the three nitroaromatic compounds (2,4-dinitrotoluene) was detected in one carp sample collected at station D29 (RM 101). This station was located just downstream from the mouth of the Willamette

River on the Washington side of the Columbia River. The concentration of 2,4-dinitrotoluene measured in this sample was 1,000 μg/kg, ten times above the laboratory detection limit for other carp samples analyzed. 2,4-Dinitrotoluene is used in the production of explosives, dyestuffs, and urethane polymers.

Nitrosamines. Tissue samples were analyzed for two nitrosamine compounds (Table 1-1). Neither of these compounds was detected in crayfish, peamouth, largescale sucker, or white sturgeon. Detection limits for these chemicals ranged from 100 to 200 μg/kg (Table 4-7).

One of the three nitrosamine compounds (N-nitroso-di-n-propylamine) was detected in carp collected at station D29 (RM 101). This station was located just downstream from the mouth of the Willamette River on the Washington side of the Columbia River. The concentration of N-nitroso-di-n-propylamine in carp collected at this site (2,900 μg/kg) was 29 times above the laboratory detection limit for other carp samples analyzed.

Chlorinated Naphthalene. Tissue samples were analyzed for one chlorinated naphthalene compound, 2-chloronaphthalene (Table 1-1). This compound was not detected in any tissue samples analyzed. Laboratory detection limits for crayfish, carp, largescale sucker, and white sturgeon were 100 μg/kg. Detection limits for peamouth ranged from 100 to 200 μg/kg (Table 4-7).

Polynuclear Aromatic Hydrocarbons (PAHs). Tissue samples were analyzed for 16 PAH compounds (Table 1-1). None of these compounds was detected in crayfish, peamouth, or white sturgeon. Laboratory detection limits for these chemicals ranged from 100 to 400 μg/kg, depending on the species and chemical being analyzed (Table 4-7).

Three of the 16 PAHs were detected in carp collected at station D29 (RM 101). This station was located just downstream from the mouth of the Willamette River on the Washington side of the Columbia River. The detected compounds were acenaphthene (3,800 μg/kg), 2-methylnaphthalene (101 μg/kg), and pyrene (5,200 μg/kg). Two PAHs were also detected in tissue samples collected at station D35 in the Camas Slough (RM 118). The chemical 2-methylnaphthalene was detected in carp (230 μg/kg) and largescale sucker (140 μg/kg), and naphthalene was detected in carp (220 μg/kg). PAHs are formed by the combustion of hydrocarbon products; therefore, potential sources are numerous. PAHs may also be released from oil spills (Sittig 1985).

Chlorinated Benzenes. Tissue samples were analyzed for eight chlorinated benzene compounds (Table 1-1). None of these compounds was detected in crayfish, peamouth, largescale sucker, or white sturgeon. Laboratory detection limits for these chemicals ranged from 100 to 1,000 μg/kg depending on the species and chemical analyzed (Table 4-7).

Two of the eight chlorinated benzene compounds were detected in carp collected at station D29 (RM 101). This station was located just downstream from the mouth of the Willamette River on the Washington side of the Columbia River. The detected compounds were 1,4-dichlorobenzene (1,800 μg/kg), and 1,2,4-trichlorobenzene (3,100 μg/kg). Tissue concentrations of these chemicals were 10 and 15 times the laboratory detection level reported for other carp samples. No other carp samples had measurable levels of these two chemicals. 1,4-Dichlorobenzene is used primarily as an air deodorant and an insecticide. 1,2,4-Trichlorobenzene is used in dyes, intermediate production, transformer dielectric fluid, and as a solvent in chemical manufacturing.

Benzidines. 3-3'-Dichlorobenzidine was the only benzidine compound analyzed for in tissue samples (Table 1-1). This compound was not detected in any tissue samples analyzed. Laboratory detection limits for crayfish, carp, largescale sucker, and white sturgeon were 1,000 μg/kg. Detection limits for peamouth ranged from 1,000 to 2,000 μg/kg (Table 4-7).

Phthalate Esters. Tissue samples were analyzed for six phthalate esters (Table 1-1). None of the species had detectable levels of dimethylphthalate, diethylphthalate, or di-n-octylphthalate. Laboratory detection limits for these chemicals ranged from 100 to 400 μg/kg, depending on the species and chemical being analyzed (Table 4-7).

Di-n-butyl phthalate was detected in one crayfish sample collected at station D23 near St. Helens (RM 85.5). The reported concentration (110 μg/kg) was only slightly above the laboratory detection limit of 100 μg/kg.

Butylbenzylphthalate was detected in one sturgeon sample collected at RM 75. The reported concentration (990 μg/kg) was almost ten times the laboratory detection limit of 100 μg/kg.

Bis-2-(ethylhexyl)phthalate was detected in 72, 33, 90, 44, and 28 percent of the crayfish, carp, peamouth, largescale sucker, and white sturgeon samples analyzed, respectively. This chemical is a common laboratory contaminant which was detected in several of the laboratory blanks analyzed (Appendix A-6); therefore, these data should be cautiously interpreted.

4.5.4 Tissue Pesticide Concentrations

4.5.4.1 Summary of Quality Assurance/Quality Control Results. A total of 73 tissue samples were analyzed for pesticides and PCBs. Eighteen samples were analyzed from white sturgeon, largescale suckers, and crayfish; ten samples were analyzed from peamouth; and nine samples were analyzed from carp. All of the tissue samples were unique field samples with the exception of sample ST-1-5-dup, which was a field duplicate of sample ST-1-5. The pesticide/PCB data were considered acceptable for use in this report, although several compounds were qualified as estimates. The pesticides 4,4'-DDT, 4,4'-DDD, o,p'-DDE, and gamma-BHC for sample D24S (sucker) and o,p'-DDE and parathion, for sample D3P (peamouth), were qualified as estimates because of poor matrix spike recoveries. All sample results for sample D10P (peamouth) were qualified as estimated and undetected because of severe matrix interference. A few of the compounds were qualified as estimates by the laboratory because of a coeluting peak present for Aroclor 1254. No blank contamination was noted for any of the eight method blanks performed. The large majority of pesticide/PCB data have been qualified as undetected. The reported DLs (2-150 μg/kg) were less than or equal to those established in the QA/QC Plan (Tetra Tech 1991b).

Analytical results, including surrogate and matrix spike recoveries and blind laboratory and field replicate samples, are presented under separate cover in the QA memorandum in Appendix A-6.

4.5.4.2 Results for Pesticides. Whole-body composite samples of crayfish, carp, largescale sucker, peamouth, and filets of individual white sturgeon were analyzed for 29 pesticides (Table 1-1). Pesticide concentrations (μg/kg wet weight) measured for each species are presented in Appendices D1-11, D2-11, D3-11, D4-11, and D5-11. Table 4-6 shows the compounds that were detected in at least one tissue sample, the number of samples for each species that had concentrations above laboratory detection limits, and the range of concentrations measured. Table 4-7 shows laboratory detection limits for those compounds that were not detected in any samples for each species.

DDT. DDT is an organochlorine pesticide whose use was banned in the U.S. in 1972. Prior to the ban, however, it was a widely used, low-cost agricultural insecticide. Technical grade DDT was mostly composed of 4,4'-DDT, but also contained up to 30 percent o,p'-DDT. Tissue samples were analyzed for both isomers of DDT (Table 1-1). The pesticide o,p'-DDT was detected in three samples collected in the lower Columbia River. White sturgeon collected downstream of Kalama (RM 75) had a tissue concentration of 30 μg/kg; carp collected at station D28, located approximately 3 miles downstream of the Willamette River discharge, had a tissue concentration of 6.9 μg/kg; and crayfish collected at station D23 (RM 79) had a tissue concentration of 3 μg/kg. The pesticide o,p'-DDT was not detected in peamouth or largescale sucker (Figure 4-12). Laboratory detection limits ranged from 3 to 25 μg/kg for peamouth samples and 3 to 15 μg/kg for largescale sucker samples analyzed (Table 4-7).

4,4'-DDT was detected at more locations and in higher concentrations than o,p'-DDT. While o,p'-DDT was not detected in largescale sucker, this species had the highest tissue concentrations and proportion of samples with measurable levels of 4,4'-DDT (78 percent). 4,4'-DDT was detected in 56 percent of the carp samples analyzed and 44 percent of the white sturgeon analyzed. Like the o,p'-DDT results, 4,4'-DDT was not detected in peamouth and was detected in crayfish collected from a single site. Median values for these species were highest for largescale sucker (5.5 μg/kg), followed by carp (3.5 μg/kg) and white sturgeon (2.3 μg/kg) (Figure 4-13).

Table 4-9 shows the species and locations of the five highest 4,4'-DDT concentrations measured in the lower Columbia River. The highest DDT concentrations (11 to 16 μg/kg) were measured in largescale sucker, white sturgeon, and carp collected at locations ranging from RM 38 to RM 136. Specific collection locations were the Clifton Channel near the upstream end of Tenasillahe Island (RM 38), Wallace Slough (RM 49.5), near Wallace Island (RM 49), Bachelor Point (RM 92.5), and near Multnomah Falls (RM 136).

DDE. DDE is not produced commercially, but is instead a degradation product of DDT. Tissue samples were analyzed for two isomers of DDE: o,p'-DDE and 4,4'-DDE (see Table 1-1). The pesticide o,p'-DDE was detected in 50 percent of the largescale sucker samples, and 33 percent of the carp samples analyzed. One peamouth sample and one white sturgeon sample had detectable levels of this chemical. The pesticide o,p'-DDE was not detected in any crayfish samples collected in the study area. Similar to the results reported for 4,4'-DDT, largescale sucker had the highest o,p'-DDE concentrations and

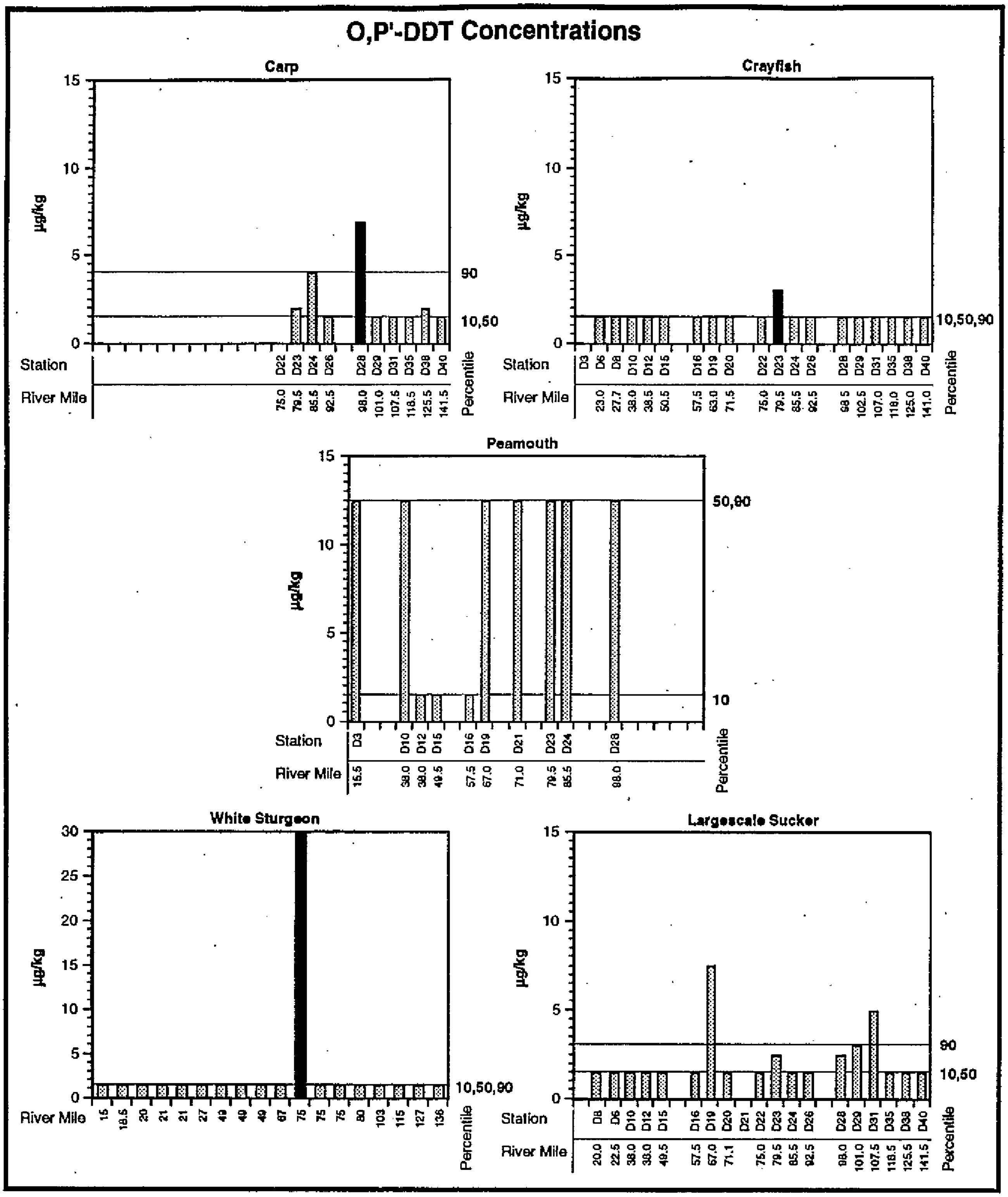


Figure 4-12. O,P'-DDT concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit. The proposed New York State Fish Flesh Criterion for DDT is 200 µg/kg based on all DDT congeners.

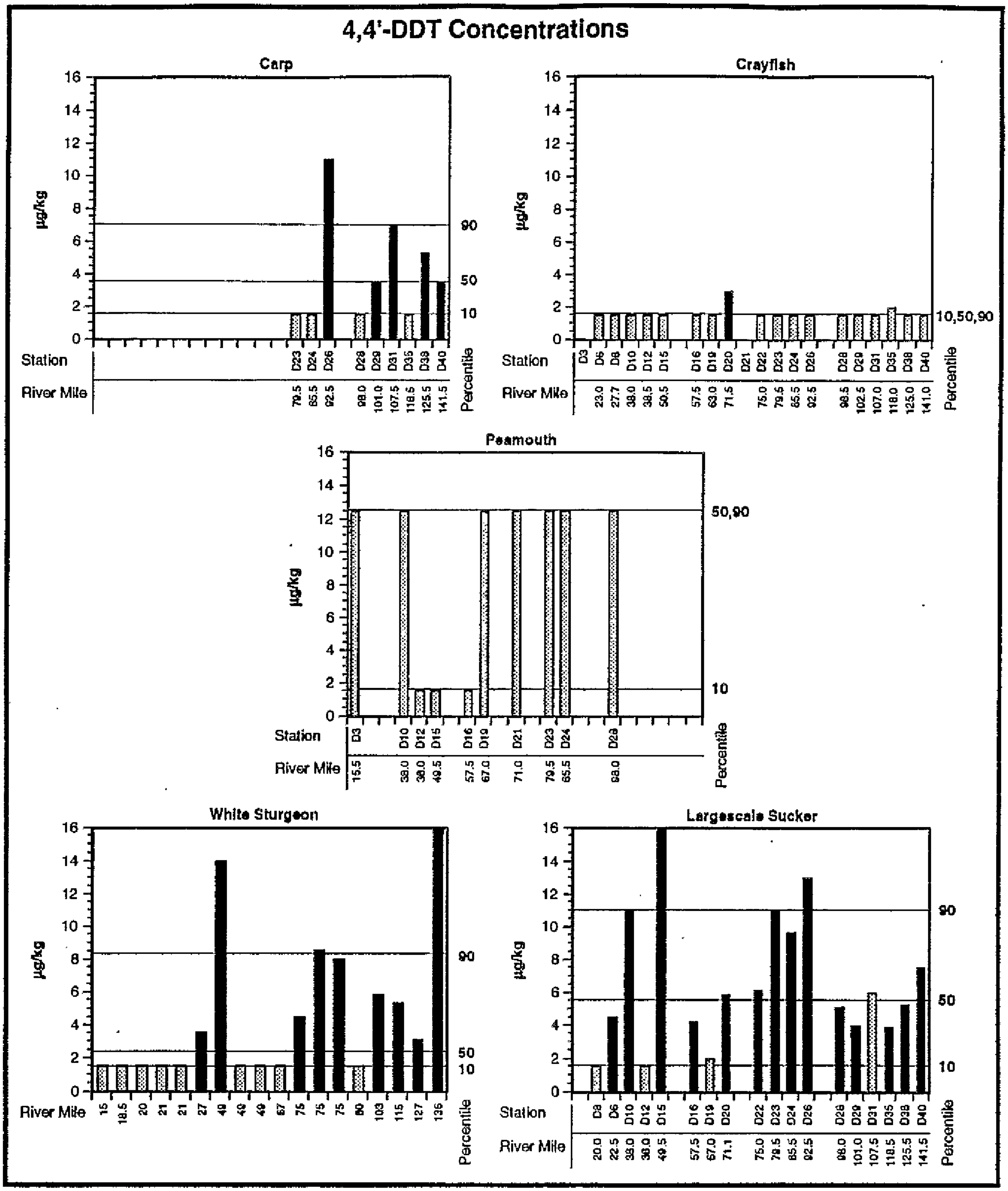


Figure 4-13. 4,4'-DDT concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit. The proposed New York State Fish Flesh Criterion for DDT is 200 µg/kg based on all DDT congeners.

TABLE 4-9. LOCATIONS OF MAXIMUM MEASURED PESTICIDE CONCENTRATIONS IN TISSUE SAMPLES (μg/kg wet weight).

(Page 1 of 3)

Compound	Maximum Concentrations	Station Designation	Type of Fish	Sample Type	Location (River Mile)	Comment
o,p'-DDE	42	D31	Largescale sucker	WB[a]	107.5	Hayden Island, N. Portland Harbor, above Interstate 5 Bridge
	24	D15	Largescale sucker	WB	49.5	Wallace Slough
	23	D19	Largescale sucker	WB	57.0	Coal Creek Slough below Alder Bluff
	21	D23	Largescale sucker	WB	79.5	Burke Slough near Martin Island
	17	D26	Carp	WB	92.5	Upstream of Bachelor Point, Bachelor Is. Slough
o,p'-DDD	49	D3	Peamouth	WB	15.5	Near Port of Astoria, OR
	29	D31	Largescale sucker	WB	107.5	Hayden Island, N. Portland Harbor, above Interstate 5 Bridge
	24	D29	Largescale sucker	WB	101.0	Willamette River Mouth
	24	D23	Largescale sucker	WB	79.5	Burke Slough near Martin Island
	24	D22	Largescale sucker	WB	75.0	Port of Kalama, WA
	24	D15	Largescale sucker	WB	49.5	Wallace Slough
o,p'-DDT	30	RM75	White sturgeon	ST[b]	75	Kalama, WA
	6.9	D28	Carp	WB	98.0	3 mi. downstream of Willamette River mouth
	3.0	D23	Crayfish	WB	79.5	Burke Slough near Martin Island
4,4'-DDT	16	D15	Largescale sucker	WB	49.5	Wallace Slough near mouth of Clatskanie River
	16	RM136	White sturgeon	ST	136	Multnomah Falls, OR
	14	RM49	White sturgeon	ST	49	Wallace Island
	13	D26	Largescale sucker	WB	92.5	Upstream of Bachelor Point, Bachelor Is. Slough
	11	D26	Carp	WB	92.5	Upstream of Bachelor Point, Bachelor Is. Slough
	11	D10	Largescale sucker	WB	38.0	Clifton Channel, along upstream end of Tenasillahe Is.
4,4'-DDE	480	D24	Peamouth	WB	85.5	Adjacent to St. Helens, OR, marina, below Multnomah Channel mouth
	270	D3	Peamouth	WB	15.5	Near Port of Astoria, OR
	200	D23	Peamouth	WB	79.5	Burke Slough near Martin Island
	170	D21	Peamouth	WB	71.0	Goble, OR, downstream of Sandy Is.
	140	D19	Peamouth	WB	57.0	Coal Creek Slough near Alder Bluff
4,4'-DDD	72	D23	Peamouth	WB	79.5	Burke Slough near Martin Island
	38	D19	Peamouth	WB	57.0	Downstream of Longview, WA
	38	D15	Peamouth	WB	49.5	Wallace Slough near mouth of Clatskanie River
	30	D26	Largescale sucker	WB	92.5	Upstream of Bachelor Point, Bachelor Island Slough
	26	D31	Largescale sucker	WB	107.5	Hayden Island, N. Portland Harbor, above Interstate 5 bridge

TABLE 4-9. LOCATIONS OF MAXIMUM MEASURED PESTICIDE CONCENTRATIONS IN TISSUE SAMPLES ($\mu g/kg$ wet weight).

(Page 2 of 3)

Compound	Maximum Concentrations	Station Designation	Type of Fish	Sample Type	Location (River Mile)	Comment
Aldrin	42	D21	Peamouth	WB	71.0	Goble, OR, downstream of Sandy Is.
	11	D15	Peamouth	WB	49.5	Wallace Slough near mouth of Clatskanie River
	9.6	D29	Carp	WB	101.0	Mouth of Willamette River
	5.6	D12	Largescale sucker	WB	38.0	Elochoman Slough near Port of Cathlamet, WA
	3.9	D10	Largescale sucker	WB	38.0	Clifton Island, along upstream end of Tenasillahe Is.
Dieldrin	35	D21	Peamouth	WB	71.0	Goble, OR, downstream of Sandy Is.
	32	D23	Peamouth	WB	79.5	Burke Slough near Martin Island
	12	RM75	White sturgeon	ST	75	Kalama, WA
	6.6	D31	Crayfish	WB	107.0	Hayden Island, Portland Harbor, above Interstate 5 bridge
						Hayden Island, Portland Harbor, above Interstate 5 bridge
	5.6	D31	Carp	WB	107.0	
Methyl parathion	38	D6	Crayfish	WB	23.0	Grays Bay near Altoona, WA
	22	RM103	White sturgeon	ST	103	Downstream of Hayden Island
	17	D24	Crayfish	WB	85.5	Adjacent to St. Helens, OR, marina below Multnomah Channel mouth
	16	R27	White sturgeon	ST	27	Woody Island, Lewis and Clark Nat'l. Wildlife Refuge
	10	D16	Crayfish	WB	57.5	Coal Creek Slough below Alder Bluff
	10	RM115	White sturgeon	ST	115	Government Island
Parathion	26	D2	Peamouth	WB	15.5	Near Port of Astoria, OR
	15	D20	Largescale sucker	WB	71.1	Carrolls Channel, upstream of Cowlitz River mouth
	7.8	D8	Largescale sucker	WB	20.0	Marsh Island, Lewis and Clark National Wildlife Refuge
	7.5	D16	Largescale sucker	WB	57.5	Coal Creek Slough below Alder Bluff
Isophorone	430	D19	Crayfish	WB	63.0	Downstream of Longview, WA
	330	D28	Crayfish	WB	98.5	3 miles downstream of Willamette River mouth
	310	D31	Crayfish	WB	107.0	Hayden Island, Portland Harbor, above Interstate 5 bridge
	280					Upstream of Bachelor Point, Bachelor Island Sough
	210	D26	Crayfish	WB	92.5	Adjacent to St. Helens, OR, marina below Multnomah
		D24	Crayfish	WB	85.5	Channel mouth
Endosulfan I	85	D23	Peamouth	WB	79.5	Burke Slough near Martin Island
	69	D21	Peamouth	WB	71.0	Goble, OR, downstream of Sandy Is.
	45	D3	Peamouth	WB	15.5	Near Port of Astoria, OR
	49	RM27	White sturgeon	ST	27	Woody Island, Lewis and Clark Nat'l. Wildlife Refuge
	3.3	D10	Largescale sucker	WB	38.0	Clifton Channel along upstream end of Tenasillahe Is.

TABLE 4-9. LOCATIONS OF MAXIMUM MEASURED PESTICIDE CONCENTRATIONS
IN TISSUE SAMPLES (µg/kg wet weight).
(Page 3 of 3)

Compound	Maximum Concentrations	Station Designation	Type of Fish	Sample Type	Location (River Mile)	Comment
Endosulfan I	85	D23	Peamouth	WB	79.5	Burke Slough near Martin Island
	69	D21	Peamouth	WB	71.0	Goble, OR, downstream of Sandy Is.
	45	D3	Peamouth	WB	15.5	Near Port of Astoria, OR
	49	RM27	White sturgeon	ST	27	Woody Island, Lewis and Clark Nat'l. Wildlife Refuge
	3.3	D10	Largescale sucker	WB	38.0	Clifton Channel along upstream end of Tenasillahe Is.
Endrin	12	D23	Largescale sucker	WB	79.5	Burke Slough near Martin Island
	6.7	D29	Largescale sucker	WB	101.0	Mouth of Willamette River
	5.1	RM75	White sturgeon	ST	75	Kalama, WA
	3.9	D38	Carp	WB	125.5	Reed Island, upsteam of Washougal, WA
	3.2	RM75[c]	White sturgeon	ST	75	Kalama, WA
Methoxychlor	180	RM75	White sturgeon	ST	75	Kalama, WA
	65	D15	Largescale sucker	WB	49.5	Wallace Slough near mouth of Clatskanie River
	50	RM27	White sturgeon	ST	27	Woody Island, Lewis and Clark Nat'l. Wildlife Refuge
	50	RM136	White sturgeon	ST	136	Multnomah Falls, OR
	34	D24	Crayfish	WB	85.5	Adjacent to St. Helens, OR, marina below Multnomah Channel mouth

[a] Whole-body tissue samples were analyzed for crayfish largescale sucker, carp, and peamouth.

[b] Filet samples of white sturgeon were analyzed.

[c] Indicates a replicate sample analysis.

proportion of samples detecting this chemical. The 10, 50, and 90 percentile concentrations of o,p'-DDE in largescale sucker tissue were 1.5, 4.7, and 23 μg/kg, respectively. Three carp samples had measurable levels of o,p'-DDE ranging from 11 to 17 μg/kg (Figure 4-14).

Table 4-9 shows the species and locations of the five highest o,p'-DDE concentrations measured in the lower Columbia River. Four of the five values were measured in largescale sucker, with the fifth highest value being measured in carp tissue. The five highest concentrations ranged from 17 to 42 μg/kg. The highest o,p'-DDE concentration was measured for largescale sucker collected in North Portland Harbor near Hayden Island (RM 107). Collection locations of the other four highest tissue concentrations of o,p'-DDE include Wallace Slough (RM 49.5), downstream of Longview (RM 63), Burke Slough (RM 79.5), and Bachelor Point (RM 92.5).

4,4'-DDE was detected in a higher proportion of tissue samples and at higher concentrations than other DDT derivatives. Unlike other DDT derivatives, 4,4'-DDE was detected in a high proportion of crayfish samples (89 percent). It was also detected in 83 percent of the white sturgeon samples, 78 percent of the carp samples, and 70 percent of the peamouth samples analyzed. This derivative of DDT was detected in one largescale sucker. However, median concentrations of 4,4'-DDE were highest for peamouth (111.5 μg/kg), followed by carp (22 μg/kg), white sturgeon (10.4 μg/kg), and crayfish (7.5 μg/kg). The concentration corresponding to the lowest 10 percentile of samples ranged from 1.5 to 2.5 μg/kg for all species. Ninety percent of the samples had concentrations below 270, 88, 50, 31, and 14 μg/kg for peamouth, carp, white sturgeon, largescale sucker, and crayfish, respectively (Figure 4-15).

Table 4-9 shows the species and locations of the five highest o,p'-DDE concentrations (140 to 480 μg/kg) measured in the lower Columbia River. All of these concentrations were measured in peamouth. The highest 4,4'-DDE concentration was measured for peamouth collected near St. Helens (RM 85.5). Collection locations of the other four highest tissue concentrations of 4,4'-DDE are near Astoria (RM 15.5), Burke Slough (RM 79.5), downstream of Kalama (RM 71), and Longview (RM 63).

DDD. DDD was an organochlorine insecticide used less frequently than DDT. DDD is also a degradation product of DDT. Tissue samples were analyzed for two isomers of DDD: o,p'-DDD and 4,4'-DDD (Table 1-1). The pesticide o,p'-DDD was detected in 33 percent of the largescale sucker samples, two white sturgeon samples and one peamouth and carp sample. The pesticide o,p'-DDD was

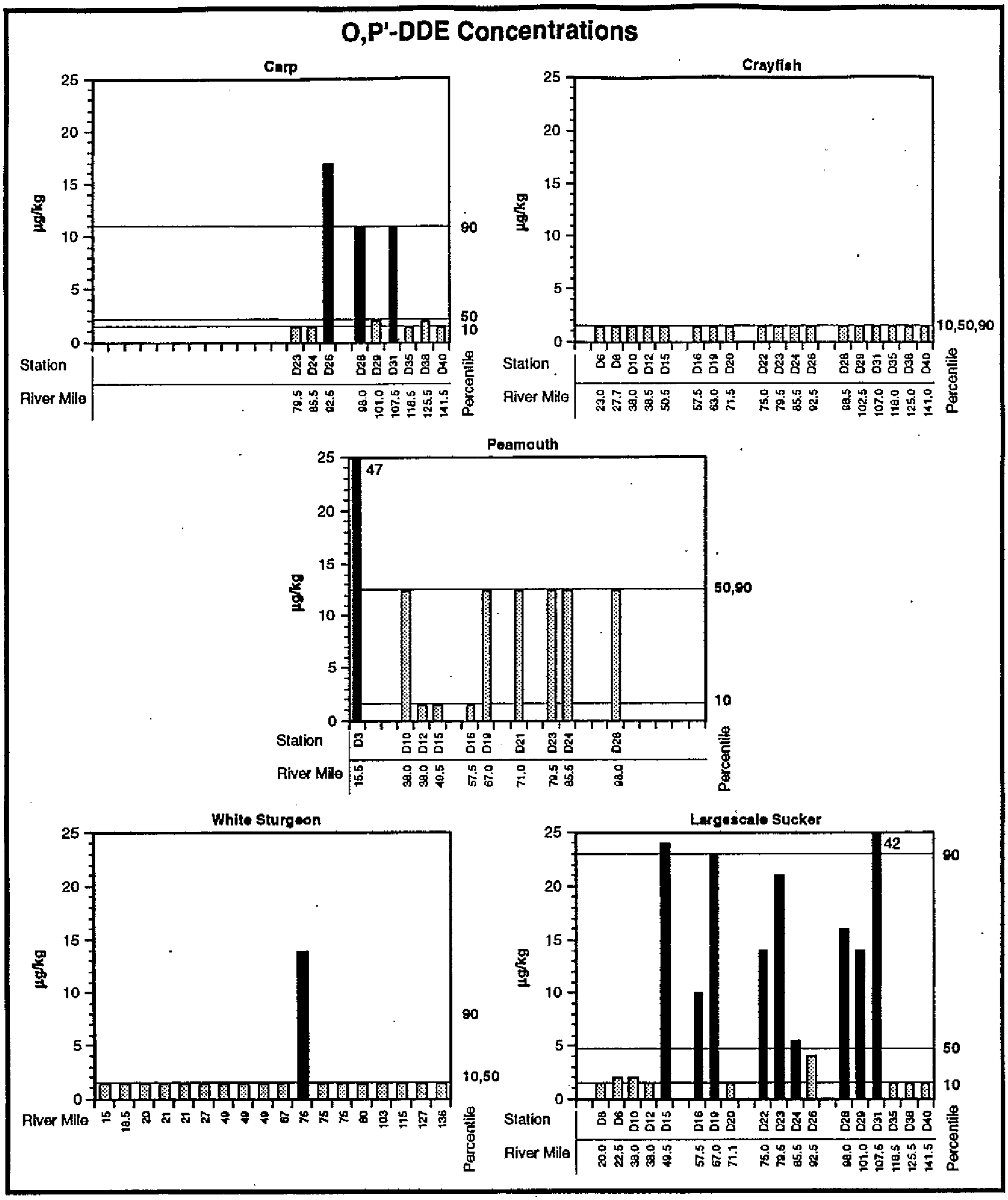


Figure 4-14. O,P'-DDE concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit. The proposed New York State Fish Flesh Criterion for DDE is 200 µg/kg based on all DDE congeners.

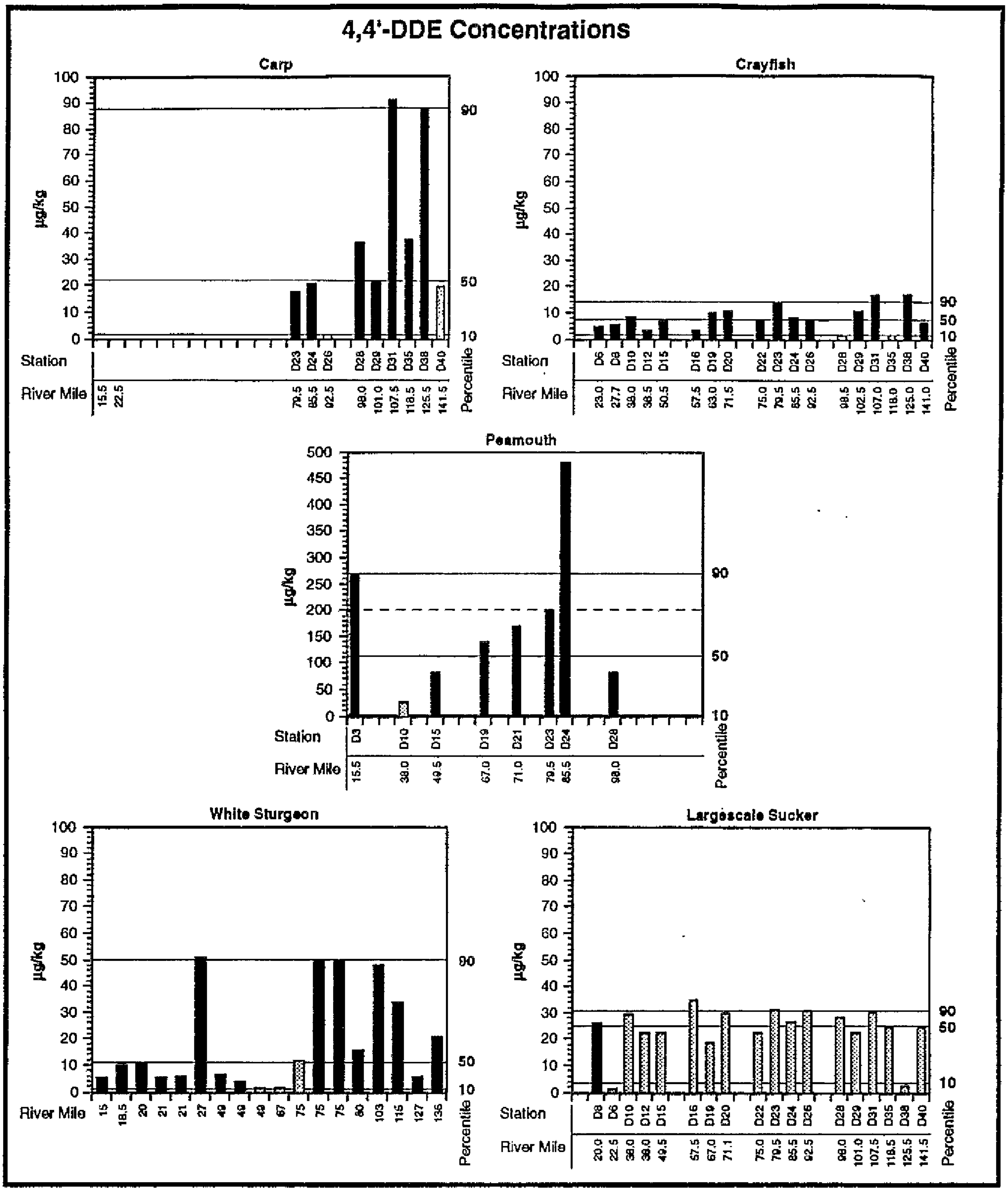


Figure 4-15. 4,4'-DDE concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit. The proposed New York State Fish Flesh Criterion for DDE is 200 µg/kg, based on all DDE congeners, and is shown here with a broken line for peamouth.

not detected in any crayfish samples collected in the lower Columbia River. Similar to the results reported for 4,4'-DDT and o,p'-DDE, largescale sucker had the highest o,p'-DDD concentrations and proportion of samples detecting this chemical (Figure 4-16).

Table 4-9 shows the species and locations of the five highest o,p'-DDD concentrations measured in the lower Columbia River. The highest concentration of this chemical was measured in peamouth collected at station D3 near Astoria. The other four highest values were measured in largescale sucker collected between RM 49.5 to RM 107.5. Collection sites include Wallace Slough (RM 49.5), Port of Kalama (RM 75), Burke Slough (RM 79.5), just downstream from the mouth of the Willamette (RM 101), and North Portland Harbor near Hayden Island (RM 107.5).

4,4'-DDD was detected in all five species. Tissue concentrations were measured at collection sites throughout the river from RM 27 to RM 141. Largescale sucker had the highest proportion of samples with detected levels of this chemical (89 percent). The 10, 50, and 90 percentile concentrations for this species were 3.5, 17, and 24 µg/kg, respectively. 4,4'-DDD was detected in 67 percent of the carp samples analyzed. The 10, 50, and 90 percentile concentrations for this species were 1.5, 4.4, and 14 µg/kg, respectively. This pesticide was detected in three (30 percent) peamouth, three white sturgeon (17 percent), and two crayfish (11 percent) samples. Concentrations corresponding to 10, 50, and 90 percentiles are indicated in Figure 4-17.

Table 4-9 shows the species and locations of the five highest 4,4'-DDD concentrations (26 to 72 µg/kg) measured in the lower Columbia River. These concentrations were measured in peamouth and largescale sucker, with the three highest concentrations occurring in peamouth. These fish were collected from RM 49.5 to RM 107.5. This stretch of river also included the five maximum tissue concentrations measured for o,p'-DDT, o,p'-DDE, and o,p'-DDD, and several of the highest values measured for 4,4'-DDT, 4,4'-DDE. Collection locations where maximum 4,4'-DDD tissue concentrations were measured include Burke Slough (RM 79.5), downstream of Longview (D19), Wallace Slough (RM 49), Bachelor Point (RM 92.5), and North Portland Harbor near Hayden Island (RM 107.5).

Heptachlor and Heptachlor Epoxide. Heptachlor, a chlorinated insecticide, was banned in the U.S. in 1987—although sales of remaining stocks were allowed after this ban. It was detected in one tissue sample collected in the lower Columbia River. A concentration of 4.5 µg/kg was measured in

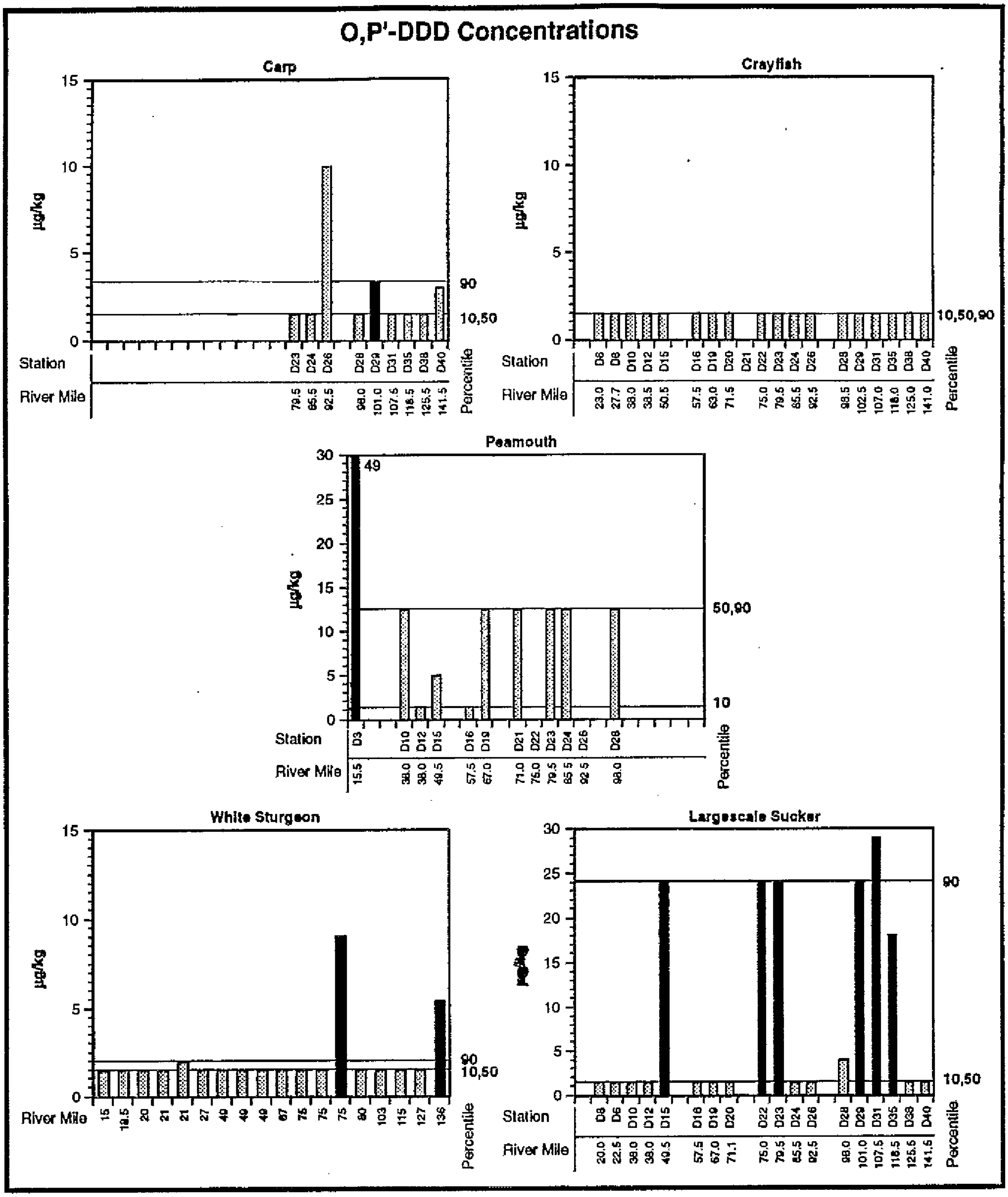


Figure 4-16. O,P'-DDD concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit. The proposed New York State Fish Flesh Criterion for DDD is 200 µg/kg based on all DDD congeners.

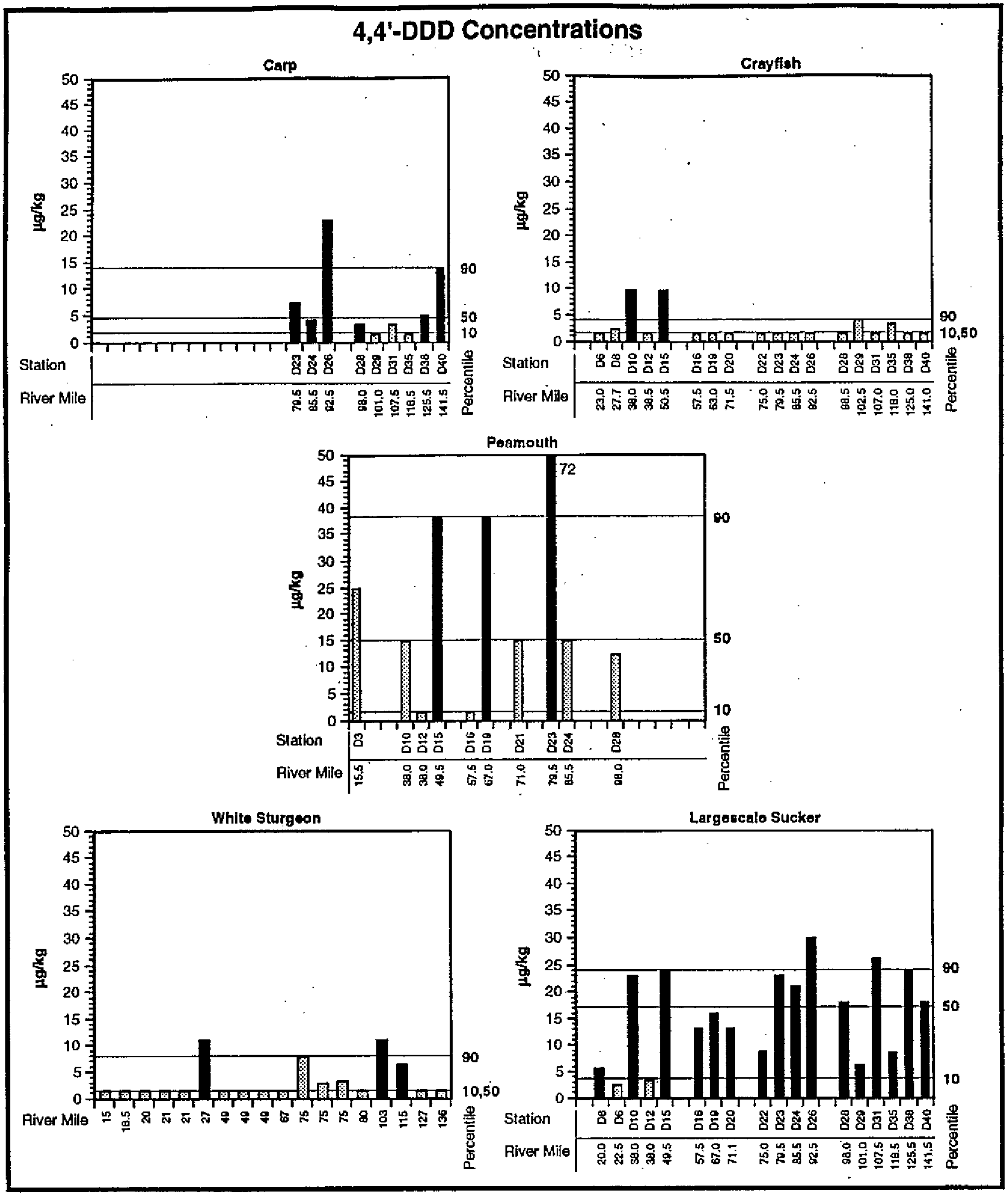


Figure 4-17. 4,4'-DDD concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit. The proposed New York State Fish Flesh Criterion for DDD is 200 µg/kg based on all DDD congeners.

crayfish collected at station D38^E (RM 125) located near Reed Island which is upstream of Washougal. Laboratory detection limits for this pesticide were 3 μg/kg for crayfish, carp, largescale sucker, and white sturgeon (Table 4-7). Detection limits were higher for peamouth, ranging from 3 to 25 μg/kg.

Heptachlor epoxide was not detected in any of the five species collected in the lower Columbia River. Laboratory detection limits were similar to those reported for heptachlor (Table 4-7).

Chlordane. Chlordane was not detected in any of the five species collected in the lower Columbia River. Laboratory detection limits for this pesticide were 3 μg/kg for crayfish, carp, largescale sucker, and white sturgeon (Table 4-7). Detection limits were higher for peamouth, ranging from 3 to 25 μg/kg.

Aldrin. Aldrin is an organochlorine pesticide that has been banned in the U.S. since 1987. It was detected in seven tissue samples collected in the lower Columbia River between RM 38 and RM 141. Tissue concentrations ranged from 3.7 to 42 μg/kg. All of these measured values occurred in carp, peamouth, and largescale sucker. Aldrin was not detected in crayfish or white sturgeon tissue (Figure 4-18).

Table 4-9 shows the species and locations where the five highest concentrations were measured. Tissue concentrations ranged from 3.9 to 42 μg/kg. The highest tissue concentration was measured in peamouth collected downstream of Kalama (RM 71). The other four highest concentrations of aldrin were measured for species collected in Wallace Slough, near the mouth of the Willamette River (RM 101), Elochoman Slough adjacent to the Port of Cathlamet, and in Clifton Channel near the upstream end of Tenasillahe Island.

Dieldrin. Dieldrin is an organochlorine pesticide banned in the U.S. since 1987. It was detected in 11 tissue samples (five white sturgeon, two peamouth, two carp, one largescale sucker, and one crayfish sample) collected in the lower Columbia River between RM 27 and RM 125 (Figure 4-19). Tissue concentrations ranged from 3 to 35 μg/kg (Figure 4-19). The five highest dieldrin tissue concentrations were measured for species collected in Carrolls Channel (RM 71), Burke Slough (RM 79.5), downstream of Kalama (RM 75), and North Portland Harbor near Hayden Island (RM 107) (Table 4-9).

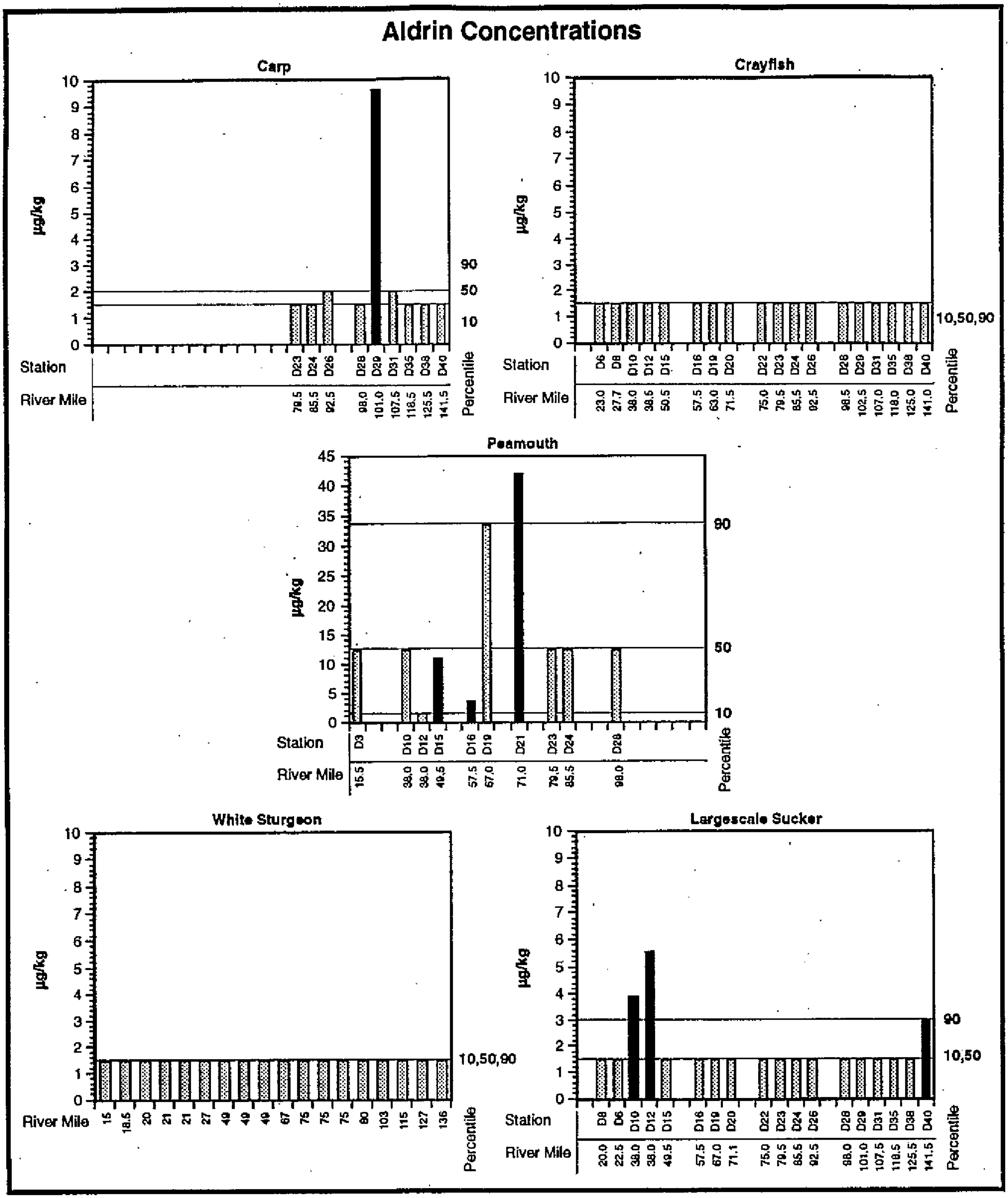


Figure 4-18. Aldrin concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit. The proposed New York State Fish Flesh Criterion for aldrin is 120 µg/kg.

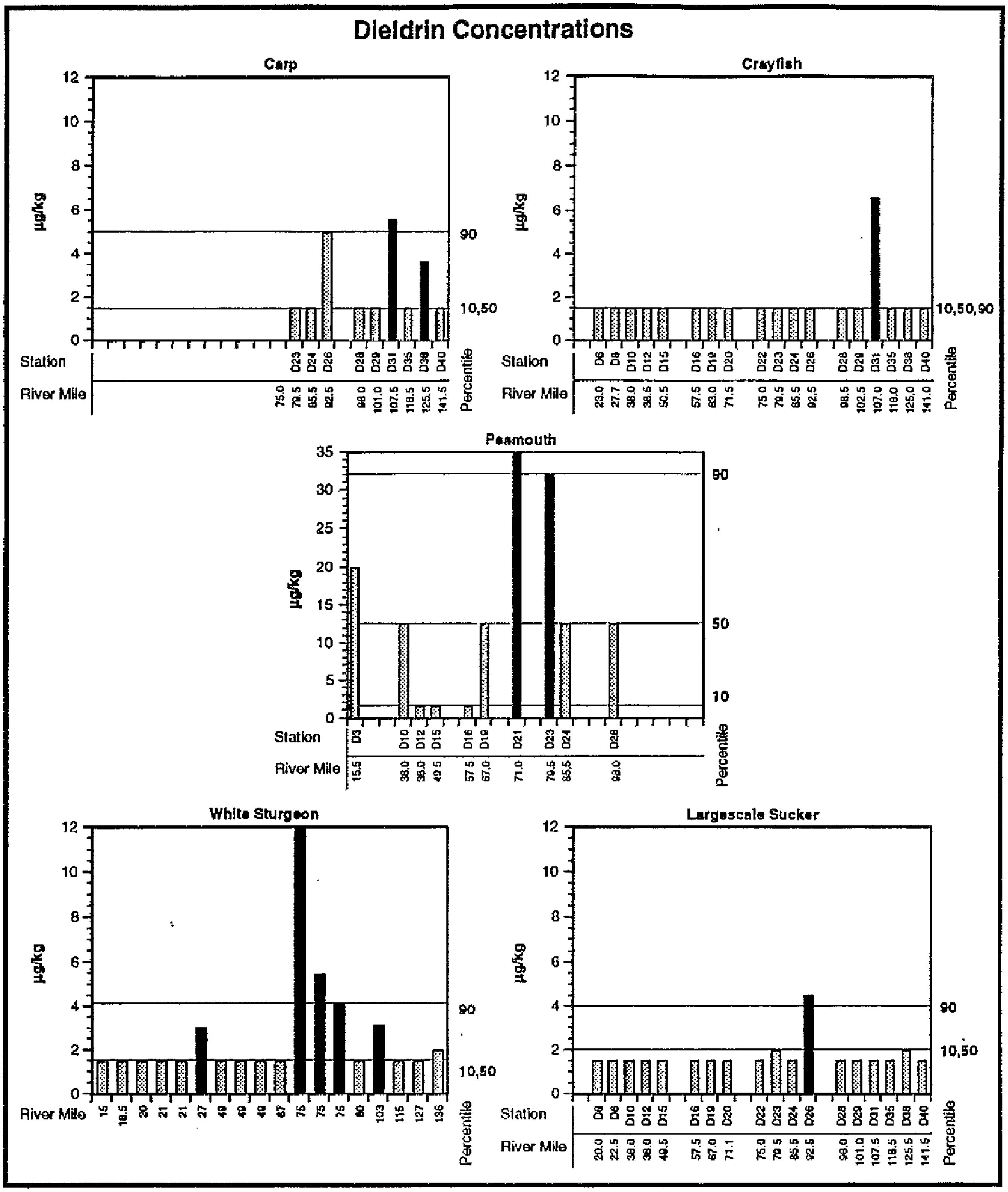


Figure 4-19 Dieldrin concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit. The proposed New York State Fish Flesh Criterion for dieldrin is 120 µg/kg.

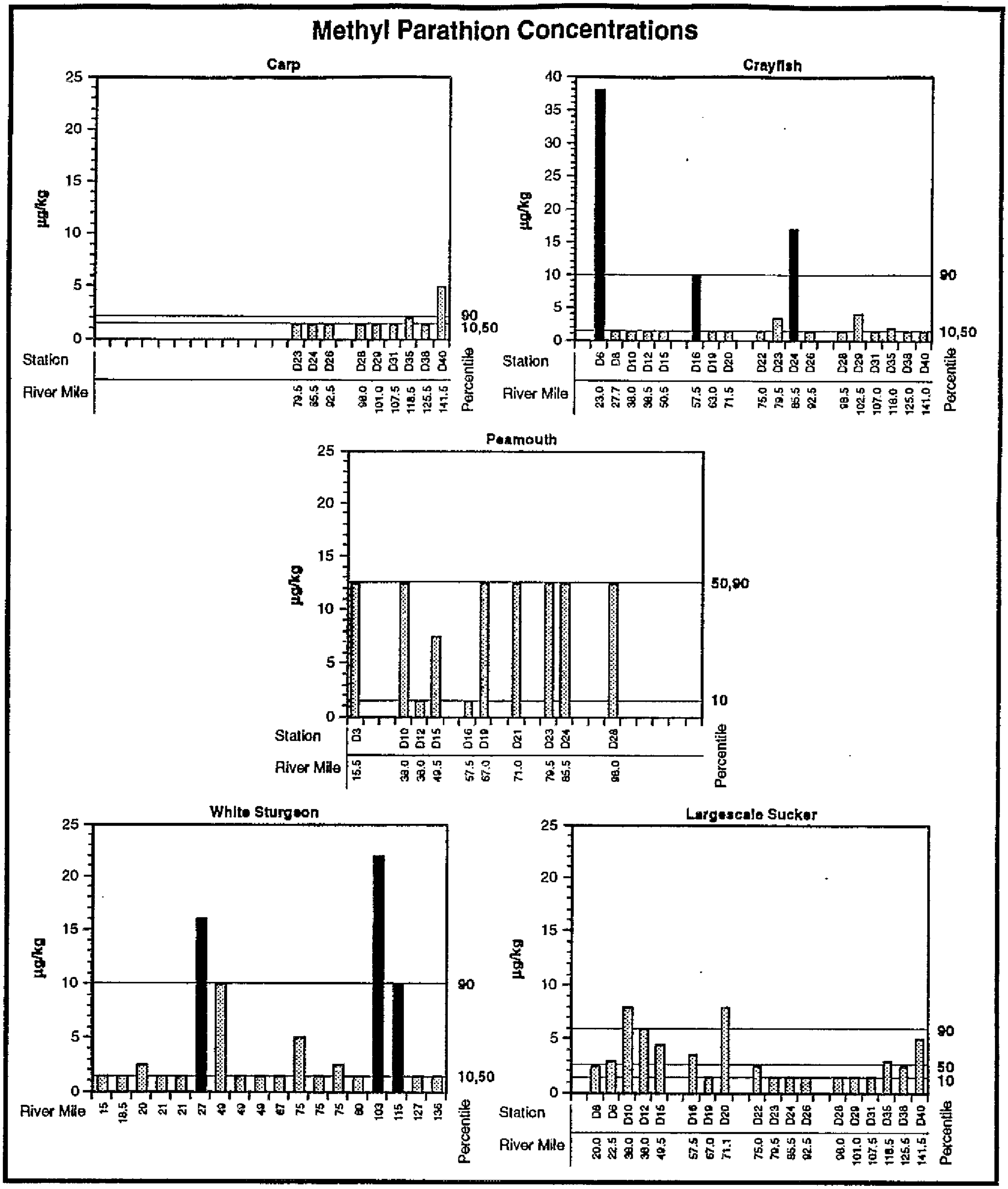
Mirex. Mirex, a pesticide and fire-retarding agent, was banned in the U.S. in 1978. It was detected in only one tissue sample collected in the lower Columbia River. A concentration of 8.8 μg/kg was measured in carp collected at station D26 (RM 92.5) near Bachelor Point. Laboratory detection limits for this pesticide were 3 μg/kg for crayfish, carp, largescale sucker, and white sturgeon (Table 4-7). Detection limits were higher for peamouth, ranging from 3 to 25 μg/kg.

Dacthal. Dacthal is a pre-emergence herbicide used for weed control on many crops. It was detected in only one tissue sample collected in the lower Columbia River. A concentration of 13 μg/kg was measured in peamouth collected at station D16 (RM 57.5) located in Coal Creek Slough. Laboratory detection limits for this herbicide ranged from 3 to 4 μg/kg for crayfish, carp, largescale sucker, and white sturgeon (Table 4-7).

Dicofol. Dicofol is an acaricide that is structurally similar to DDT. In 1989 its use was banned for those products that contained greater than 0.1 percent DDT. Technical grade dicofol is 90 percent pure. Dicofol was not detected in any of the five species collected in the lower Columbia River. Laboratory detection limits for this pesticide were 30 μg/kg for crayfish, carp, largescale sucker, and white sturgeon (Table 4-7). Detection limits were higher for peamouth, ranging from 30 to 250 μg/kg.

Methyl Parathion. Methyl parathion is an organophosphate insecticide effective for controlling soil-dwelling insects. This insecticide was detected in three crayfish samples collected near Altoona (RM 23), Coal Creek Slough (RM 57.5), and St. Helens (RM 85.5) (Figure 4-20). Tissue concentrations ranged from 10 to 17 μg/kg. Methyl parathion was also detected in three white sturgeon collected near Portland (RM 103 and RM 115) and near Woody Island in the Lewis and Clark National Wildlife Refuge (RM 27). Tissue concentrations in white sturgeon ranged from 10 to 22 μg/kg (Figure 4-20). This insecticide was not detected in carp, peamouth, or largescale sucker. Laboratory detection limits for these species ranged from 3 to 25 μg/kg (Table 4-7).

Parathion. Parathion is an organophosphate insecticide and acaricide effective for controling soil-dwelling insects. This insecticide was detected in three largescale sucker samples collected near Marsh Island in the Lewis and Clark National Wildlife Refuge (RM 20), Coal Creek Slough (RM 57.5), and downstream of Kalama (RM 71.1) (Figure 4-21). Tissue concentrations in these samples ranged from 7.5 to 15 μg/kg. Parathion was also detected in one peamouth sample (26 μg/kg) collected near Astoria.



Methyl Parathion Concentrations

Carp

Crayfish

Peamouth

White Sturgeon

Largescale Sucker

Figure 4-20. Methyl Parathion concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

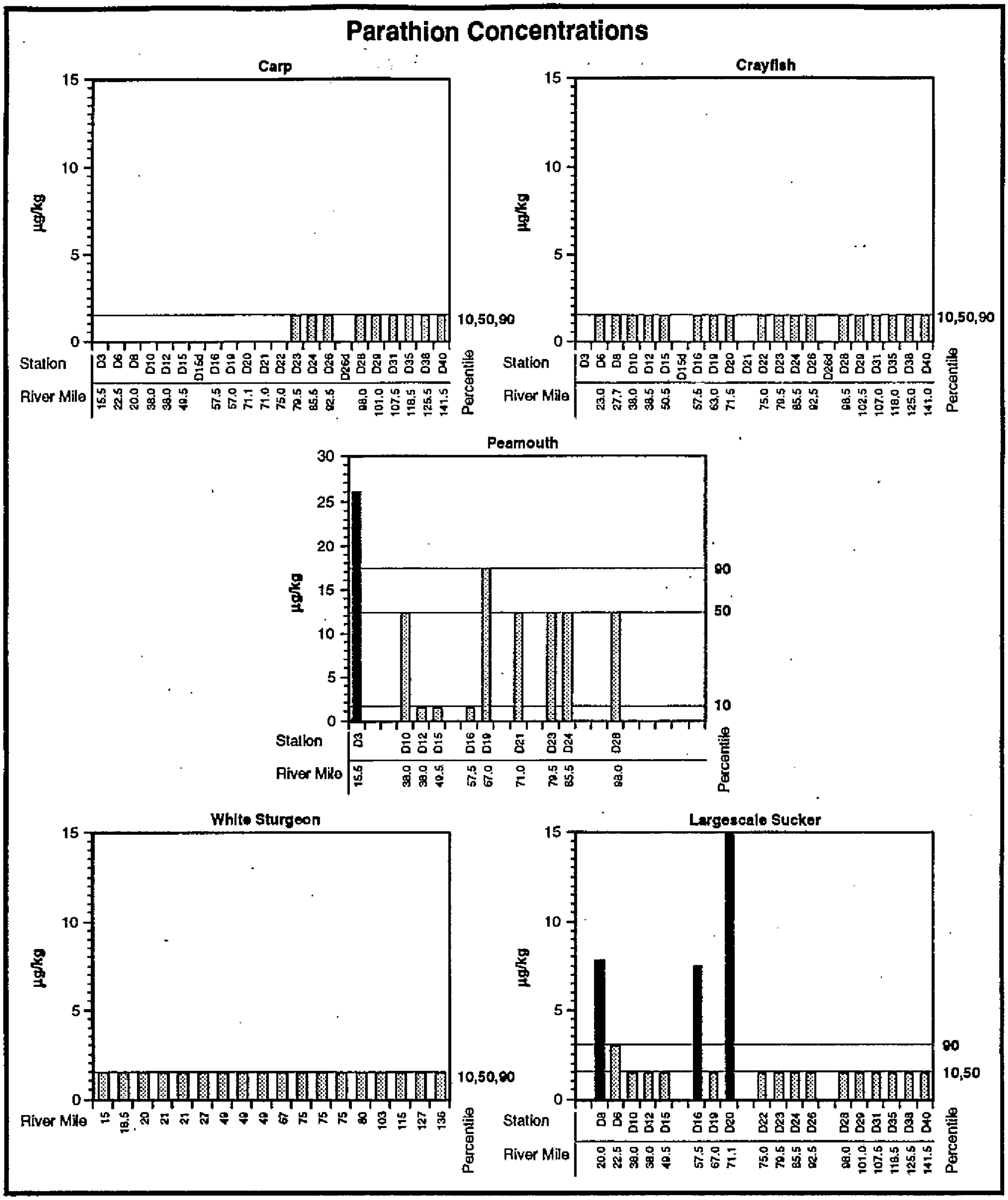


Figure 4-21. Parathion concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

This insecticide was not detected in crayfish, carp, or white sturgeon collected in the lower Columbia River (see Figure 4-21).

Malathion. Malathion is an insecticide and acaricide used in a wide range of agricultural and horticultural applications. It was detected in two peamouth samples collected at station D10 in the Clifton channel, near the upstream end of Tenasillahe Island, and near St. Helens (RM 85.5). Tissue concentrations at these two sites were 110 and 66 μg/kg, respectively. Malathion was not detected in crayfish, carp, largescale sucker, or white sturgeon tissue samples. Laboratory detection limits for these species ranged from 3 to 6 μg/kg (Table 4-7).

Toxaphene. The insecticide toxaphene was not detected in any of the five species collected in the lower Columbia River. Laboratory detection limits for this pesticide were 150 μg/kg for crayfish, carp, largescale sucker, and white sturgeon (Table 4-7). Detection limits were higher for peamouth, ranging from 150 to 1,500 μg/kg.

Isophorone. Isophorone is a cyclic ketone used as an industrial solvent or cosolvent for finishes, lacquers, resins, pesticides, herbicides, fats, oils, and gums. This chemical was detected in 39 percent of the crayfish samples analyzed, but was not detected in carp, peamouth, largescale sucker, or white sturgeon (Figure 4-22). Laboratory detection limits for fish samples ranged from 100 to 200 μg/kg (Table 4-7). Concentrations measured in crayfish ranged from 110 to 430 μg/kg. The five highest isophorone concentrations were measured in crayfish collected in Coal Creek Slough (RM 57), near the mouth of the Willamette River (RM 98.5), North Portland Harbor near Hayden Island (RM 107), Bachelor Point (RM 92.5), and St. Helens, OR (RM 85.5) (Table 4-9).

Endosulfan and Endosulfan Sulfate. Endosulfan is an insecticide used on crops including cereals, fruit, potatoes, and vegetables. Technical grade endosulfan has a purity of 95 percent and consists of a mixture of endosulfan I (70 percent) and endosulfan II (30 percent) isomers. Three endosulfan derivatives were measured in tissue samples: endosulfan I, endosulfan II, and endosulfan sulfate.

Endosulfan I was detected in three peamouth samples collected near Astoria (RM 15.5), downstream of Kalama (RM 71), and in Burke Slough (RM 79.5) (Figure 4-23). Tissue concentrations of these samples

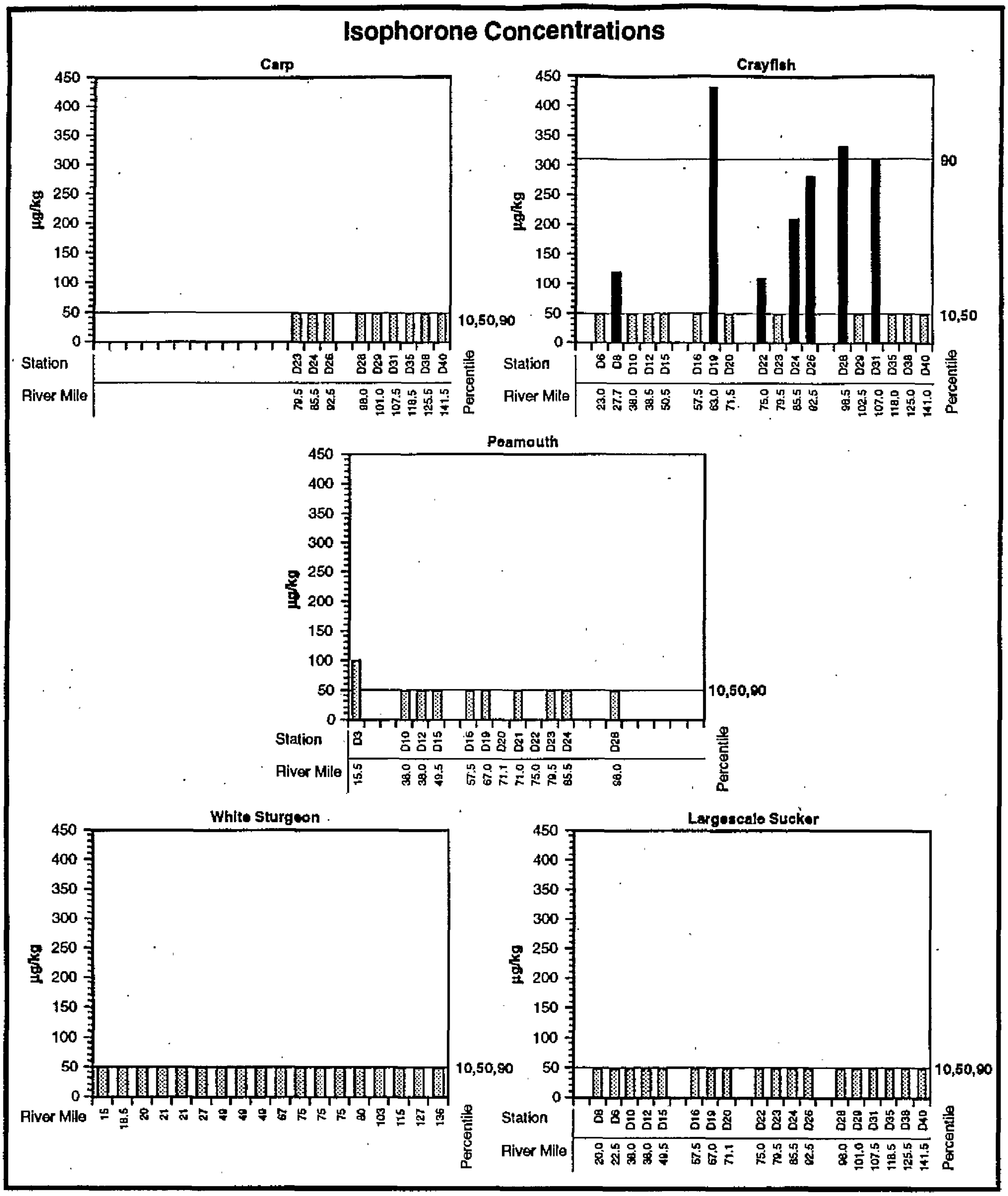


Figure 4-22. Isophorone concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

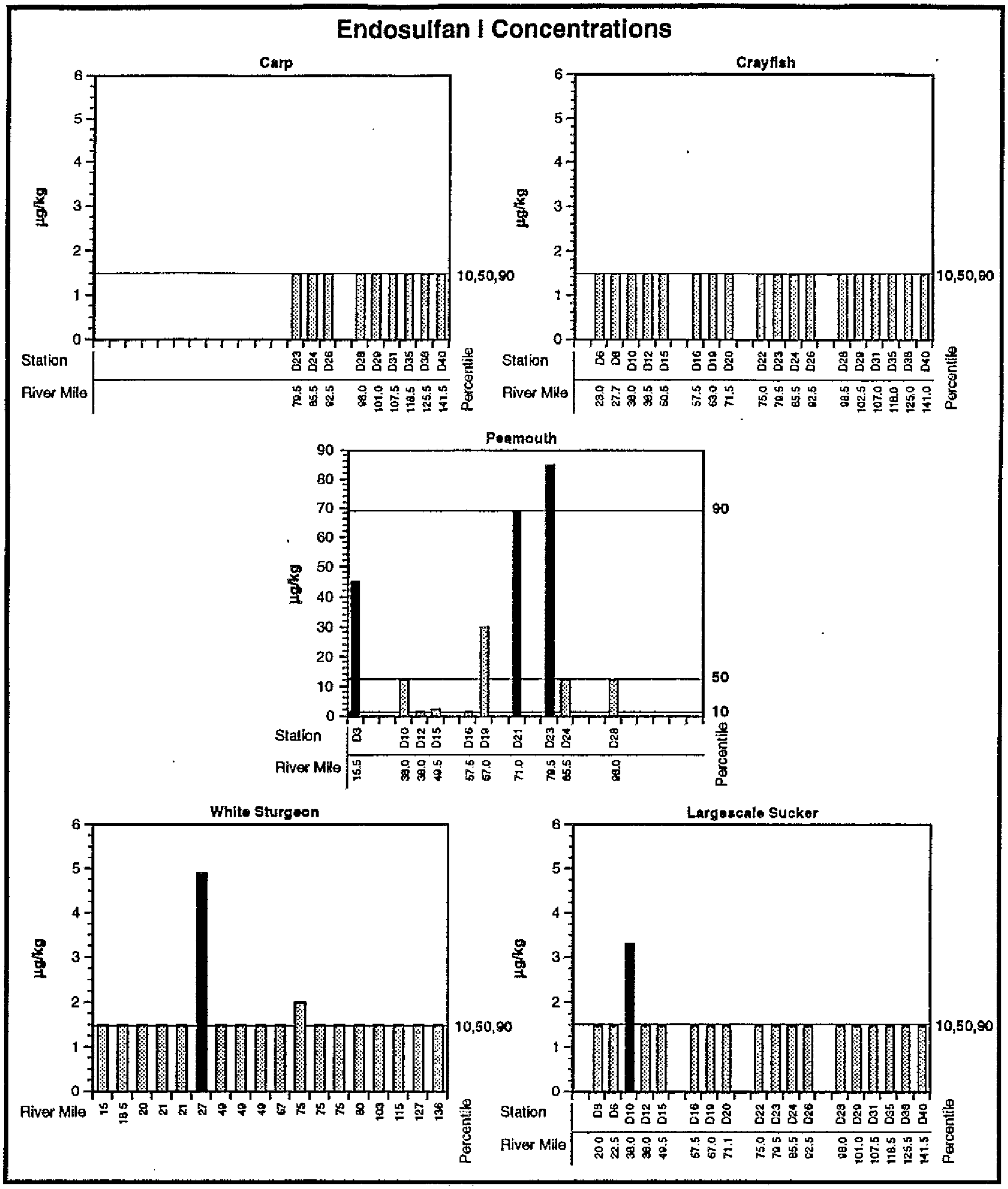


Figure 4-23. Endosulfan I concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

ranged from 45 to 85 μg/kg. Endosulfan I was also detected in one white sturgeon (4.9 μg/kg) collected near Woody Island in the Lewis and Clark National Wildlife Refuge, and in largescale sucker (3.3 μg/kg) collected in Clifton Channel near the upstream end of Tenasillahe Island. This isomer was not detected in either carp or crayfish samples collected in the lower Columbia River (Figure 4-23).

Endosulfan II was detected in only one tissue sample. A concentration of 7.6 μg/kg was measured in crayfish collected at station D29 (RM 102.5) near the mouth of the Willamette River. Laboratory detection limits for this insecticide ranged from 3 to 25 μg/kg for the species sampled in this study (Table 4-7).

Endosulfan sulfate was detected in three tissue samples collected in the lower Columbia River. White sturgeon collected downstream of Kalama, WA had a tissue concentration of 5.5 μg/kg; largescale sucker collected at station D35 in the Camas Slough (RM 118.5) had a tissue concentration of 3.5 μg/kg; and crayfish collected in Coal Creek Slough had a tissue concentration of 3.0 μg/kg.

Endrin and Endrin Aldehyde. Endrin is an organochlorine pesticide that has not been produced since 1984. This pesticide was detected in two largescale sucker samples, two white sturgeon, and one carp sample. Measured concentrations ranged from 3.9 to 12 μg/kg (Figure 4-24). Tissue concentrations of endrin were all measured between RM 75 and RM 125.5. The highest concentration was measured in largescale sucker collected near Burke Slough (RM 79.5). Other collection locations where endrin was detected include Wallace Island (RM 75), the mouth of the Willamette River (RM 101), and Reed Island (RM 125.5).

Endrin aldehyde was detected in four tissue samples collected in the lower Columbia River. Two white sturgeon and peamouth caught downstream of Kalama, WA had tissue concentrations of 7.0, 8.4, and 40 μg/kg, respectively (Figure 4-25). Largescale sucker collected in Elochoman Slough near the Port of Cathlamet had a tissue concentration of 8.4 μg/kg (Figure 4-25).

Methoxychlor. Methoxychlor is an organochlorine pesticide with a chemical structure and function similar to DDT. It has been used to control houseflies, blackflies, and mosquitos in areas of human habitation. Other uses include treatment of post-harvest crops, treatment of seeds and soil, and mothproofing.

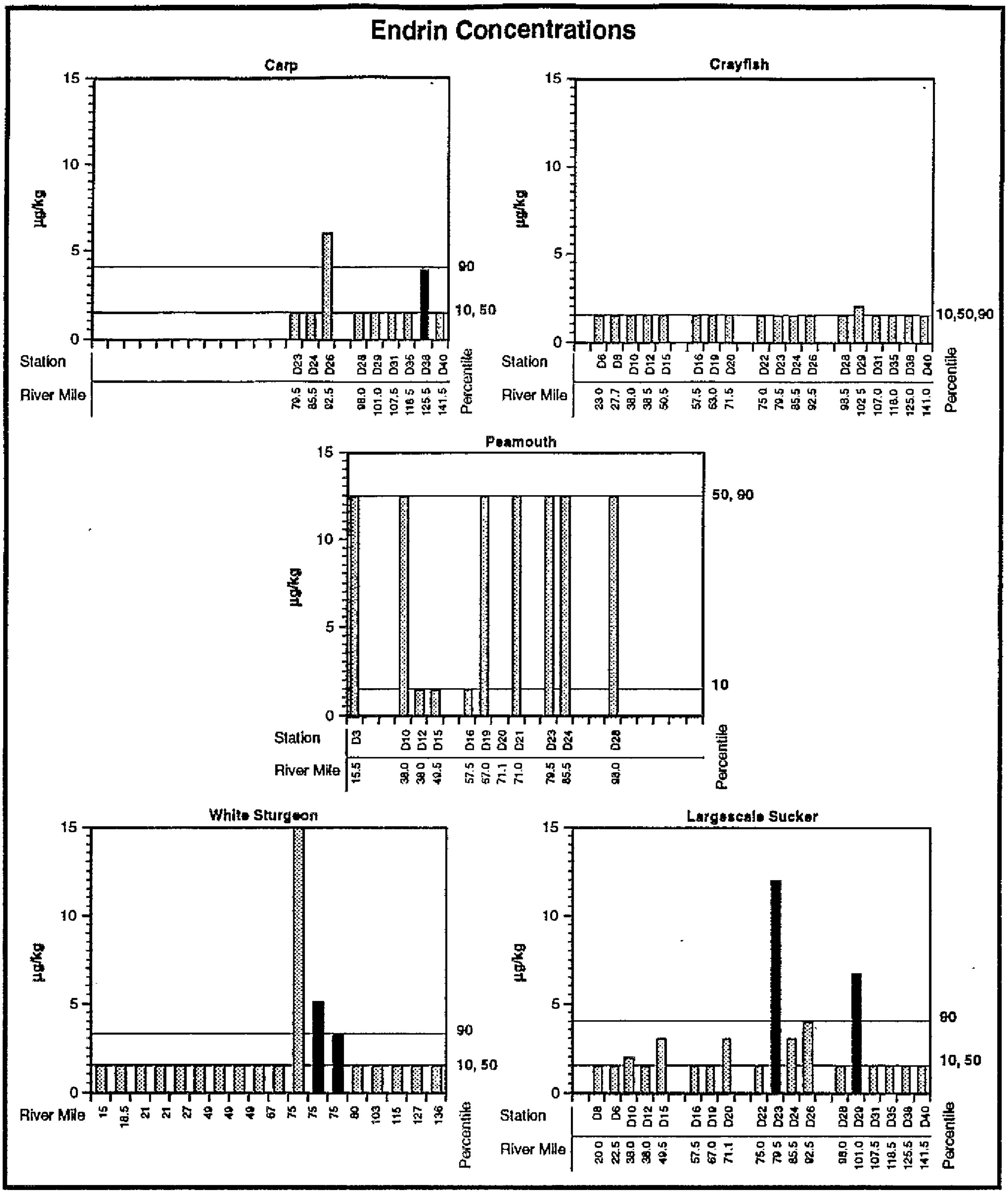


Figure 4-24. Endrin concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

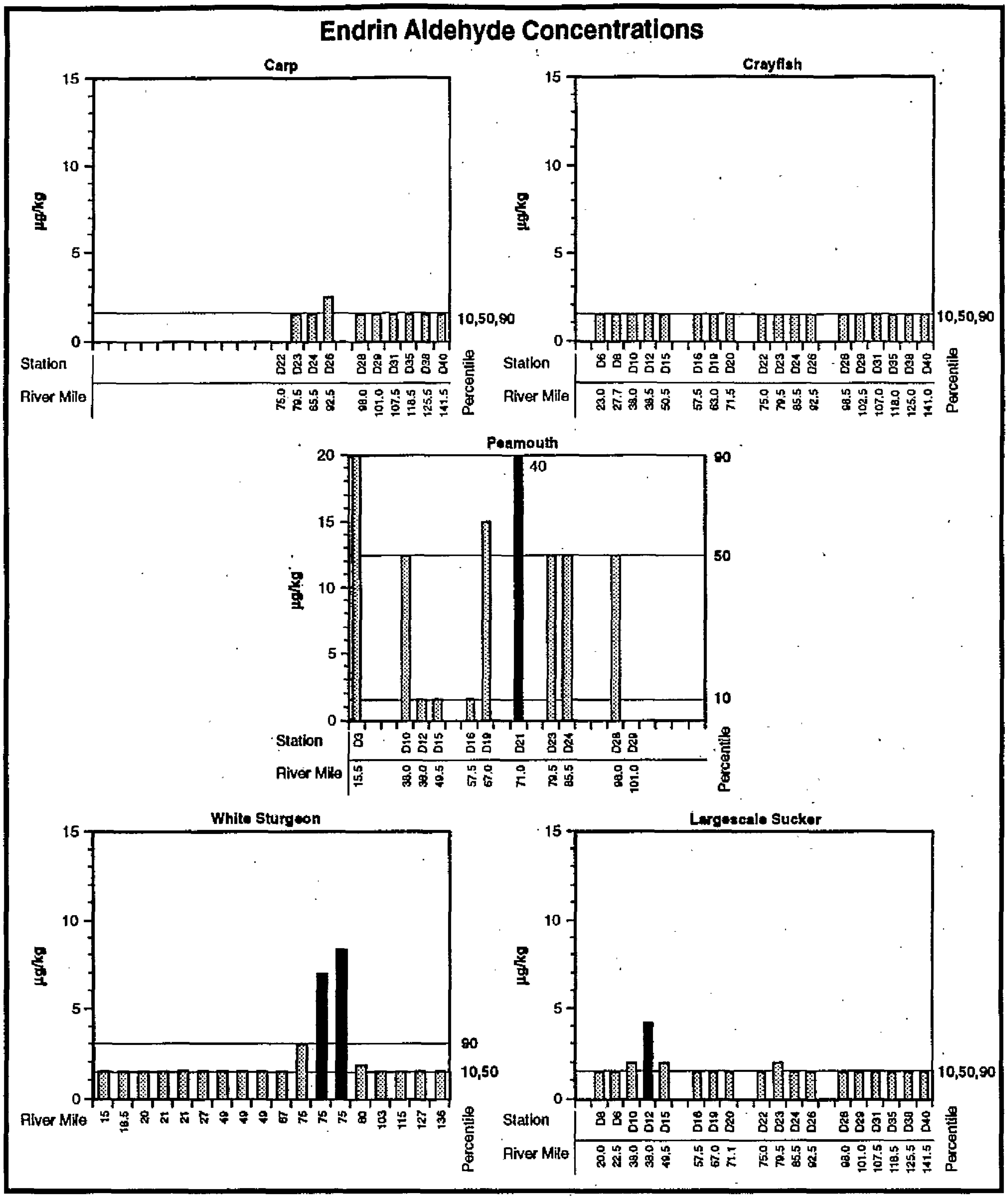


Figure 4-25. Endrin Aldehyde concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

Methoxychlor was detected in six tissue samples collected in the lower Columbia River (three white sturgeon, one largescale sucker sample, and one crayfish sample). Tissue concentrations for these samples ranged from 34 to 180 μg/kg (Figure 4-26). Collection locations where methoxychlor was detected were near Woody Island in the Lewis and Clark National Wildlife Refuge [white sturgeon (RM 27)], Wallace Slough [largescale sucker (RM 49.5)], near Wallace Island [white sturgeon (RM 75)], St. Helens, OR [crayfish (RM 85.5)], and Multnomah Falls, OR [white sturgeon (RM 136)] (see Figure 4-26).

Alpha-BHC, Beta-BHC, Delta-BHC, and Gamma-BHC. Lindane is an insecticide and acaricide used in both agriculture and forestry. It is registered for use on an number of fruit and vegetable crops, feed storage areas, farm animal areas, wooden structures, and domestic and outdoor uses. Technical grade lindane consists primarily of the gamma-BHC isomer (approximately 65 percent), but it also contains a mixture of several other isomers.

Alpha-BHC was detected in only two largescale sucker samples collected in the lower Columbia River. These samples had tissue concentrations of 3.9 and 5.6 μg/kg; they were collected in Clifton Channel (RM 38) and in Elochoman Slough near the Port of Cathlamet (RM 40).

Beta-BHC was detected in five tissue samples collected in the lower Columbia River (two peamouth, two crayfish, and one largescale sucker) (Figure 4-27). The highest concentrations (150 and 13 μg/kg) were detected in peamouth collected downstream of Kalama, WA (RM 71) and in Elochoman Slough near the Port of Cathlamet (RM 40), respectively. The two crayfish samples with measured levels of beta-BHC were collected in Coal Creek Slough (RM 57.5) and near Reed Island (RM 125). The one largescale sucker sample with measured levels was collected at the mouth of the Willamette River (RM 101).

Delta-BHC was not detected in any of the tissue samples collected in the lower Columbia River. Laboratory detection limits for this pesticide were 3 μg/kg for crayfish, carp, largescale sucker, and white sturgeon (Table 4-7). Detection limits were higher for peamouth, ranging from 3 to 4 μg/kg.

Gamma-BHC was detected in five tissue samples collected in the lower Columbia River (three largescale sucker samples, one peamouth sample, and one carp sample) (Figure 4-28). Measured tissue concentrations ranged from 3.5 to 14 μg/kg. Collection locations where gamma-BHC concentrations

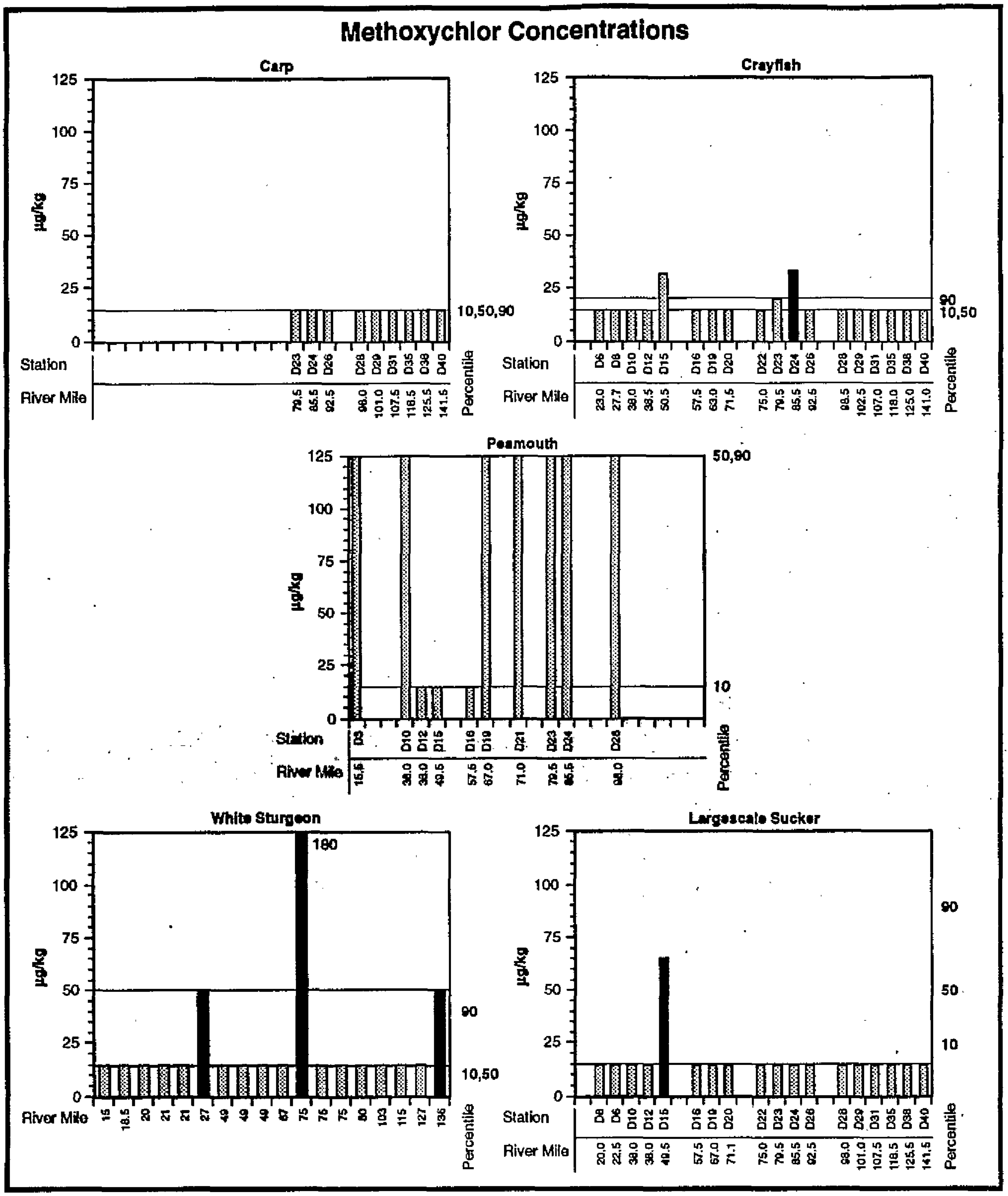


Figure 4-26. Methoxychlor concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit.

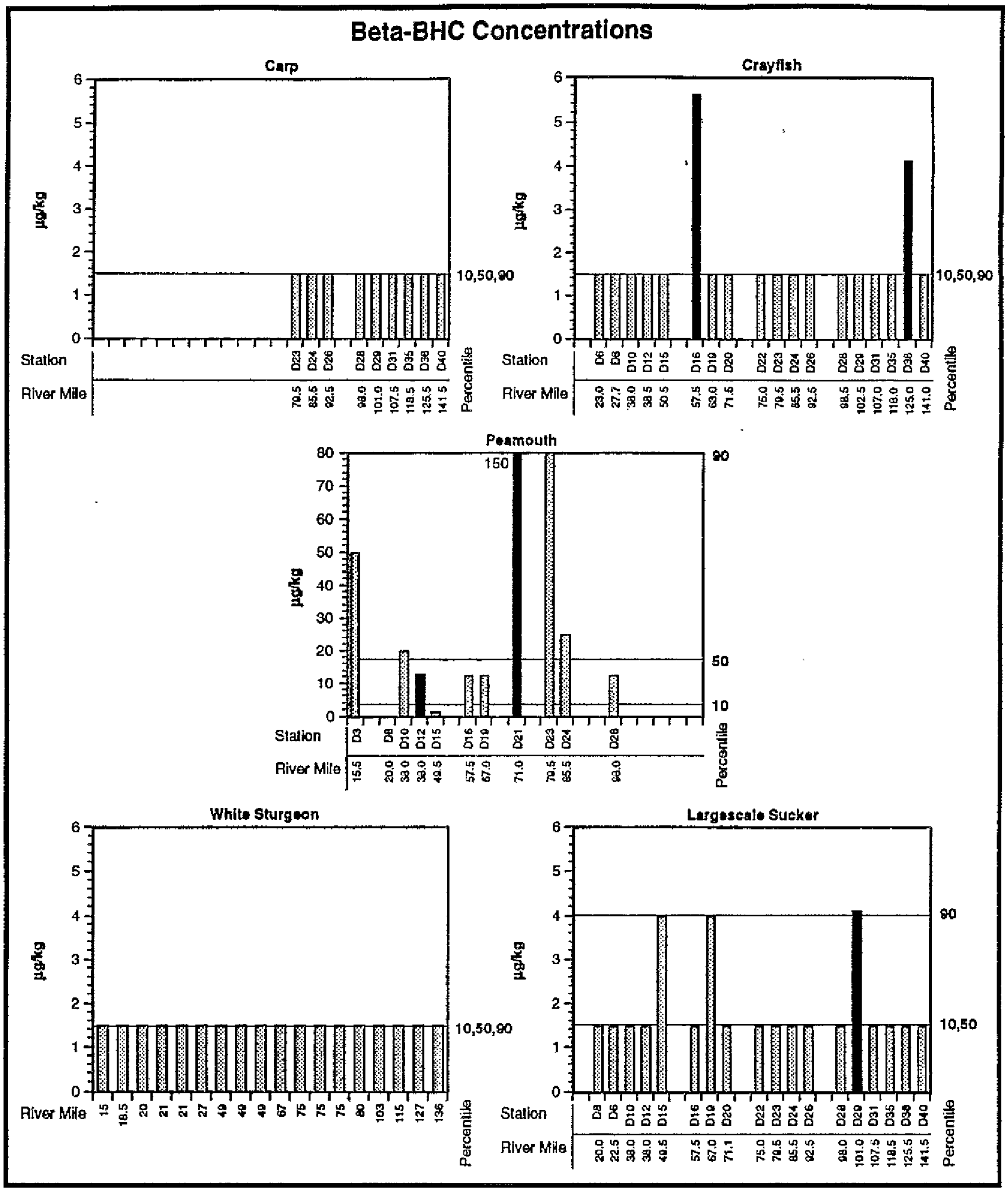


Figure 4-27. Beta-BHC concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit. The proposed New York State Fish Flesh Criterion for beta-BHC is 100 µg/kg.

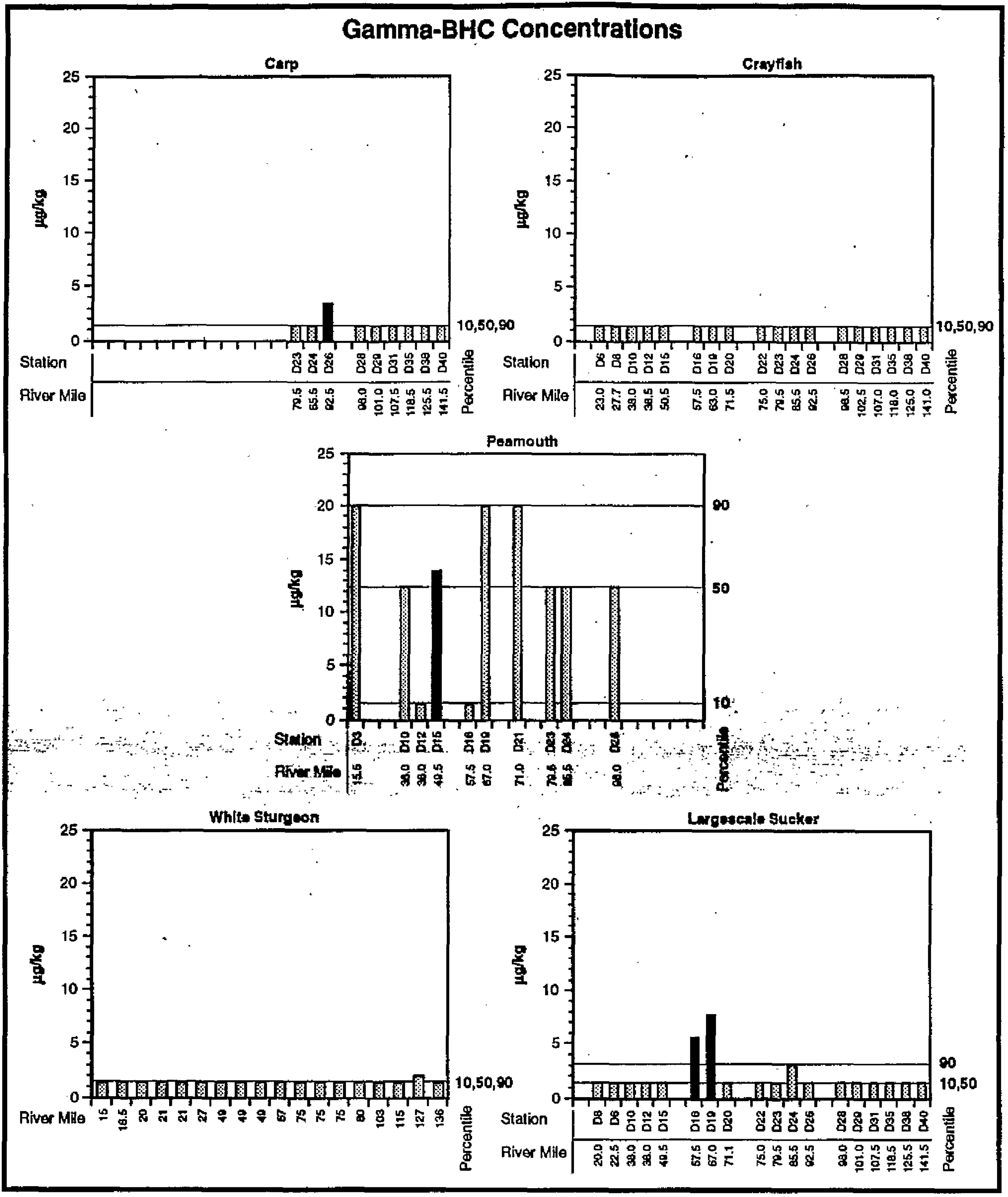


Figure 4-28. Gamma-BHC concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit. The proposed New York State Fish Flesh Criterion for BHC is 100 µg/kg based on beta-BHC.

were measured include Wallace Slough [peamouth (RM 49.5)], Coal Creek Slough [largescale sucker (RM 57.5)], downstream of Longview, WA [largescale sucker (RM 63)], and Bachelor Point [carp (RM 92.5)].

4.5.4.3 Results for Polychlorinated Biphenyls (PCBs). Whole-body composite samples of crayfish, carp, largescale sucker, peamouth, and filets of individual white sturgeon were analyzed for seven PCBs (Table 1-1). PCB concentrations (μg/kg wet weight) measured for each species are presented in Appendices D1-12, D2-12, D3-12, D4-12, and D5-12. Table 4-6 shows the compounds that were detected in at least one tissue sample, the number of samples for each species that had concentrations above laboratory detection limits, and the range of concentrations measured. Table 4-7 shows laboratory detection limits for those compounds that were not detected in any samples for each species.

PCBs represent a group of 209 chemicals (U.S. EPA 1991a) that are man-made and have no natural sources. Manufacturing of PCBs was discontinued in the United States in 1977, and importing the chemical was banned in 1979. Mixtures of individual congeners are commonly referred to by their trade name, Aroclor.

Only three PCBs were detected in tissue samples collected in the lower Columbia River (Aroclor 1242, Aroclor 1254, and Aroclor 1260). Aroclor 1242 was detected in two tissue samples. Tissue concentrations of 78 and 99 μg/kg were detected in peamouth collected near Astoria, OR and downstream of the mouth of the Willamette River [station D28 (RM 98)].

Aroclor 1254 was detected in 94 percent of the largescale sucker samples, 39 percent of the carp samples, and 22 percent of the white sturgeon samples. This PCB was not detected in crayfish or peamouth (Figure 4-29). The concentrations of Aroclor 1254 corresponding to 10, 50, and 90 percent of the samples analyzed were 55, 115, and 210 μg/kg, respectively (see Figure 4-29). The 10, 50, and 90 percentile concentrations for carp were 25, 60, and 260 μg/kg and 25, 25, and 96 μg/kg for white sturgeon (see Figure 4-29).

The highest concentration of Aroclor 1254 (500 μg/kg) was measured in white sturgeon caught downstream of Kalama, WA. The next four highest Aroclor 1254 tissue concentrations were measured in largescale sucker and carp collected downstream of the Willamette River (RM 98), largescale sucker

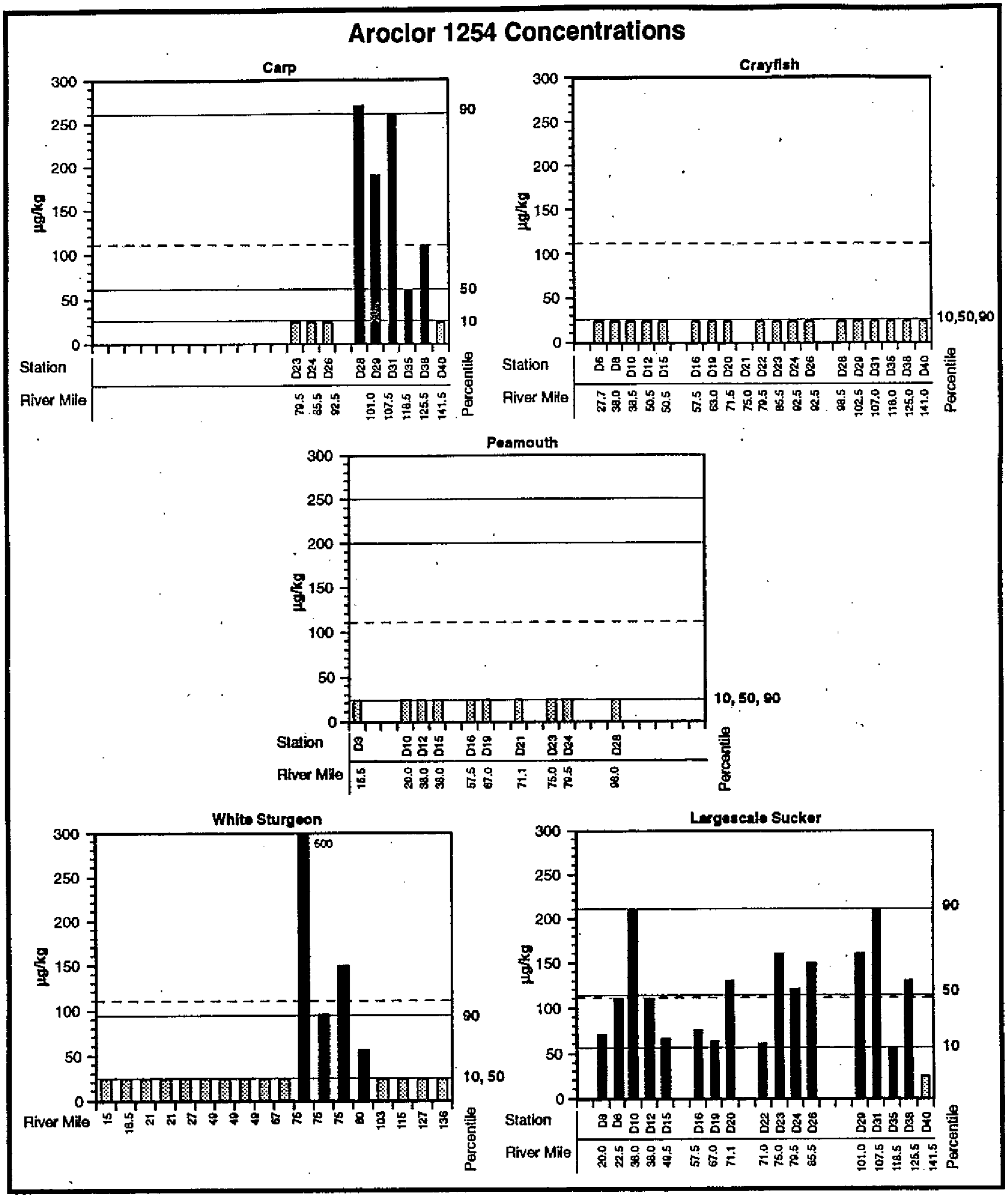


Figure 4-29. Aroclor 1254 concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit. The proposed New York State Fish Flesh Criterion for PCBs is 110 µg/kg, based on all PCB congeners, and is shown here with a broken line.

and carp collected in North Portland Harbor near Hayden Island (RM 107.5), and largescale sucker collected in Clifton Channel near the upstream end of Tenasillahe Island (RM 38).

Aroclor 1260 was detected in 100, 44, and 6 percent of the peamouth, carp, and largescale sucker samples analyzed (Figure 4-30). This PCB was not detected in any crayfish or white sturgeon samples collected in the lower Columbia River. The tissue concentrations of Aroclor 1260 below which 10, 50, and 90 percent of the peamouth samples occurred were 80, 165, and 280 μg/kg, respectively (see Figure 4-30). The 10, 50, and 90 percentile concentrations for carp were 25, 25, and 80 μg/kg, respectively.

The five highest tissue concentrations of Aroclor 1260 ranged from 170 to 520 μg/kg; all were measured in peamouth. The highest concentration was measured for fish collected near St. Helens, OR (RM 85.5). Collection locations of the other four highest values were near Astoria (RM 15.5), Coal Creek Slough (RM 57), Burke Slough (RM 79.5), and Wallace Slough (RM 49.5).

4.5.5 Tissue Dioxin and Furan Concentrations

4.5.5.1 Summary of Quality Assurance/Quality Control Results. A total of forty-four tissue samples were analyzed for dioxins and furans. Eight samples were analyzed for white sturgeon, 12 for both crayfish and largescale suckers, 7 for peamouth, and 5 for carp. All of the tissue samples were field samples (i.e., no field duplicates). The dioxin/furan data were considered acceptable for use in this report. A number of isotopically labeled internal standards were recovered outside QC criteria, but since the analyte in question was not detected in the associated sample, no data qualification was necessary. No indication of blank contamination above the lower method calibration limit (LMCL) was noted. The high RPD for some analytes for the MS/MSD pairs analyzed for sturgeon and suckers indicate poor analytical precision for the samples associated with these species. All octachlordibenzodioxin (OCDD) and 1,2,3,4,6,7,8-HpCDF values for both sturgeon and sucker; octochlordibenzofuran (OCDF) values for sturgeon; and 1,2,3,7,8,9-HxCDD values for suckers were qualified as estimates based on RPDs exceeding 50 percent. A number of sample results were qualified as estimates by the laboratory (qualifier code 'S') because the reported levels were less than the LMCL. The reported estimated detection limits (EDLs) were less than or equal to those specified in the QA/QC plan (Tetra Tech 1991b).

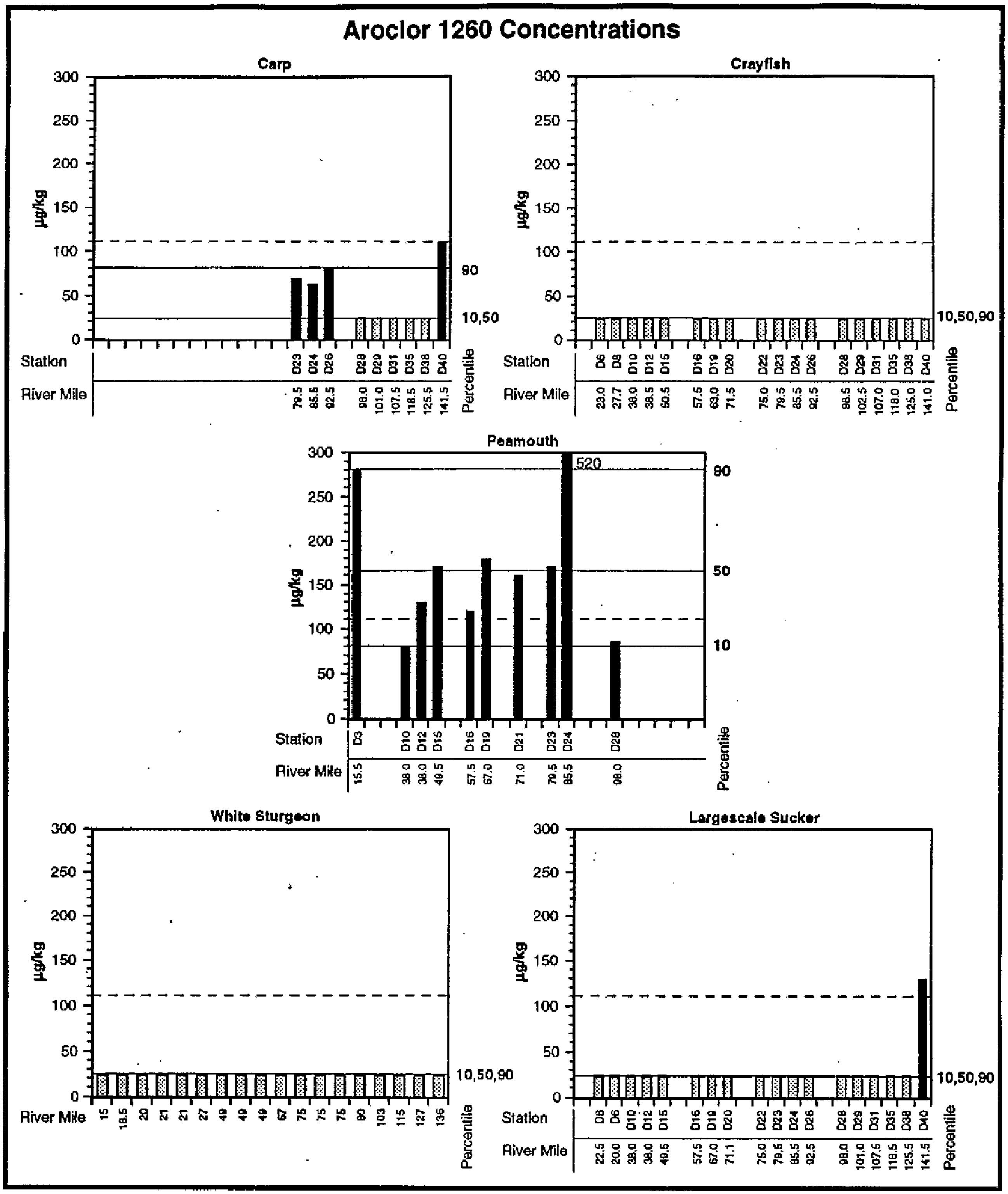


Figure 4-30. Aroclor 1260 concentrations in tissue. Black bars indicate measured concentrations, stippled bars indicate nondetects and are equal to one-half the reported detection limit. The proposed New York State Fish Flesh Criterion for PCBs is 110 µg/kg, based on all PCB congeners, and is shown here with a broken line.

Analytical results, including surrogate and matrix spike recoveries and blind laboratory and field replicate samples, are presented under separate cover in the QA memorandum in Appendix A-7.

4.5.5.2 ***Results.*** Whole-body composite samples of crayfish, carp, largescale sucker, peamouth, and filets of individual white sturgeon were analyzed for seven dioxins and ten furan congeners (Table 1-1). Dioxin and furan concentrations (μg/kg wet weight) measured for each species are presented in Appendices D1-13, D2-13, D3-13, D4-13, and D5-13. Table 4-6 shows the compounds that were detected in at least one tissue sample, the number of samples for each species that had concentrations above laboratory method detection limits, and the range of concentrations measured. Table 4-7 shows laboratory detection limits for those compounds that were not detected in any samples for each species.

All seven dioxin congeners were detected in tissue samples collected in the lower Columbia River (Table 4-6). The most toxic member of this of this group of chemicals, 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), was detected in all peamouth, crayfish, sucker, and carp samples, and one of the sturgeon samples collected in the lower Columbia River. Tissue concentrations in these species were 1.44 to 4.41, 0.27 to 0.86, 0.49 to 1.56, and 1.28 to- 2.10 pg/g for peamouth, crayfish, largescale sucker, and carp, respectively. This congener was detected at a concentration of 1.66 pg/g in one sturgeon sample.

The five highest TCDD tissue concentrations were all measured in peamouth collected between RM 38 and RM 85.5. Concentrations ranged from 2.32 to 4.41 pg/g. The highest tissue concentration was measured for fish collected downstream of the mouth of the Multnomah channel near St. Helens, OR. The other four highest concentrations were measured in fish collected downstream of Longview, WA [3.29 pg/g, station D19 (RM 63)], in Burke Slough [3.10 pg/g, station D23 (RM 79.5)], near Goble, OR [2.77 pg/g, station D21 (RM 71)], and in Clifton Channel [2.32 pg/g, station D10 (RM 38)].

The other six dioxin congeners detected were 1,2,3,7,8-pentachlorodibenzo-p-dioxin (1,2,3,7,8-PeCDD), 1,2,3,6,7,8-hexachlorodibenzo-p-dioxin (1,2,3,6,7,8-HxCDD), 1,2,3,4,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin (HpCDD), and OCDD. It should be noted that many of these other dioxin congeners were detected at levels below the LMCL. These values should be considered as estimates. All but two of the carp, peamouth, and sucker samples had detectable levels of the hexadioxin congeners. Only 31 percent of the crayfish samples, and none of the sturgeon samples, had detectable levels of the three hexadioxin congeners (Table 4-6). All but one crayfish sample and six sturgeon samples contained detectable levels of 1,2,3,4,6,7,8-HpCDD, while all but one sturgeon sample contained detectable levels of OCDD.

All ten furan congeners were detected in tissue samples collected in the lower Columbia River. The most toxic furan congener, (2,3,7,8-PeCDF), was detected in all samples for crayfish, carp, peamouth, and largescale sucker at concentrations ranging from 0.20 to 3.05 pg/g (Table 4-6). TCDF was detected in all of the tissue samples collected in the lower Columbia River, while the other furan congeners were detected less frequently (Table 4-6).

Toxicity equivalency factors (TEFs) for chlorinated dibenzo-p-dioxins and dibenzo-p-furans have been developed as a method for estimating the hazard and dose-response of complex mixtures containing dioxin and furan congeners in addition to TCDD (U.S. EPA 1989). Each congener is assigned a toxicity relative to TCDD (i.e., their TEF). The concentration of each congener is then multiplied by its TEF and the sum of these products for all dioxin and furan congeners gives an overall toxicity equivalency concentration (TEC).

TECs calculated for the five species collected in the lower Columbia River are shown in Figure 4-31. Peamouth had the highest TECs of the five species collected, with the lowest values being measured in crayfish. Median concentrations for the five species were 7.93, 4.87, 3.02, 2.63, and 1.38 for peamouth, carp, white sturgeon, largescale sucker, and crayfish, respectively. The trend between species appears to be due to differences in body lipid content. When TECs are normalized for percent body lipid there are no significant differences between species (Kruskal-Wallis test, alpha=0.05). The 10, 50, and 90 percentile lipid-normalized TECs for all species in the lower Columbia River were 0.692, 1.000, 1.918, respectively.

4.6 DISCUSSION

The reconnaissance survey analyzed crayfish, carp, largescale sucker, peamouth, and white sturgeon for the presence of 11 trace metals and 104 organic compounds. The main objectives of this survey were to document the presence or absence of these substances in aquatic biota, characterize their spatial

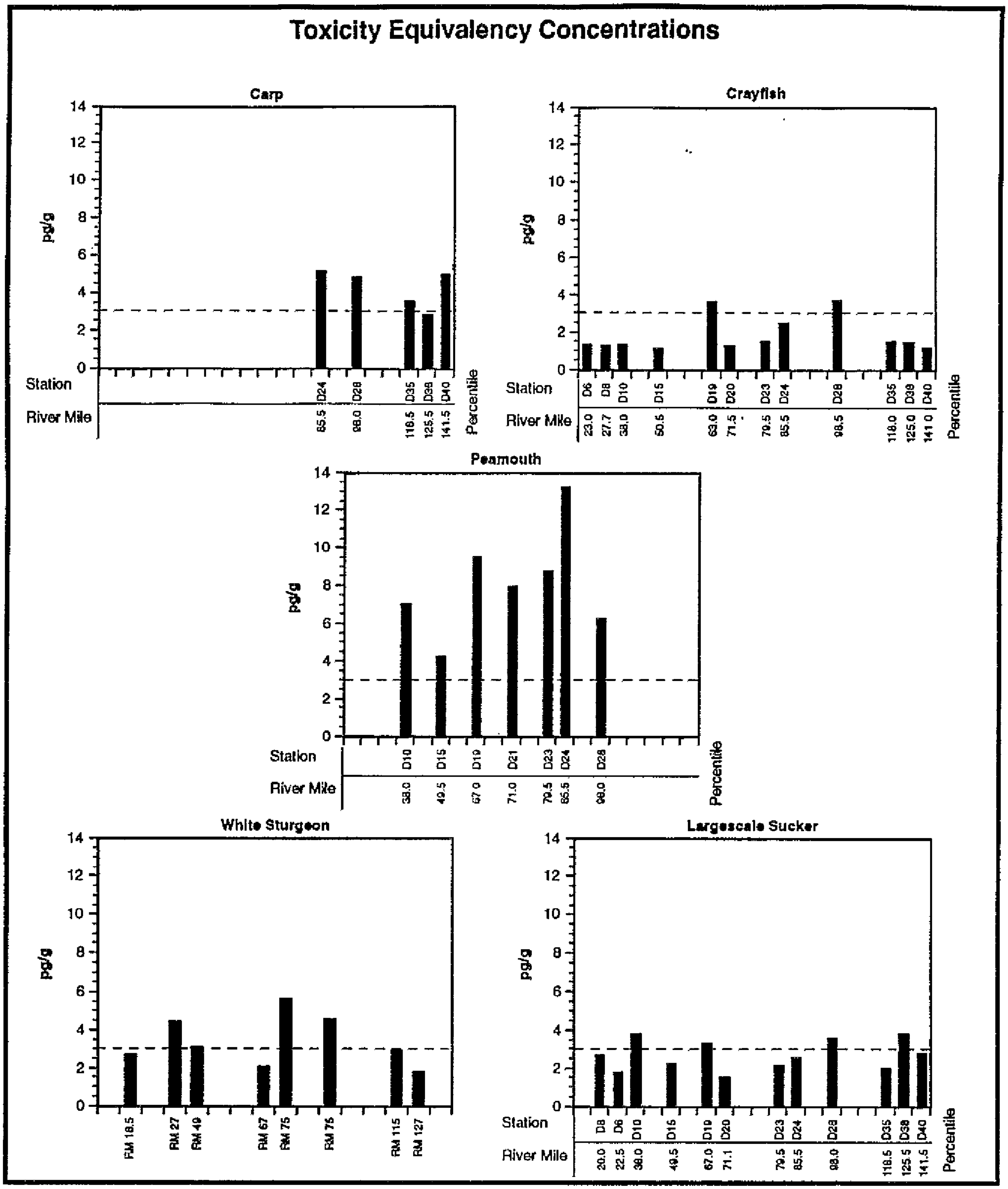


Figure 4-31. Toxicity equivalency concentrations for Dioxins and Furans in tissue. The proposed New York State Fish Flesh Criterion is 3 pg/g and is shown here with a broken line across the graph.

distribution, and identify those locations or species where tissue levels were sufficiently high to be of potential concern to wildlife and human health. In the discussion that follows, these objectives are evaluated for each of the main categories of chemicals evaluated in this reconnaissance survey.

A sound assessment of the human health risks posed by consumption of contaminated fish tissue requires careful evaluation of several factors, including rates of consumption, duration of exposure, toxicity of the chemicals of concern, acceptable risk levels, and alternate exposure pathways. It is not feasible to conduct this analysis within the scope of the present study. Therefore, human health risk will not be addressed further in this section. The tissue contaminant data collected in the survey, however, are considered suitable and adequate to support a quantitative assessment of human health risk.

4.6.1 Trace Metals

All trace metals, except antimony and selenium, were detected in aquatic biota collected within the lower Columbia River (Figure 4-32). Overall, carp had the highest concentration of total metals, with decreasing concentrations present in crayfish, peamouth, largescale sucker, and white sturgeon. Lead was detected in all tissue samples analyzed. Mercury and zinc were detected in all but one tissue sample analyzed. White sturgeon filets had significantly lower concentrations of total metals than whole body samples of other species. Antimony, barium, and selenium were not detected in any of the white sturgeon filets analyzed; cadmium, nickel, and silver were detected in only a single sample, and copper was detected in two of the sturgeon filets analyzed. This greater occurrence of metals in species for which whole bodies were analyzed than in white sturgeon, for which only filet tissue was analyzed, indicates a tendency for metals to concentrate in internal organs and bone rather than muscle tissue.

4.6.1.1 Comparison with Historical Data and Identification of Potential Sources. The results of the fish tissue metal analyses, conducted as part of the lower Columbia River reconnaissance survey, are compared to tissue metal sampling results of the National Pesticide Monitoring Program and the National Contaminant Biomonitoring Program conducted by the U.S. Fish and Wildlife Service (May and McKinney 1981, Lowe et al. 1985, Schmitt and Brumbaugh 1990) which reported whole body tissue concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc; and the results of the U.S. EPA National Bioaccumulation Study (U.S. EPA 1991a) which reported whole fish (bottom-feeding fish) and filet (game fish) tissue concentrations of mercury (see Table 4-10). Several of the stations sampled in these studies were located in the Columbia River Basin, but relatively few stations were

TISSUE–METALS

Fish Species:
C = Carp
Cy = Crayfish
P = Peamouth
ST = Sturgeon
Su = Largescale sucker

	Astoria, OR	Astoria, OR		Deep River	Marsh Island	Deep River Mouth	Grays Bay	Woody Island Channel	Clifton Channel	Elochoman Slough	Wallace Island	Wallace Slough	Coal Creek Slough	Longview, WA	Rainier, OR	Goble, OR	Carrolls Channel	Port of Kalama, WA	Kalama, WA	Burke Slough	Martin Bluff, WA	St. Helens, OR	Bachelor Point, WA	Sauvie Island	Willamette River Mouth		N. Portland Harbor	Government Island	Camas Slough	Reed Island		Multnomah Falls, OR	Beacon Rock
CHEMICAL CLASS	RM 15 ST	RM 15.5 D3	RM 18.5 ST	RM 20 ST	RM 20 D8	RM 21 ST	RM 22.5 D6	RM 27 ST	RM 38 D10	RM 40 D12	RM 49 ST	RM 49.5 D15	RM 57 D16	RM 63 D19	RM 67 ST	RM 71 D21	RM 71.1 D20	RM 75 D22	RM 75 ST	RM 79.5 D23	RM 80 ST	RM 85.5 D24	RM 92.5 D26	RM 98 D28	RM 101 D29	RM 103 ST	RM 107.5 D31	RM 115 ST	RM 118.5 D35	RM 125.5 D38	RM 127 ST	RM 136 ST	RM 141.5 D40
METALS																																	
Species Analyzed	ST	P	ST	ST	Cy Su	ST	Cy Su	ST	Cy Su P	Cy Su P	ST	Cy Su P	Cy Su P	Cy Su P	ST	P	Cy Su	Cy Su	ST	Cy Su P	ST	Cy C Su P	Cy C Su P	Cy C Su P	Cy C Su P	ST	Cy C Su	ST	Cy C Su	Cy C Su	ST	ST	Cy C Su
Arsenic	●							●			●				●																●	●	
Barium		●			●		●		●	●		●	●	●		●	●	●		●		●	●	●	●		●		●	●			●
Cadmium		●			●		●		●	●		●	●	●		●	●	●	●	●		●	●	●	●		●	●	●	●			●
Copper		●		●	●		●		●	●		●	●	●		●	●	●		●		●	●	●	●		●		●	●		●	●
Lead	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Mercury		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Nickel					●		●		●	●		●	●	●			●	●		●		●	●	●	●		●		●	●			●
Silver					●		●		●	●	●	●	●				●	●		●		●		●	●		●		●	●			●
Zinc	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Figure 4-32. Metals detected in fish and crayfish tissue samples collected for the lower Columbia River Reconnaissance Survey.

TABLE 4-10. COMPARISON OF RECONNAISSANCE SURVEY TISSUE CONTAMINANT LEVELS WITH THOSE MEASURED NATIONWIDE IN THE NATIONAL BIOACCUMULATION STUDY AND NATIONAL CONTAMINANT BIOMONITORING PROGRAM

Chemical	Lower Columbia River Reconnaissance Survey 1991		National Bioaccumulation Study	National Contaminant Biomonitoring Program
	Median	Geometric Mean	(Median) (EPA 1991h)[a]	(Geometric Mean) (Schmitt & Brumbaugh 1990)[a]
METALS [mg/kg wet weight (ppm)]				
Arsenic[c]	0.22	0.24	–	0.14
Barium	2.19	0.95	–	–
Cadmium	0.04	0.04	–	0.03
Copper	1.20	2.30	–	0.65
Lead	0.04	0.05	–	0.11
Mercury	0.07	0.06	0.17	0.10
Nickel	0.39	0.48	–	–
Selenium	ND	ND	–	0.42
Zinc	23.35	19.95	–	21.7
PESTICIDES [mg/kg wet weight (ppm)]				
4,4'-DDT	0.0030	0.0033	–	0.030
4,4'-DDE	0.0190	0.0154	0.058	0.190
4,4'-DDD	0.0375	0.0049	–	0.060
Heptachlor	0.0015	0.0019	ND	0.010
Dieldrin	0.0015	0.0023	0.0042	0.040
Endrin	0.0015	0.0022	ND	ND(<0.01)
Methoxychlor	0.0150	0.0206	ND	–
alpha-BHC	0.0015	0.0020	0.00072	ND(<0.01)
gamma-BHC (Lindane)	0.0015	0.0021	ND	ND(<0.01)
PCBs [mg/kg (ppm)]				
Aroclor 1254	0.0250	0.0445	–	0.210
Aroclor 1260	0.0250	0.0352	–	0.150
DIOXINS AND FURANS [ng/kg wet weight (ppt)]				
2,3,7,8-TCDD	0.76	0.84	1.38	–
1,2,3,7,8-PeCDD	0.48	0.43	0.93	–
1,2,3,4,7,8-HxCDD	0.20	0.19	1.24	–
1,2,3,6,7,8-HxCDD	0.39	0.37	1.32	–
1,2,3,7,8,9-HxCDD	0.18	0.19	0.69	–
1,2,3,4,6,7,8-HpCDD	1.10	1.22	2.83	–
OCDD	4.21	4.66	–	–
2,3,7,8-TCDF	6.41	8.39	2.97	–
1,2,3,7,8-PeCDF	0.24	0.28	0.45	–
2,3,4,7,8-PeCDF	0.48	0.48	0.75	–
1,2,3,4,7,8-HxCDF	0.21	0.21	1.42	–
1,2,3,7,8,9-HxCDF	0.17	0.18	1.38	–
1,2,3,6,7,8-HxCDF	0.18	0.18	1.42	–
2,3,4,6,7,8-HxCDF	0.49	0.68	0.98	–
1,2,3,4,6,7,8-HpCDF	0.29	0.30	–	–
1,2,3,4,7,8,9-HpCDF	0.12	0.13	1.30	–
OCDF	0.41	0.49	–	–

ND = Not detected above the laboratory detection limit.

[a] Geometric mean of 1984 data

[b] Statistics were calculated using one-half the detection limit for samples where analyte was undetected.

[c] Arsenic was detected only in sturgeon tissue although calculated statistics include all species.

located within the study area below Bonneville Dam. Columbia River Basin stations sampled as part of the National Pesticide and National Contaminant Biomonitoring programs included several locations on the Snake River, and single stations on the Flathead, Salmon, Yakima, and Willamette rivers. Stations on the mainstem of the Columbia River include locations near Grand Coulee, Pasco, and Cascade Locks, but none of these is located within the study area. Station locations in the Columbia River Basin sampled during the National Bioaccumulation Study for tissue mercury levels included several stations in the lower Columbia River (i.e., Wauna, Longview, St. Helens, Portland, and Camas). The species analyzed in the National Pesticide Monitoring and National Contaminant Biomonitoring programs in the Columbia River Basin included black crappie, carp, channel catfish, chiselmouth, largescale sucker, northern squawfish, and yellow perch. The species analyzed for mercury in the lower Columbia River in the National Bioaccumulation Study included carp (whole body), northern squawfish (filet), and suckers (whole body). The U.S. Fish and Wildlife Service's National Pesticide Monitoring and National Contaminant Biomonitoring programs typically analyzed northern squawfish, largescale sucker, peamouth, and chiselmouth collected near Cascade Locks, OR in the Columbia River and Oregon City, OR on the Willamette River; these stations were nearest the study area.

The reconnaissance survey data are compared to the results of these studies, and potential sources of these metals to the lower Columbia River are identified below.

Antimony. Antimony was not detected in any of the tissue samples collected during the reconnaissance survey (see Table 4-7). The National Contaminant Biomonitoring Program, which has measured metal concentrations in aquatic biota throughout the United States (May and McKinney 1981, Lowe et al. 1985, Schmitt and Brumbaugh 1990), did not analyze fish tissue samples for antimony; therefore, no historical comparisons can be made with the reconnaissance survey data.

Tetra Tech (1992c) identified three aluminum industries that have National Pollution Discharge Elimination System (NPDES) permits that require monitoring of effluent concentrations of antimony. These facilities are located at RMs 63, 103, and 120. Their combined discharge of antimony to the river during 1990 was approximately 1.8 lb/day.

Arsenic. White sturgeon filets were the only tissue samples analyzed that had arsenic concentrations above analytical detection limits. Measured concentrations for the six samples where arsenic was detected ranged from 0.27 to 1.86 mg/kg wet weight (see Table 4-6).

No published measurements of arsenic concentrations in fish collected from the lower Columbia River were identified by Tetra Tech (1992a) and no data are available for arsenic concentrations in white sturgeon. May and McKinney (1981), Lowe et al. (1985), and Schmitt and Brumbaugh (1990) measured arsenic concentrations in fish tissues collected at eight locations in the Columbia River Basin, but none of these stations was located in the lower river below Bonneville Dam. The range of arsenic concentrations reported for fish collected from the two stations nearest the study area [Willamette River - Oregon City (RM 26) and the Columbia River - Cascade Locks (RM 149)] in 1984 was 0.06 to 0.32 mg/kg wet weight, with the maximum concentration reported for northern squawfish collected near Cascade Locks (Schmitt and Brumbaugh 1990). This is lower than the maximum concentration measured in white sturgeon filets reported in this study. The historical maximum fish tissue arsenic concentration measured in the National Pesticide Monitoring and National Contaminant Biomonitoring programs was 2.92 mg/kg wet weight, measured in bloater collected from Lake Michigan (May and McKinney 1981). However, the maximum concentration reported for monitoring conducted in 1984 was 1.5 mg/kg wet weight which also occurred in bloater collected from Lake Michigan (Schmitt and Brumbaugh 1990). This concentration is also lower than the maximum tissue concentration reported in this study.

The reconnaissance survey tissue arsenic concentrations that were detected were generally higher than available historical data, although comparison of measured concentrations in white sturgeon could not be made with a comparable species. The geometric mean arsenic concentration of 0.24 mg/kg wet weight was greater than the geometric mean concentration of the 1984-sample analyses conducted as part of the National Contaminant Biomonitoring Program (0.14 mg/kg wet weight) (Table 4-10). Historical data also indicated that typical whole-body fish tissue arsenic concentrations are generally below the detection limits achieved in this study.

Sources of arsenic include natural activities such as volcanic emissions, the weathering of soils and rocks that contain arsenic, and human activities that range from metal smelting, glass manufacturing, pesticide production and application, pharmaceutical industry, metal alloy production, and the combustion of fossil fuels. Arsenic may also be present in phosphate-based detergents due to its close chemical association with phosphorus (Galvin et al. 1984). Point sources within the lower Columbia River that are required to monitor effluent discharge for arsenic include the cities of Gresham, Portland, and St. Helens (Tetra Tech 1992c). Estimated arsenic loading from permitted point-source discharges directly to the lower Columbia River for 1989 and 1990 were 14.1 and 15.4 lb/day, respectively (Tetra Tech 1992c). However, these estimates were based primarily on analyses that indicated that arsenic concentrations in the monitored effluents were below laboratory detection limits. Arsenic was detected in the City of Gresham effluent in 1990 (due to the achievement of lower detection limits) which resulted in an arsenic loading estimate of 2.4 lb/day for 1990 from this facility.

Barium. Barium was frequently detected in all of the tissues collected, except white sturgeon filets, which did not contain detectable levels of barium (see Table 4-6). Detected concentrations of barium ranged from 0.6 to 5.4 mg/kg wet weight with the highest concentration reported for whole-body tissue analysis of largescale sucker. The National Pesticide Monitoring and National Contaminant Biomonitoring programs, which have measured metal concentrations in aquatic biota throughout the United States (May and McKinney 1981, Lowe et al. 1985, Schmitt and Brumbaugh 1990), have not analyzed fish tissue samples for barium; therefore, no historical comparisons can be made with the reconnaissance survey data.

Until 1991, the municipal wastewater facilities in Portland and Gresham were required to monitor effluent concentrations of barium; however, the concentration of barium was typically reported as below the laboratory detection limit and monitoring requirements of the current NPDES permits for these facilities does not require the monitoring of effluent concentrations of barium (Tetra Tech 1992c). Based on the detection limits reported by these facilities, the combined discharge of barium from these facilities probably does not exceed an annual average of 63 lb/day (Tetra Tech 1992c).

Cadmium. Cadmium was detected in all of the species sampled, except for white sturgeon filets in which cadmium was detected in only 13 percent of the samples analyzed. Detected concentrations ranged from 0.02 to 0.35 mg/kg wet weight with the maximum concentration reported for whole-body analysis of common carp (see Table 4-6).

No published measurements of cadmium concentrations in fish collected from the lower Columbia River were identified by Tetra Tech (1992a), and no data are available for cadmium concentrations in white sturgeon. May and McKinney (1981), Lowe et al. (1985), and Schmitt and Brumbaugh (1990) measured cadmium concentrations in fish tissues collected at eight locations in the Columbia River Basin, but none of these stations was located in the lower river below Bonneville Dam. The range of cadmium concentrations reported for fish collected from the two stations nearest the study area [Willamette River - Oregon City (RM 26) and the Columbia River - Cascade Locks (RM 149)] in 1984 was from below detection (no detection limit reported) to 0.05 mg/kg wet weight, with the maximum concentration reported for northern squawfish collected near Cascade Locks (Schmitt and Brumbaugh 1990). These concentrations are comparable to the concentrations measured in the reconnaissance survey, although somewhat higher concentrations were reported for samples of all species, except white sturgeon, at several stations. The historical maximum concentration of fish tissue cadmium concentration measured in the National Pesticide Monitoring and National Contaminant Biomonitoring programs was 1.04 mg/kg wet weight in carp collected from the Des Moines River, IA (May and McKinney 1981). However, the maximum concentration reported for monitoring conducted in 1984 was 0.22 mg/kg wet weight measured in carp collected from Lake St. Clair, MI (Schmitt and Brumbaugh 1990). This concentration is lower than the reconnaissance survey maximum concentration measured in common carp (0.35 mg/kg wet weight) at station D26 in Bachelor Island Slough. However, the reconnaissance survey geometric mean cadmium concentration of 0.04 mg/kg wet weight was similar to the geometric mean concentration of the 1984 sample analyses conducted as part of the National Contaminant Biomonitoring Program (see Table 4-10).

Sources of cadmium to the environment include smelting operations, surface mine drainage, and phosphate fertilizer (May and McKinney 1981). Mining and smelting operations in the upper river basin have been cited as a major source of cadmium to the Columbia River (May and McKinney 1981). Additional sources of cadmium include fossil fuel burning and the natural weathering of cadmium-containing rocks and soils. Point sources within the lower Columbia River that are required to monitor effluent discharge for cadmium include the municipal wastewater treatment facilities of Portland, Gresham, and St. Helens, and the industrial facilities of Reynolds Metals Co. in Longview, and Kalama Chemical (Tetra Tech 1992c). Tetra Tech (1992c) identified data on effluent cadmium discharge for the municipal facilities in Portland and Gresham only; however, cadmium was typically undetected in the effluent of these sources.

Copper. Copper was detected in all of the species sampled, except for white sturgeon filets in which copper was detected in only 13 percent of the samples analyzed. Detected concentrations ranged from 0.90 to 46.50 mg/kg wet weight with the maximum concentration reported for whole-body analysis of crayfish (see Table 4-6).

No published measurements of copper concentrations in fish from the lower Columbia River were identified by Tetra Tech (1992a), and no data are available for copper concentrations in white sturgeon. Lowe et al. (1985) and Schmitt and Brumbaugh (1990) measured copper concentrations in fish tissues collected at eight locations in the Columbia River Basin, but none of these stations was located in the lower river below Bonneville Dam. The range of copper concentrations reported for fish collected from the two stations nearest the study area [Willamette River - Oregon City (RM 26) and the Columbia River - Cascade Locks (RM 149)] in 1984 was from 0.50 to 1.01 mg/kg wet weight, with the maximum concentration reported for largescale sucker collected near Cascade Locks, OR (Schmitt and Brumbaugh 1990). These concentrations are generally lower than the concentrations measured in the reconnaissance survey. The historical maximum concentration of fish tissue copper concentration, measured in the National Contaminant Biomonitoring Program, was 38.7 mg/kg wet weight in white perch collected from the Susquaehanna River, MD (Lowe et al. 1985). However, the maximum concentration reported for monitoring conducted in 1984 was 23.1 mg/kg wet weight measured in Mozambique tilapia collected from Waikele Stream, HI (Schmitt and Brumbaugh 1990). This concentration is much lower than the maximum tissue concentrations of copper reported for crayfish and peamouth collected during the reconnaissance survey. The reconnaissance survey geometric mean copper concentration of 2.30 mg/kg wet weight was also greater than the geometric mean concentration of the 1984 sample analyses conducted as part of the National Contaminant Biomonitoring Program (0.65 mg/kg wet weight) (see Table 4-10).

Sources of copper to the environment include inputs due to both natural (volcanic eruptions, soil and rock weathering) and human (copper smelting and mining operations, corrosion of domestic water systems, wood treatment, metal plating, agricultural chemical production and application, phosphate fertilizer production and application, waste incineration, and fossil fuel combustion) activities. Those facilities discharging directly to the Columbia River that are required to monitor effluent copper concentrations include the Portland General Electric power plant in Beaver, OR, Weyerhaeuser Paper Co. (Longview), Trojan Nuclear Power Plant, Kalama Chemical, and the municipal wastewater facilities of St. Helens, Portland, and Gresham (Tetra Tech 1992c). The Portland, Gresham, Portland General Electric (Beaver

Generating Plant), and Weyerhaeuser (Longview) facilities typically reported undetectable levels of copper in their effluents. Kalama Chemical and the Trojan Nuclear Power facilities reported copper loadings averaging 0.11 and 0.03 lb/day in 1990 (Tetra Tech 1992c).

Lead. Lead was frequently detected in all of the species sampled. Detected concentrations ranged from 0.01 to 1.35 mg/kg wet weight with the maximum concentration reported for whole-body analysis of peamouth (see Table 4-6).

No published measurements of lead concentrations in fish from the lower Columbia River were identified by Tetra Tech (1992a) and no data are available for lead concentrations in white sturgeon. May and McKinney (1981), Lowe et al. (1985), and Schmitt and Brumbaugh (1990) measured lead concentrations in fish tissues collected at eight locations in the Columbia River Basin, but none of these stations was located in the lower river below Bonneville Dam. The range of lead concentrations reported for fish collected from the two stations nearest the study area [Willamette River - Oregon City (RM 26) and the Columbia River - Cascade Locks (RM 149)] in 1984 was 0.03 to 0.09 mg/kg wet weight with the maximum concentration reported for largescale sucker collected near Cascade Locks, OR (Schmitt and Brumbaugh 1990). These concentrations are generally lower than the maximum concentrations measured in carp, peamouth, largescale sucker, and white sturgeon measured in the reconnaissance survey. The historical maximum concentration of fish tissue lead concentration measured in the National Contaminant Biomonitoring Program was 6.73 mg/kg wet weight in Mozambique tilapia collected from Monoa Stream, HI (Lowe et al. 1985). However, the maximum concentration reported for monitoring conducted in 1984 was 4.88 mg/kg wet weight measured in Cuban limpia also collected from Monoa Stream, HI (Schmitt and Brumbaugh 1990). This concentration is higher than the maximum tissue concentrations of lead reported for fish collected during the reconnaissance survey. The reconnaissance survey geometric mean lead concentration of 0.05 mg/kg wet weight was also less than the geometric mean concentration of the 1984 sample analyses conducted as part of the National Contaminant Biomonitoring Program (0.11 mg/kg wet weight) (see Table 4-10).

Sources of lead include fossil fuel combustion (especially from lead-additive fuels), natural mineral deposits, and surface mining and smelting operations (May and McKinney 1981). Point sources required to monitor effluent lead discharge include Weyerhaeuser Paper Co. (Longview), Reynolds Metals (Longview), Kalama Chemical, and the municipal wastewater treatment facilities in St. Helens, Portland,

and Gresham. Lead was typically undetected in the effluents monitored in 1989 and 1990 (Tetra Tech 1992c).

Mercury. Mercury was frequently detected in all of the species sampled. Detected concentrations ranged from 0.022 to 0.347 mg/kg wet weight with the maximum concentration reported for analysis of white sturgeon filets (see Table 4-6).

The U.S. EPA National Bioaccumulation Study reported mercury concentrations in fish tissues collected in the lower Columbia River near Wauna, Longview, St. Helens, Portland, and Camas (U.S EPA 1991a). May and McKinney (1981), Lowe et al. (1985), and Schmitt and Brumbaugh (1990) measured mercury concentrations in fish tissues collected at eight locations in the Columbia River Basin, but none of these stations was located in the lower river below Bonneville Dam. The range of mercury concentrations reported for fish collected from the two stations nearest the study area [Willamette River - Oregon City (RM 26) and the Columbia River - Cascade Locks (RM 149)] in 1984 was 0.04 to 0.21 mg/kg wet weight with the maximum concentration reported for northern squawfish collected in the Willamette River near Oregon City, OR (Schmitt and Brumbaugh 1990). The range of fish tissue mercury concentrations reported by the U.S. EPA (1991a) for the lower Columbia River ranged from 0.09 to 0.74 mg/kg wet weight of squawfish filets and 0.05 to 0.1 mg/kg wet weight in whole-body samples of carp and suckers. The filet concentrations reported for the EPA study are lower than the maximum concentration measured in white sturgeon collected in the reconnaissance survey although higher concentrations in this long-lived species is expected. The historical whole-body analysis results are also somewhat lower than the maximum concentrations reported for the reconnaissance survey. Filet concentrations of mercury are generally expected to be somewhat higher than whole-body analyses due to the greater affinity of mercury for muscle tissue (U.S. EPA 1991a).

The historical maximum concentration of fish tissue mercury concentration measured in the National Pesticide Monitoring and National Contaminant Biomonitoring programs was 1.10 mg/kg wet weight in northern squawfish collected in the Columbia River near Cascade Locks (RM 149) just above Bonneville Dam (Lowe et al. 1985). However, the maximum concentration reported for monitoring conducted in 1984 was 0.37 mg/kg wet weight measured in largemouth bass collected from the Pee Dee River, SC (Schmitt and Brumbaugh 1990). This concentration is higher than the maximum tissue concentrations of mercury reported for fish collected during the reconnaissance survey. The reconnaissance survey geometric mean mercury concentration of 0.06 mg/kg wet weight was also less than the geometric mean concentration of the 1984 sample analyses conducted as part of the National Contaminant Biomonitoring Program (0.10 mg/kg wet weight) and the median concentration of the reconnaissance survey tissue mercury data was also lower than the median concentration determined from the National Bioaccumulation Study (see Table 4-10).

Sources of mercury include mining operations and natural mineral deposits that occur near the mouth of the river (Fuhrer 1986) and in upper drainage areas of the Willamette River (May and McKinney 1981), combustion of fossil fuels, and storage battery production and disposal. Historically, chlor-alkali plant process effluents associated with the pulp and paper industry were also a source of mercury to the river (Fuhrer 1986). Tetra Tech (1992c) identified a number of municipal wastewater treatment facilities that were required to monitor mercury concentrations in their effluent discharges to the lower Columbia River. These facilities included the cities of St. Helens, Portland, and Gresham. However, for 1989 and 1990 data were only available for the city of Gresham which typically reported that mercury concentrations were below laboratory detection limits. Based on these data, mercury discharged from the Gresham facility probably did not exceed 4.2 lb/day.

Nickel. Nickel was not frequently detected in the species sampled. Reported results for tissue nickel concentrations ranged from below detection (detection limit of 0.43 mg/kg) to 17.29 mg/kg wet weight with the maximum concentration reported for whole-body analysis of common carp (see Table 4-6).

No published measurements of nickel concentrations in fish from the lower Columbia River were identified by Tetra Tech (1992a) and no data are available for nickel concentrations in white sturgeon. May and McKinney (1981), Lowe et al. (1985), and Schmitt and Brumbaugh (1990) did not measure nickel concentrations in fish tissues collected as part of the National Pesticide Monitoring and National Contaminant Biomonitoring programs; therefore, comparisons with reconnaissance survey results for fish tissue analyses of nickel are not possible.

The potential sources of nickel to lower Columbia River fish include sources due to both natural (e.g., weathering of soils and rocks containing nickel) and human (e.g., metal smelting and mining operations, metal plating industries, burning of fossil fuels, commercial fertilizer production and application) activities. Several NPDES-permitted point sources are required to monitor effluent discharges for nickel. These facilities include the cities of Gresham, Portland, and St. Helens, and the industrial facilities of Weyerhaeuser (Longview), Reynolds Metals (Longview), Kalama Chemical, Reynolds Metals (Troutdale), and ALCOA (Vancouver) (Tetra Tech 1992c). Estimated point source loading of nickel, based on the available monitoring data, indicated that as much as 4.8 and 5.4 lb/day were discharged in 1989 and 1990, respectively. However, a portion of these estimates was based on calculations using reported detection limits (i.e., nickel was not detected in some effluents above the detection limit) (Tetra Tech 1992c).

Selenium. Selenium was not detected in any of the species sampled during the reconnaissance survey. The reported laboratory detection limits ranged from 0.24 to 0.55 mg/kg wet weight (see Table 4-7).

No published measurements of selenium concentrations in fish from the lower Columbia River were identified by Tetra Tech (1992a), and no data are available for selenium concentrations in white sturgeon. May and McKinney (1981), Lowe et al. (1985), and Schmitt and Brumbaugh (1990) measured selenium concentrations in fish tissues collected at eight locations in the Columbia River Basin, but none of these stations was located in the lower river below Bonneville Dam. The range of selenium concentrations reported for fish collected from the two stations nearest the study area [Willamette River - Oregon City (RM 26) and the Columbia River - Cascade Locks (RM 149)] in 1984 was 0.11 to 0.35 mg/kg wet weight with the maximum concentration reported for northern squawfish collected near Cascade Locks, OR (Schmitt and Brumbaugh 1990). These concentrations are generally lower than the laboratory detection limits reported for fish tissue analyses conducted for the reconnaissance survey. The historical maximum concentration of fish tissue selenium concentration, measured in the National Pesticide Monitoring and National Contaminant Biomonitoring programs, was 3.65 mg/kg wet weight in common carp collected from Lake Havasu, Arizona (Lowe et al. 1985). However, the maximum concentration reported for monitoring conducted in 1984 was 2.30 mg/kg wet weight measured in common carp collected from Lake Martinez (Colorado River), AZ (Schmitt and Brumbaugh 1990). These maximum concentrations are higher than the maximum detection limits reported for the lower Columbia River reconnaissance survey. The reconnaissance survey fish tissue selenium detection limits were also generally lower than the geometric mean concentration of the 1984 sample analyses conducted as part of the National Contaminant Biomonitoring Program (0.42 mg/kg wet weight) (see Table 4-10).

No point sources of selenium have been identified in the lower Columbia River (Tetra Tech 1992c). However, irrigation return flows from areas with high soil selenium content may be a potential source of selenium (Hem 1970).

Silver. Silver was generally not detected in the species sampled, except for crayfish in which silver was detected in 80 percent of the samples. Reported concentrations ranged from below detection (detection limit of 0.12 mg/kg) to 1.54 mg/kg wet weight with the maximum concentration reported for whole-body analysis of crayfish (see Table 4-6).

No published measurements of silver concentrations in fish from the lower Columbia River were identified by Tetra Tech (1992a), and no data are available for silver concentrations in white sturgeon. May and McKinney (1981), Lowe et al. (1985), and Schmitt and Brumbaugh (1990) did not measure silver concentrations in fish tissues collected as part of the National Pesticide Monitoring and National Contaminant Biomonitoring programs. Therefore, comparisons with reconnaissance survey results for fish tissue analyses of silver is not possible.

Potential sources of silver to lower Columbia River fish include sources due to both natural (e.g., weathering of soils and rocks containing silver and volcanic eruptions) and human (e.g., ore smelting and mining, fossil fuel consumption, photographic industry, and cement manufacturing) activities. Facilities discharging directly to the lower Columbia River that are required to monitor effluent silver concentrations include the cities of Gresham, Portland, and St. Helens. The silver concentration in the effluents that were monitored in 1989 and 1990 were generally below the detection limits achieved by the analytical laboratories. Based on these limited data, the silver loading to the lower Columbia River from these facilities was probably less than 2.1 and 3.6 lb/day in 1989 and 1990, respectively (Tetra Tech 1992c).

Zinc. Zinc was frequently detected in all of the species sampled. Detected concentrations ranged from 17.3 to 133.7 mg/kg wet weight with the maximum concentration reported for whole-body analysis of common carp (see Table 4-6).

No published measurements of zinc concentrations in fish from the lower Columbia River were identified by Tetra Tech (1992a), and no data are available for zinc concentrations in white sturgeon. Lowe et al.

(1985) and Schmitt and Brumbaugh (1990) measured zinc concentrations in fish tissues collected at eight locations in the Columbia River Basin, but none of these stations was located in the lower river below Bonneville Dam. The range of zinc concentrations reported for fish collected from the two stations nearest the study area [Willamette River - Oregon City (RM 26) and the Columbia River - Cascade Locks (RM 149)] in 1984 was 16.35 to 21.17 mg/kg wet weight with the maximum concentration reported for northern squawfish collected near Cascade Locks, OR (Schmitt and Brumbaugh 1990). These concentrations are generally lower than the maximum concentrations measured in whole-body samples of crayfish, carp, peamouth, and largescale sucker and higher than white sturgeon filets measured in the reconnaissance survey. The historical maximum concentration of fish tissue zinc concentration measured in the National Contaminant Biomonitoring Program was 168.1 mg/kg wet weight in common carp collected from Utah Lake, UT (Lowe et al. 1985). However, the maximum concentration reported for monitoring conducted in 1984 was 118.4 mg/kg wet weight measured in common carp collected from Lake St. Claire, MI (Schmitt and Brumbaugh 1990). This concentration is lower than the maximum tissue concentration of zinc reported for common carp collected during the reconnaissance survey. However, the reconnaissance survey geometric mean zinc concentration of 19.95 mg/kg wet weight was less than the geometric mean concentration of the 1984 sample analyses conducted as part of the National Contaminant Biomonitoring Program (21.7 mg/kg wet weight) (see Table 4-10).

Potential sources of zinc include both natural (e.g., soil and rock weathering) and human (e.g., metal smelting and mining, metal plating, corrosion of domestic water supply systems, and production and erosion of automobile tires) sources. Permitted point sources that are required to monitor effluent concentrations of zinc include the municipal wastewater treatment facilities of Gresham, Portland, and St. Helens, and the industrial facilities of Kalama Chemical, Reynolds Metals (Troutdale), and ALCOA (Vancouver) (Tetra Tech 1992c). Detectable concentrations of zinc were reported in the effluents of Kalama Chemical (0.03 lb/day), Reynolds Metals (Troutdale) (0.03 lb/day), ALCOA (Vancouver) (0.17 lb/day), Portland (33.4 lb/day), and Gresham (6.8 lb/day) (Tetra Tech 1992c).

4.6.1.2 Significance and Recommendations. As mentioned above, metals were detected in fish tissue throughout the lower river, with no clear trends. A few stations, however, tended to show higher tissue metal concentrations: D15 at Wallace Slough, D38^E at Reed Island, and D40 at Beacon Rock. High tissue metal levels at the two upriver stations (D38^E and D40) are interesting in that there are no known sources of metals immediately upstream of these stations. These results, then, may indicate significant input of metals from above Bonneville. Sediments at these two stations had high levels of several metals, including lead and zinc. Station D15 in Wallace Slough is near the mouth of the Clatskanie River. This station did not have high metals concentrations in the sediment. There are no obvious sources of metals input to fish at this station.

The ubiquitous occurrence of metals in fish tissue throughout the lower river could be attributable to a multitude of natural and anthropogenic (point and nonpoint sources including urban run-off and other nonpoint sources, as well as natural and anthropogenic pollutant sources to tributaries and the upper Columbia River above Bonneville Dam) sources.

Tissue metals concentrations measured in the lower Columbia were compared to those measured at over 100 stations nationwide from 1976-77 to 1984 (Schmitt and Brumbaugh 1990). In general, the lower Columbia River values were similar to those measured in the national studies, but usually did not approach the maximum national values. Exceptions included a few high Columbia River values for cadmium and zinc in carp, copper in crayfish and peamouth, and lead in sturgeon and peamouth. The geometric mean concentration of arsenic measured in white sturgeon filets was also greater than the geometric mean of the results of nationwide sampling conducted in 1984 (Schmitt and Brumbaugh 1990).

Relatively little information is available on the toxicity of metals in fish tissue to piscivorous wildlife or humans. One exception is for mercury, for which the Food and Drug Administration (FDA) action level for fish is 1 ppm (mg/kg), and concentrations of 1-2 ppm in consumed fish have been shown to be lethal to mink and river otter (U.S. EPA 1991a). Almost all tissue levels of mercury measured in this study were well below these toxic levels, although the highest sturgeon (0.35 ppm) and peamouth (0.23 ppm) concentrations were within an order of magnitude of potentially toxic levels.

Relevant questions for further research include the following:

- What are the major sources (point and nonpoint sources as well as background levels) of these metals to the river?

- What is the fate of the metals delivered to the river?

- What are the effects of these metals on the biota?
- Are the metals detected in fish tissues in this survey the result of bioaccumulation or bioconcentration?
- Are some metals and their various forms more available than others?
- Which is the most important pathway (water column or sediments) for metal contaminant exposure and accumulation?
- What is the biological turnover time of these metals in fish tissue?
- How and in what forms are metals accumulated and metabolized by the biota?
- What physical and biological factors control the variation in measured tissue concentrations of metals?
- What are the forms and concentrations of metals in sediments and prey items and how does this relate to the metals concentrations measured in fish and crayfish tissues?
- What are the species consumed, the rate of consumption, and the tissues consumed by wildlife and humans?
- What is the risk of human health impairment associated with the consumption of various quantities of the species sampled, based on the reconnaissance survey fish tissue data?
- How are the metals partitioned in the various tissues (i.e., skin, muscle, organs, bone) and how might this affect the evaluation of the effects of tissue contaminant levels on piscivorous wildlife and humans?

Answers to these questions are essential for identifying the most important sources of specific metals, and the acceptable limits of the input of these contaminants into the lower Columbia River system. An integrated monitoring program of both dissolved and total metals in the lower Columbia River, and the various point and nonpoint sources, should be performed on a seasonal basis to improve the understanding of the sources, forms, and fate of metals in the lower Columbia River. An assessment of chemical forms of the metals in various fish species and tissues in the lower river, and the role of various environmental factors that control the toxic effects of these metals and the degree of accumulation, would also aid in further assessing the relative effects of these metals on the biota of the river and the effect of the consumption of these species on wildlife and humans.

4.6.2 Organic Compounds

Fish and crayfish samples were analyzed for a total of 104 organic compounds, including semivolatile organic compounds, pesticides, PCBs, and dioxin and furan compounds. Dioxins and furans were the most commonly detected organic compounds. Pesticides and PCBs were less frequently detected throughout the river in all of the species sampled. Semivolatile compounds were also detected (primarily phenols, PAHs, and phthalate esters), but the detection of these compounds was generally isolated to the whole-body analysis of carp collected from station D29 (RM 101) which was located in the Lake Vancouver flushing channel.

4.6.2.1 Comparison with Historical Data and Identification of Potential Sources. The results of the fish tissue organic compound analyses, conducted as part of the lower Columbia River reconnaissance survey, are compared to tissue organic compound sampling results of the National Pesticide Monitoring Program and the National Contaminant Biomonitoring Program conducted by the U.S. Fish and Wildlife Service (Schmitt et al. 1990)—which reported whole body tissue concentrations of organochlorine pesticides (including PCBs) for tissue samples collected between 1976 and 1984—and the results of the U.S. EPA National Bioaccumulation Study (U.S. EPA 1991a) which reported whole fish (bottom-feeding fish) and filet (game fish) tissue concentrations of organochlorine pesticides, PCBs, and dioxins and furans (except octa- forms) (see Table 4-10). Several of the stations sampled in these studies were located in the Columbia River Basin, but relatively few stations were located within the study area below Bonneville Dam. Columbia River Basin stations sampled as part of the National Pesticide and National Contaminant Biomonitoring programs included several locations on the Snake River, and single stations on the Flathead, Salmon, Yakima, and Willamette rivers. Stations on the mainstem of the Columbia River included locations near Grand Coulee, Pasco, and Cascade Locks, but none of these are located within the study area. Station locations in the Columbia River Basin sampled during the National

Bioaccumulation Study included several stations in the lower Columbia River [i.e., Columbia River estuary (Woody Island), Wauna, Longview, Kalama, Deer Island, St. Helens, Portland, and Camas]. The species analyzed in the National Pesticide Monitoring and National Contaminant Biomonitoring programs in the Columbia River Basin included black crappie, carp, channel catfish, chiselmouth, largescale sucker, northern squawfish, and yellow perch. The species analyzed for organic compounds in the lower Columbia River in the National Bioaccumulation Study included carp (whole body), northern squawfish (filet), suckers (whole body), and sturgeon (whole body). Sturgeon tissues were only analyzed for dioxin and furan compounds. The U.S. Fish and Wildlife Service's National Pesticide Monitoring and National Contaminant Biomonitoring programs typically analyzed northern squawfish, largescale sucker, peamouth, and chiselmouth collected near Cascade Locks, OR in the Columbia River and Oregon City, OR on the Willamette River, the stations nearest the study area.

The reconnaissance survey data are compared to the results of these studies, and potential sources of these organic compounds to the lower Columbia River are identified below.

Semivolatile Organic Compounds. Crayfish, carp, largescale sucker, peamouth, and white sturgeon were analyzed for 52 semivolatile organic compounds. Fifteen of these compounds were detected (Figure 4-33). This group of chemicals was unique in that, with the exception of the common laboratory contaminant, bis-2-(ethylhexyl)phthalate, virtually all of the measured concentrations occurred for a single sample. Carp tissue from station D29, was the only sample where the following chemicals were measured: phenolic compounds (phenol, 2-chlorophenol, 4-chloro-3-methylphenol, 4-nitrophenol); a nitroaromatic compound (2,4-dinitrotoluene); a nitrosamine compound (N-nitroso-di-n-propylamine); polynuclear aromatic compounds (PAHs) (acenapthene, naphthalene, pyrene, 1,4-dichlorobenzene); and chlorinated benzene compound (1,4-dichlorobenzene, 1,2,4-trichlorobenzene) (see Table 4-6). The PAH compound 2-methylnaphthalene was also detected in the carp tissue sample at this station and in a largescale sucker tissue sample at another station (see Table 4-6).

Of this group of chemicals, 1,2,4-trichlorobenzene is the only compound that was measured in tissue as part of U.S. EPA's National Bioaccumulation Study (U.S. EPA 1991a) (see Table 4-11). The tissue concentration measured at station D29 (3,100 μg/kg) is 12 times higher than the maximum value (264.8 mg/kg) measured during the EPA study—and over 22,000 times higher than the median concentration calculated for 362 sites sampled during the National Bioaccumulation study. In general, trichlorobenzene

TISSUE–SEMIVOLATILE COMPOUNDS

Fish Species:
C = Carp
Cy = Crayfish
P = Peamouth
ST = Sturgeon
Su = Largescale sucker

	Astoria, OR	Astoria, OR		Deep River	Marsh Island	Deep River Mouth	Grays Bay	Woody Island Channel	Clifton Channel	Elochoman Slough	Wallace Island	Wallace Slough	Coal Creek Slough	Longview, WA	Rainier, OR	Goble, OR	Carrolls Channel	Port of Kalama, WA	Kalama, WA	Burke Slough	Martin Bluff, WA	St. Helens, OR	Bachelor Point, WA	Sauvie Island	Willamette River Mouth		N. Portland Harbor	Government Island	Camas Slough	Reed Island		Multnomah Falls, OR	Beacon Rock
CHEMICAL CLASS	RM 15 ST	RM 15.5 D3	RM 18.5 ST	RM 20 ST	RM 20 D8	RM 21 ST	RM 22.5 D6	RM 27 ST	RM 38 D10	RM 40 D12	RM 49 ST	RM 49.5 D15	RM 57 D16	RM 63 D19	RM 67 ST	RM 71 D21	RM 71.1 D20	RM 75 D22	RM 75 ST	RM 78.5 D23	RM 80 ST	RM 85.5 D24	RM 92.5 D26	RM 98 D28	RM 101 D29	RM 103 ST	RM 107.5 D31	RM 115 ST	RM 118.5 D35	RM 125.5 D38	RM 127 ST	RM 136 ST	RM 141.5 D40
SEMIVOLATILE COMPOUNDS																																	
Species Analyzed	ST	P	ST	ST	Cy Su	ST	Cy Su	ST	Cy Su P	Cy Su P	ST	Cy Su P	Cy Su P	Cy Su P	ST	P	Cy Su	Cy Su	ST	Cy C Su P	ST	Cy C Su P	Cy C Su	Cy C Su P	Cy C Su	ST	Cy C Su	ST	Cy C Su	Cy C Su	ST	ST	Cy C Su
PHENOLIC COMPOUNDS																																	
Phenol																									●								
2-Chlorophenol																									●								
4-Chloro-3-methylphenol																									●								
4-Nitrophenol																									●								
NITROAROMATICS																																	
2,4-Dinitrotoluene																									●								
NITROSAMINES																																	
N-Nitroso-di-n-propylamine																									●								
POLYNUCLEAR AROMATIC HYDROCARBONS																																	
Acenaphthene																									●								
Naphthalene																													●				
2-Methylnaphthalene																									●				●				
Pyrene																									●								
CHLORINATED BENZENES																																	
1,4-Dichlorobenzene																									●								
1,2,4-Trichlorobenzene																									●								
PHTHALATE ESTERS																																	
Di-n-butylphthalate			●								●								●	●				●						●	●		
Bis-2-(ethylhexyl)phthalate		●	●		●				●	●		●	●	●		●	●	●		●		●	●	●	●	●	●	●	●	●		●	●
Butylbenzylphthalate																			●														

Figure 4-33. Semivolatile compounds detected in tissue samples in the lower Columbia River Reconnaissance Survey.

TABLE 4-11. CONCENTRATIONS OF MERCURY, CHLORINATED BENZENES, POLYCHLORINATED BIPHENYL COMPOUNDS, AND PESTICIDES IN FISH COLLECTED FROM THE LOWER COLUMBIA RIVER FOR THE NATIONAL BIOACCUMULATION STUDY

(all concentrations in ng/g wet weight unless otherwise noted)
(Page 1 of 6)

Sample Location	Portland	St. Helens	St. Helens	St. Helens	Wauna	Wauna
Species	Carp	Squawfish	Sucker	Sucker	Squawfish	Sucker
Sample Type	Whole Body	Fillet	Whole Body	Lab. Dup.	Fillet	Whole Body
Mercury (in $\mu g/g$)	0.1	0.33	0.05	NA	0.09	0.36
1,2,3-Trichlorbenzene	ND	ND	0.24D	ND	--	ND
1,2,4-Trichlorbenzene	0.72D	ND	ND	0.48D	--	ND
1,3,5-Trichlorbenzene	ND	ND	ND	ND	--	ND
1,2,3,4-Tetrachlorobenzene	ND	ND	ND	ND	--	ND
1,2,3,5-Tetrachlorobenzene	ND	ND	ND	ND	--	ND
1,2,4,5-Tetrachlorobenzene	ND	ND	ND	ND	--	ND
Octachlorostyrene	ND	ND	ND	ND	--	ND
Pentachlorobenzene	0.54D	ND	ND	ND	--	ND
Pentrachlornitrobenzene	ND	ND	ND	ND	--	ND
Hexachlorobenzene	2.12D	ND	ND	ND	--	ND
Alpha BHC	1.11D	ND	2.74	5.48	--	ND
Gamma BHC	ND	ND	ND	ND	--	ND
Cis chlordane	9.68	0.17D	ND	ND	--	0.73D
Trans chlordane	6.7	ND	ND	ND	--	ND
Oxychlordane	ND	ND	ND	ND	ND	--
Cis nonachlor	5.41	ND	ND	ND	ND	--
Trans nonachlor	14.4	1.58D	ND	ND	2.67	--
Heptachlor	ND	ND	ND	ND	ND	--

TABLE 4-11. CONCENTRATIONS OF MERCURY, CHLORINATED BENZENES, POLYCHLORINATED BIPHENYL COMPOUNDS, AND PESTICIDES IN FISH COLLECTED FROM THE LOWER COLUMBIA RIVER FOR THE NATIONAL BIOACCUMULATION STUDY

(all concentrations in ng/g wet weight unless otherwise noted)
(Page 2 of 6)

Sample Location	Portland	St. Helens	St. Helens	St. Helens	Wauna	Wauna
Species	Carp	Squawfish	Sucker	Sucker	Squawfish	Sucker
Sample Type	Whole Body	Fillet	Whole Body	Lab. Dup.	Fillet	Whole Body
Mercury (in $\mu g/g$)	0.1	0.33	0.05	NA	0.09	0.36
Heptachlor epoxide	ND	ND	ND	ND	ND	--
p,p'-DDE	333E	34.3	80.9	89.8	52	--
Dieldrin	12.4	ND	ND	ND	ND	--
Endrin	ND	ND	ND	ND	ND	--
Dicofol	ND	ND	ND	ND	ND	--
Methoxychlor	ND	0.39D	ND	ND	ND	--
Perthane	ND	ND	ND	ND	ND	--
Mirex	0.94D	0.26D	ND	ND	ND	--
Nitrofen	ND	ND	ND	ND	ND	--
Chlorpyrifost	ND	ND	ND	ND	ND	--
Isopropalin	ND	ND	ND	ND	ND	--
Trifluralin	ND	ND	ND	ND	ND	--
Pentachloroanisole	2.13D	ND	0.92D	1.32D	ND	--
Biphenyl	3.41	0.06D	0.73D	1.09D	0.06D	--
Total PCBs	2043.1	37.1	127.9	173	55.6	--
Total Monochlorobiphenyls	1.32D	ND	ND	ND	ND	--
Total Dichlorobiphenyls	ND	ND	ND	ND	ND	--
Total Trichlorobiphenyls	14.5	ND	ND	ND	ND	--

TABLE 4-11. CONCENTRATIONS OF MERCURY, CHLORINATED BENZENES, POLYCHLORINATED BIPHENYL COMPOUNDS, AND PESTICIDES IN FISH COLLECTED FROM THE LOWER COLUMBIA RIVER FOR THE NATIONAL BIOACCUMULATION STUDY
(all concentrations in ng/g wet weight unless otherwise noted)
(Page 3 of 6)

Sample Location	Portland	St. Helens	St. Helens	St. Helens	Wauna	Wauna
Species	Carp	Squawfish	Sucker	Sucker	Squawfish	Sucker
Sample Type	Whole Body	Fillet	Whole Body	Lab. Dup.	Fillet	Whole Body
Mercury (in µg/g)	0.1	0.33	0.05	NA	0.09	0.36
Total Tetrachlorobiphenyls	208E	ND	15	21.7	ND	--
Total Pentachlorobiphenyls	890E	12.4	55.1	71	20.8	--
Total Hexachlorobiphenyls	713E	19.8	57.8	68.6	29.7	--
Total Hectachlorobiphenyls	186E	4.9	ND	11.7	5.1	--
Total Octachlorobiphenyls	30.3	ND	ND	ND	ND	--
Total Nonachlorobiphenyls	ND	ND	ND	ND	ND	--
Total Decachlorobiphenyls	ND	ND	ND	ND	ND	--
Diphenyl Disulfide	ND	ND	ND	ND	ND	--
Hexachlorobutadiene	ND	ND	ND	ND	ND	--
Percent Lipids	8.9	1.4	7.8	7.7	2.8	NA
qualifier codes: D = value below limit of quantitation E = value exceeds calibration standard						

TABLE 4-11. CONCENTRATIONS OF MERCURY, CHLORINATED BENZENES, POLYCHLORINATED BIPHENYL COMPOUNDS, AND PESTICIDES IN FISH COLLECTED FROM THE LOWER COLUMBIA RIVER FOR THE NATIONAL BIOACCUMULATION STUDY
(all concentrations in ng/g wet weight)
(Page 4 of 6)

Sample Location	Longview	Longview	Camas	Camas
River Segment	2C	2C	4A	4A
Species	Squawfish	Sucker	Squawfish	Sucker
Sample Type	Filet	Whole Body	Filet	Whole Body
Mercury (in μg/g)	0.23	0.05	0.74	ND
1,2,3-Trichlorbenzene	--	ND	--	ND
1,2,4-Trichlorbenzene	--	ND	--	ND
1,3,5-Trichlorbenzene	--	ND	--	ND
1,2,3,4-Tetrachlorobenzene	--	ND	--	ND
1,2,3,5-Tetrachlorobenzene	--	ND	--	ND
1,2,4,5-Tetrachlorobenzene	--	ND	--	ND
Octachlorostyrene	--	ND	--	ND
Pentachlorobenzene	--	ND	--	ND
Pentrachlornitrobenzene	--	ND	--	ND
Hexachlorobenzene	--	ND	--	1.49D
Alpha BHC	--	ND	--	ND
Gamma BHC	--	ND	--	ND
Cis chlordane	--	ND	--	ND
Trans chlordane	--	ND	--	ND
Oxychlordane	--	ND	--	ND
Cis nonachlor	--	ND	--	ND
Trans nonachlor	--	ND	--	4.5

TABLE 4-11. CONCENTRATIONS OF MERCURY, CHLORINATED BENZENES, POLYCHLORINATED BIPHENYL COMPOUNDS, AND PESTICIDES IN FISH COLLECTED FROM THE LOWER COLUMBIA RIVER FOR THE NATIONAL BIOACCUMULATION STUDY

(all concentrations in ng/g wet weight)
(Page 5 of 6)

Sample Location	Longview	Longview	Camas	Camas
River Segment	2C	2C	4A	4A
Species	Squawfish	Sucker	Squawfish	Sucker
Sample Type	Filet	Whole Body	Filet	Whole Body
Heptachlor	--	ND	--	ND
Heptachlor expoxide	--	ND	--	ND
4,4'-DDE	--	107	--	89.2E
Dieldrin	--	ND	--	ND
Endrin	--	ND	--	ND
Dicofol	--	ND	--	ND
Methoxychlor	--	ND	--	ND
Perthane	--	ND	--	ND
Mirex	--	ND	--	ND
Nitrofen	--	ND	--	ND
Chlorpyrifost	--	ND	--	ND
Isopropalin	--	ND	--	ND
Trifluralin	--	ND	--	ND
Pentachloroanisole (PCA)	--	6.74	--	0.68D
Biphenyl	--	ND	--	0.2D
Total PCBs	--	174.72	--	92.36
Total Monochlorobiphenyls	--	ND	--	ND
Total Dichlorobiphenyls	--	ND	--	ND

TABLE 4-11. CONCENTRATIONS OF MERCURY, CHLORINATED BENZENES, POLYCHLORINATED BIPHENYL COMPOUNDS, AND PESTICIDES IN FISH COLLECTED FROM THE LOWER COLUMBIA RIVER FOR THE NATIONAL BIOACCUMULATION STUDY

(all concentrations in ng/g wet weight)
(Page 6 of 6)

Sample Location	Longview	Longview	Camas	Camas
River Segment	2C	2C	4A	4A
Species	Squawfish	Sucker	Squawfish	Sucker
Sample Type	Filet	Whole Body	Filet	Whole Body
Total Trichlorobiphenyls	--	0.72D	--	0.63D
Total Tetrachlorobiphenyls	--	41.3	--	24.9
Total Pentachlorobiphenyls	--	67.1	--	37.5
Total Hexachlorobiphenyls	--	55.1	--	25.3
Total Hectachlorobiphenyls	--	10.5	--	4.03
Total Octachlorobiphenyls	--	ND	--	ND
Total Nonachlorobiphenyls	--	ND	--	ND
Total Decachlorobiphenyls	--	ND	--	ND
Diphenyl Disulfide	--	ND	--	ND
Hexachlorobutadiene	--	ND	--	ND
Percent Lipids	NA	15.9	NA	20.06

Qualifier codes:

D = value below limit of quantitation
E = value exceeds calibration standard

ND = Not detected. No detection limit given.

Source: U.S. EPA 1991g.

compounds analyzed for in the fish tissue samples, collected in the lower Columbia River as part of the National Bioaccumulation Study (U.S. EPA 1991a) (Table 4-11), were below the limits of detection with the exception of a laboratory duplicate analysis of a sucker (whole body) collected near St. Helens, OR, for which a concentration of 0.48 μg/kg wet weight was reported.

The compounds detected in carp at this site could potentially be derived from a variety of sources. The phenolic compounds and 2,4-dinitrotoluene are all chemical intermediates used in the production of other chemicals in a variety of industries. The PAHs acenaphthene and pyrene are formed by the combustion of hydrocarbon products and may be released into the environment as a result of oil spills. The chemical 1,4-dichlorobenzene is used as an insecticide and 1,2,4-trichlorobenzene is used in the production of dyes, transformer dielectric fluid, and as a solvent in chemical manufacturing.

The proximity of station D29 to the industrialized areas of Portland, OR and Vancouver, WA suggests that contaminant levels measured at this site may be due to industrial and municipal point and non-point discharges in this portion of the river. However, the relatively high tissue levels measured in carp at station D29 and the fact that none of these compounds were detected in carp collected three miles downstream at station D28, or six miles upstream at station D31 (or in any other tissue sample collected during the reconnaissance survey, with the exception of one compound at one other station) might indicate a local source of these contaminants or possible contamination of these samples in the field or laboratory. Further investigation of contaminant levels in fish in the vicinity of station D29 is needed to resolve this issue.

Station D35 located in the Camas Slough (RM 118) was the only other site where a PAH compound was detected in fish tissue (2-methylnaphthalene) (see Figure 4-33). From 1989 through 1991 Camas Slough experienced several small accidental oils spills (Tetra Tech 1992c). The PAH compound measured in carp and largescale sucker collected from Camas Slough can be released from oil spills (Sittig 1985), as well as from the combustion of hydrocarbon products.

Pesticides. Crayfish, carp, largescale sucker, peamouth, and white sturgeon were analyzed for 29 pesticides and pesticide metabolites. Twenty-four of these compounds were detected in at least one tissue sample (Figure 4-34). Pesticides were detected in fish and crayfish throughout the lower Columbia River. Particularly apparent were DDT, DDE, and DDD, which were detected in 98.6 percent of the

TISSUE–PESTICIDES

Fish Species:
C = Carp
Cy = Crayfish
P = Peamouth
ST = Sturgeon
Su = Largescale sucker

	Astoria, OR	Astoria, OR		Deep River	Marsh Island	Deep River Mouth	Grays Bay	Woody Island Channel	Clifton Channel	Elochoman Slough	Wallace Island	Wallace Slough	Coal Creek Slough	Longview, WA	Rainier, OR	Goble, OR	Carrolls Channel	Port of Kalama, WA	Kalama, WA	Burke Slough	Martin Bluff, WA	St. Helens, OR	Bachelor Point, WA	Sauvie Island	Willamette River Mouth		N. Portland Harbor	Government Island	Camas Slough	Reed Island		Multnomah Falls, OR	Beacon Rock
CHEMICAL CLASS	RM 15 ST	RM 15.5 D3	RM 18.5 ST	RM 20 ST	RM 20 D8	RM 21 ST	RM 22.5 D6	RM 27 ST	RM 38 D10	RM 40 D12	RM 49 ST	RM 49.5 D15	RM 57 D16	RM 63 D19	RM 67 ST	RM 71 D21	RM 71.1 D20	RM 75 D22	RM 75 ST	RM 79.5 D23	RM 80 ST	RM 85.5 D24	RM 92.5 D26	RM 98 D28	RM 101 D29	RM 103 ST	RM 107.5 D31	RM 115 ST	RM 118.5 D35	RM 125.5 D38	RM 127 ST	RM 136 ST	RM 141.5 D40
PESTICIDES																																	
Species Analyzed	ST	P	ST	ST	Cy Su	ST	Cy Su	ST	Cy Su P	Cy Su P	ST	Cy Su P	Cy Su P	Cy Su P	ST	P	Cy Su	Cy Su	ST	Cy C Su P	ST	Cy C Su P	Cy C Su	Cy C Su P	Cy C Su P	ST	Cy C Su	ST	Cy C Su	Cy C Su	ST	ST	Cy C Su
o,p'-DDE		●										●	●	●				●	●	●		●	●	●	●		●						
o,p'-DDD		●										●						●	●	●					●		●		●			●	
o,p'-DDT																			●	●				●									
p,p'-DDE	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
p,p'-DDD					●			●	●			●	●	●			●	●		●		●	●	●	●	●	●	●	●	●			●
p,p'-DDT							●	●	●		●	●	●				●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●
Heptachlor																														●			
Aldrin									●	●		●	●			●									●								●
Dieldrin								●								●			●	●			●			●	●			●			
Endrin																●			●	●					●					●			
Endrin aldehyde										●									●														
Mirex																							●										
Isophorone					●													●				●	●	●			●						
Dacthal													●																				
Methyl parathion							●	●					●									●				●		●					
Parathion		●			●								●				●																
Malathion									●													●											
Endosulfan I		●						●	●							●				●													
Endosulfan II																									●								
Endosulfan sulfate													●						●										●				
Methoxychlor								●				●							●			●										●	
alpha-BHC																				●			●										
beta-BHC										●			●			●									●					●			
gamma-BHC												●	●	●								●	●										

Figure 4-34. Pesticides detected in fish and crayfish tissue samples collected for the lower Columbia River Reconnaissance Survey.

samples analyzed. The 4,4'-DDE isomer was detected in a higher proportion of tissue samples and at higher concentrations than other DDT metabolites. The relatively higher detection frequency of the 4,4'-DDE form was also noted by Schmitt et al. (1990), in a summary of sampling results for organochlorine residues in freshwater fish from 1976 to 1984, as part of the National Contaminant Biomonitoring Program.

Schmitt et al. (1990) measured DDT and DDT homolog concentrations in fish tissues collected at eight locations in the Columbia River Basin, but none of these stations was located in the lower river below Bonneville Dam. The range of DDT concentrations reported for fish collected from the two stations nearest the study area [Willamette River - Oregon City (RM 26) and the Columbia River - Cascade Locks (RM 149)] in 1984 was from below detection for 4,4'-DDT to 730 μg/kg wet weight for largescale sucker collected near Cascade Locks, OR (Schmitt et al. 1990). This is somewhat higher than the maximum concentration measured in peamouth (480 μg/kg) measured in the reconnaissance survey. The range of fish tissue DDT concentrations (only 4,4'-DDE was reported) reported by the U.S. EPA (1991a) for the lower Columbia River ranged from 0.09 to 34 μg/kg wet weight in northern squawfish (filets) collected near St. Helens to an estimated concentration of 333 μg/kg in whole body samples of carp collected near Portland (see Table 4-11).

Median concentrations of 4,4'-DDE were 111.5, 25.5, 22, 10.4, and 7.5 μg/kg for peamouth, largescale sucker, carp, white sturgeon, and crayfish, respectively. The median tissue concentration for peamouth exceeded the U.S. EPA National Bioaccumulation Study's median concentration for 4,4'-DDE (58.3 μg/kg) (U.S. EPA 1991a). However, the median concentration of 4,4'-DDE in all fish tissue sampled during the reconnaissance survey was lower than the median concentration from the National Bioaccumulation Survey, and the geometric mean concentration was much lower than the 1984 geometric mean concentration from the National Contaminant Biomonitoring Program (see Table 4-10).

Other organochlorine and organophosphate pesticides were detected in species collected throughout the lower Columbia River; however, the frequency of detection of these chemicals was relatively low—a pattern similar to that observed for pesticides detected in sediments. Dieldrin, aldrin, methyl parathion, and isophorone were the most commonly detected pesticides in tissue other than DDT metabolites, being detected in 11, 10, 8, and 8 percent of the tissue samples analyzed, respectively.

Schmitt et al. (1990) measured 13 pesticides in addition to DDT compounds in fish tissues collected at eight locations in the Columbia River Basin, but none of these stations was located in the lower river below Bonneville Dam. The pesticides in fish collected from the two stations nearest the study area in 1984 [Willamette River - Oregon City (RM 26) and the Columbia River - Cascade Locks (RM 149)] included dieldrin, *cis*- and *trans*-chlordane, *cis*- and *trans*-nonachlor, oxy-chlordane, toxaphene, *alpha*-BHC, HCB, and dacthal (Schmitt et al. 1990). These pesticides were most commonly detected in the largescale sucker collected near Cascade Locks, OR. The pesticide concentrations reported by Schmitt et al. (1990) are comparable to those reported for the reconnaissance survey although the detection limits achieved in the National Contaminant Biomonitoring Program were somewhat higher than those of the reconnaissance survey. The additional pesticide compounds detected by the U.S. EPA (1991a) for the lower Columbia River were *alpha*-BHC, *cis*- and *trans*-chlordane, *cis*- and *trans*-nonachlor, dieldrin, and mirex (see Table 4-11). All of these pesticides were detected in the whole body carp tissue collected near Portland. In general, the EPA results were comparable to those of the reconnaissance survey although the detection limits achieved in the National Bioaccumulation Study were lower than those achieved in the reconnaissance survey, especially for the pesticides methoxychlor and mirex.

Many of the pesticides detected in the lower Columbia River (e.g., DDT, heptachlor, aldrin, dieldrin, mirex, and endrin) are no longer used (or use is severely limited) in the United States and must therefore represent continued cycling within the aquatic environment and terrestrial runoff from historical applications. Sources of pesticides detected in biota include chemicals that were or are used in agriculture, forestry, and household applications for the control of pests.

PCBs. Crayfish, carp, largescale sucker, peamouth, and white sturgeon were analyzed for eight PCBs. Three compound mixtures were detected in tissue samples (Aroclor 1242, Aroclor 1254, Aroclor 1260). Patterns of tissue contamination for PCBs differed among the five species collected in this study. PCBs were not detected in crayfish at any of the stations sampled in the lower Columbia River. Peamouth was the only species with detected levels of Aroclor 1242; Aroclor 1260 was also present in this species. The PCBs Aroclor 1254 and 1260 were both detected in carp and largescale sucker, although fish at each location had measurable tissue concentrations of one of these PCBs. The only PCB detected in white sturgeon filets was Aroclor 1254.

PCBs were widely distributed in fish tissue from samples collected throughout the lower Columbia River, with levels being detected in fish collected at station D40 below Bonneville Dam downriver to station D3 near Astoria (Figure 4-35). This is in contrast to the relatively infrequent detection of PCBs in the sediments sampled for the reconnaissance survey (see Section 3.6.2).

Schmitt et al. (1990) measured three PCB compound mixtures (Aroclor 1248, 1254, and 1260) in fish tissues collected at eight locations in the Columbia River Basin, but none of these stations was located in the lower river below Bonneville Dam. The PCBs detected in fish collected from the two stations nearest the study area in 1984 [Willamette River - Oregon City (RM 26) and the Columbia River - Cascade Locks (RM 149)] included Aroclor 1254 and 1260, but Aroclor 1248 was not detected (Schmitt et al. 1990). Aroclor 1254 was detected most frequently and at higher concentrations than Aroclor 1260 with the highest concentration (approximately 500 μg/kg wet weight) reported for northern squawfish tissue collected near Cascade Locks, OR (Schmitt et al. 1990). These data are comparable to the concentrations reported for fish tissues sampled in the reconnaissance survey (see Table 4-6). The U.S. EPA National Bioaccumulation Study (1991g) reported total PCB and additional biphenyl compound concentrations for fish tissues sampled in the lower Columbia River (see Table 4-11). The highest total PCB concentration was reported for the whole-body analysis of carp collected near Portland (2,043 μg/kg). Additional biphenyl compounds detected included mono-, tri-, penta-, hexa-, hepta-, and octa-chlorobiphenyls, at concentrations ranging from less than 1 to 830 μg/kg wet weight.

Aroclor 1254 was detected in only white sturgeon, largescale sucker, and carp. The geometric mean concentration of Aroclor 1254 in these fish was 36.8, 106.1, and 68.8 μg/kg, respectively. These values are approximately two to six times lower than the geometric mean concentration of Aroclor 1254 (210 μg/kg) reported by the National Contaminant Biomonitoring Program for fish collected during in 1984 (Schmitt et al. 1990). The geometric mean concentration in all fish tissues sampled in the reconnaissance survey was also lower than the 1984 geometric mean concentration reported for the National Contaminant Biomonitoring Program (see Table 4-10). The maximum Aroclor 1254 concentration reported by the National Contaminant Biomonitoring Program was 4,000 μg/kg. This concentration is eight times higher than the maximum concentration of 500 μg/kg measured in fish tissue in the lower Columbia River.

TISSUE–PCBs, DIOXINS, AND FURANS

Fish Species:
C = Carp
Cy = Crayfish
P = Peamouth
ST = Sturgeon
Su = Largescale sucker

	Astoria, OR	Astoria, OR		Deep River	Marsh Island	Deep River Mouth	Grays Bay	Woody Island Channel	Clifton Channel	Elochoman Slough	Wallace Island	Wallace Slough	Coal Creek Slough	Longview, WA	Rainier, OR	Goble, OR	Carrolls Channel	Port of Kalama, WA	Kalama, WA	Burke Slough	Martin Bluff, WA	St. Helens, OR	Bachelor Point, WA	Sauvie Island	Willamette River Mouth		N. Portland Harbor	Government Island	Camas Slough	Reed Island		Multnomah Falls, OR	Beacon Rock
CHEMICAL CLASS	RM 15	RM 15.5	RM 18.5	RM 20	RM 20	RM 21	RM 22.5	RM 27	RM 38	RM 40	RM 49	RM 49.5	RM 57	RM 63	RM 67	RM 71	RM 71.1	RM 75	RM 75	RM 79.5	RM 80	RM 85.5	RM 92.5	RM 98	RM 101	RM 103	RM 107.5	RM 115	RM 118.5	RM 125.5	RM 127	RM 136	RM 141.5
	ST	D3	ST	ST	D8	ST	D6	ST	D10	D12	ST	D15	D16	D19	ST	D21	D20	D22	ST	D23	ST	D24	D26	D28	D29	ST	D31	ST	D35	D38	ST	ST	D40
PCBs, DIOXINS, AND FURANS																																	
PCBs																																	
Species Analyzed	ST	P	ST	ST	Cy Su	ST	Cy Su	ST	Cy Su P	Cy Su P	ST	Cy Su P	Cy Su P	Cy Su P	ST	P	Cy Su	Cy Su	ST	C Cy Su P	ST	Cy C Su P	Cy C Su	Cy C Su P	Cy C Su P	ST	Cy C Su	ST	Cy C Su	Cy C Su	ST	ST	Cy C Su
Aroclor 1242		●																						●									
Aroclor 1254					●		●		●	●		●	●	●			●	●	●	●	●	●	●	●	●		●		●	●			
Aroclor 1260		●							●	●		●	●	●		●				●		●	●										●
DIOXINS AND FURANS																																	
Species Analyzed			ST		Cy Su		Cy Su	ST	Cy Su P		ST	Cy Su P		Cy Su P	ST	P	Cy Su		ST	Cy Su P		Cy C Su P		Cy C Su P				ST	Cy C Su	Cy C Su	ST		Cy C Su
2,3,7,8-TCDD					●		●		●			●		●		●	●		●	●		●		●					●	●		●	●
1,2,3,7,8-PeCDD					●		●		●			●		●		●	●			●		●		●					●	●			●
1,2,3,4,7,8-HxCDD					●		●		●			●		●		●	●			●		●		●					●	●			●
1,2,3,6,7,8-HxCDD					●		●		●			●		●		●	●			●		●		●					●	●			●
1,2,3,7,8,9-HxCDD					●		●		●			●		●		●	●			●		●		●					●	●			●
1,2,3,4,6,7,8-HpCDD					●		●	●	●			●		●		●	●			●		●		●				●	●	●			●
OCDD					●		●	●	●		●	●		●	●	●	●		●	●		●		●				●	●	●	●		●
2,3,7,8-TCDF			●		●		●	●	●		●	●		●	●	●	●		●	●		●		●				●	●	●	●		●
1,2,3,7,8-PeCDF					●		●		●			●		●		●	●		●	●		●		●					●	●			●
2,3,4,7,8-PeCDF					●		●		●			●		●		●	●		●	●		●		●					●	●			●
1,2,3,4,7,8-HxCDF					●		●		●			●		●		●						●		●					●	●			●
1,2,3,6,7,8-HxCDF					●		●		●			●		●		●						●		●					●	●			●
2,3,4,6,7,8-HxCDF					●		●		●			●		●		●	●			●		●		●					●	●			●
1,2,3,7,8,9-HxCDF					●		●		●			●		●			●			●		●		●					●	●			●
1,2,3,4,6,7,8-HpCDF					●		●		●			●		●		●	●			●		●		●					●	●			●
1,2,3,4,7,8,9-HpCDF					●		●		●			●		●		●	●			●		●		●					●	●			●
OCDF									●			●		●		●	●			●		●		●					●	●			●

Figure 4-35 Polychlorinated biphenyl compounds (PCBs) and dioxin and furan compounds detected in fish and crayfish samples collected for the lower Columbia River Reconnaissance Survey.

Shaded areas indicate stations that were not sampled for dioxins or furans.

Aroclor 1260 was detected in carp, peamouth, and only one tissue sample of largescale sucker. The geometric mean concentration of Aroclor 1260 in carp and peamouth was 41.5, and 162.7 μg/kg, respectively. The geometric mean concentration for peamouth is approximately four times lower than the geometric mean for this PCB reported by the National Contaminant Biomonitoring Program (150 μg/kg). However, the geometric mean for carp collected from the lower Columbia River exceeds the corresponding value reported by National Contaminant Biomonitoring Program for fish collected in 1984. The maximum value of Aroclor 1260 reported by the National Contaminant Biomonitoring Program was 2,300 μg/kg. This concentration is over four times higher than the maximum value of 520 μg/kg measured in the lower Columbia River. However, the geometric mean concentration of Aroclor 1260 for all fish tissues sampled in the reconnaissance survey is lower than the 1984 geometric mean concentration reported for the National Contaminant Biomonitoring Program (see Table 4-10).

PCBs were used in many locations and processes in the past and hence have been found historically in almost all urban, and many industrial, discharges. PCBs have been used as insulators and lubricants in transformers, capacitors, and other electrical equipment. Although the manufacture and importation of PCBs has been prohibited in the United States, transformers manufactured or imported prior to the ban are still in use and continue to be a potential source of these compounds. PCBs are also slowly degraded in the environment and are known to bioaccumulate. Therefore, it is likely that PCBs are present in depositional areas near many urban areas, near former PCB production facilities, and near areas where power transformers have been in use since before PCB use was controlled.

Dioxins and Furans. Chloro-dibenzo dioxins and furans refer to two structurally similar groups of compounds consisting of approximately, 75 and 135 different compounds, respectively. Only a small subset of these compounds have sufficient toxicity and potential for bioaccumulation to be of interest when examining accumulation in aquatic biota. These "biologically active" compounds consist of the 2,3,7,8- substituted tetra-, penta-, hexa-, hepta-, and octa-chlorodibenzo dioxins and furan congeners. Tissue samples of crayfish and five fish species were analyzed for the seventeen dioxin and furan congeners that comprise this group of compounds.

Dioxin and furans were widely distributed throughout the lower Columbia River, with levels being detected in fish collected at station D40 below Bonneville Dam downriver to station D3 near Astoria (Figure 4-35). This was consistent with the frequency of detection of dioxins and furans in sediments collected for the reconnaissance survey (see Section 3.6.2). Peamouth had the highest tissue concentrations of dioxins and furans with a median toxicity equivalent concentration (TEC) of 7.93 pg/g. Median TECs for other species were 4.87, 3.02, 2.63, and 1.38 pg/g for carp, white sturgeon, largescale sucker, and crayfish, respectively. The differences between species could be accounted for by species differences in the percentages of body lipids. When TECs were normalized for lipid content there were no significant differences between species. This result indicates that highest doses of dioxins and furans to either wildlife or humans will result from the consumption of lipid-rich species.

In general, the dioxin and furan concentrations reported for the reconnaissance survey are comparable to the results of fish tissue analyses conducted on samples collected from the lower Columbia River as part of the National Bioaccumulation Study (see Table 4-12). The maximum concentration of 2,3,7,8-TCDD measured in sturgeon filets analyzed for the reconnaissance survey (1.66 pg/g wet weight) was only slightly higher than the maximum concentration reported for the National Bioaccumulation Study for whole-body analysis of sturgeon (1.06 pg/g wet weight). The maximum concentration of 2,3,7,8-TCDD in whole-body analyses of fish tissue was also similar; 4.41 pg/g wet weight in peamouth collected in the reconnaissance survey and 5.23 pg/g wet weight in sucker collected in the National Bioaccumulation Study. The maximum concentration of 2,3,7,8-TCDD in sturgeon filets analyzed in the reconnaissance survey was also similar to the whole-body sturgeon concentrations reported for the National Bioaccumulation Study (17.75 to 22.15 pg/g wet weight). The maximum concentration of 2,3,7,8-TCDF in whole-body analyses of fish tissue was also similar; 58.8 pg/g wet weight in peamouth collected in the reconnaissance survey and 28.34 pg/g wet weight in sucker collected in the National Bioaccumulation Study.

The tissue concentration of 2,3,7,8-TCDD, the most toxic congener of this group of chemicals, can be compared to the median concentration measured in U.S EPA's National Bioaccumulation Study (NBS), which measured tissue concentrations at 388 sites nationwide (U.S. EPA 1991a). The median fish tissue concentration of TCDD in the U.S. EPA study was 1.38 pg/g. This value is identical to the median value measured for crayfish in the lower Columbia River. However, median concentrations measured for peamouth, carp, white sturgeon, and largescale sucker all exceeded this value by factors ranging from approximately two to six. It should be noted that this comparison may be somewhat misleading in that the U.S. EPA median value was calculated using data from many species of fish, with whole bodies being analyzed for bottom-feeding species and filets being analyzed for game species. The median concentra-

TABLE 4-12. DIOXIN AND FURAN CONCENTRATIONS IN FISH FROM THE LOWER COLUMBIA RIVER COLLECTED FOR THE NATIONAL BIOACCUMULATION STUDY

(all concentrations in pg/g wet weight)
(Page 1 of 2)

Sample Location	Woody Island	Woody Island	Wauna	Wauna	Longview	Longview	Longview	Kalama
Species	Sturgeon	Sturgeon	Squawfish	Sucker	Squawfish	Squawfish	Sucker	Sturgeon
Sample Type	Whole Body	Lab. Dup.	Filet	Whole Body	Filet	Lab. Dup.	Whole Body	Whole Body
2,3,7,8-TCDD	ND	0.88	1.73	2.78	1.48	1.75	5.23	1.06
1,2,3,7,8-PeCDD	ND	ND	0.78	ND	0.49	ND	0.68	ND
1,2,3,4,7,8-HxCDD	ND	ND	ND	ND	ND	ND	ND	ND
1,2,3,6,7,8-HxCDD	ND	ND	0.77	0.66	0.56	ND	ND	ND
1,2,3,7,8,9-HxCDD	ND	ND	ND	ND	ND	ND	ND	ND
1,2,3,4,6,7,8-HpCDD	0.72	0.84	2	ND	1.16	ND	2.2	ND
2,3,7,8-TCDF	22.05	20.94	21.63	16.39	20.12	20.73	28.34	17.75
1,2,3,7,8-PeCDF	ND	0.52	0.29	ND	0.21	ND	0.3	ND
2,3,4,7,8-PeCDF	ND	ND	0.36	ND	ND	0.26	0.67	ND
1,2,3,4,7,8-HxCDF	ND	ND	ND	0.6	ND	ND	ND	ND
1,2,3,6,7,8-HxCDF	ND	NDN	ND	ND	ND	ND	ND	ND
1,2,3,7,8,9-HxCDF	ND	ND	ND	ND	ND	ND	ND	ND
2,3,4,6,7,8-HxCDF	ND	ND	ND	ND	ND	ND	ND	ND
1,2,3,4,6,7,8-HpCDF	ND	ND	ND	0.28	ND	ND	ND	ND
1,2,3,4,7,8,9-HpCDF	ND	ND	ND	ND	ND	ND	ND	ND
Percent Lipids	2.9	2.6	2.9	7	3	3	11.4	3.2

TABLE 4-12. DIOXIN AND FURAN CONCENTRATIONS IN FISH FROM THE LOWER COLUMBIA RIVER COLLECTED FOR THE NATIONAL BIOACCUMULATION STUDY
(all concentrations in pg/g wet weight)
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Site	Deer Island	St. Helens	St. Helens	St. Helens	Portland	Camas	Camas
Species	Sturgeon	Squawfish	Sucker	Sucker	Carp	Squawfish	Sucker
Sample Type	Whole Body	Filet	Whole Body	Lab. Dup.	Whole Body	Filet	Whole Body
2,3,7,8-TCDD	ND	1.28	2.57	2.01	2.86	1.14	2.28
1,2,3,7,8-PeCDD	ND	0.95	0.68	0.55	3.33	ND	0.32
1,2,3,4,7,8-HxCDD	ND	ND	ND	ND	ND	ND	ND
1,2,3,6,7,8-HxCDD	ND	0.8	0.9	0.77	8.68	0.2	0.45
1,2,3,7,8,9-HxCDD	ND	ND	0.18	0.19	1.09	ND	ND
1,2,3,4,6,7,8-HpCDD	0.62	0.9	5.86	4.66	13.27	ND	1.65
2,3,7,8-TCDF	22.15	9.03	11.38	10.27	4.1	11.95	15.95
1,2,3,7,8-PeCDF	ND	0.51	0.28	ND	0.57	ND	ND
2,3,4,7,8-PeCDF	ND	0.59	0.44	0.43	2.19	0.21	0.25
1,2,3,4,7,8-HxCDF	ND	ND	ND	ND	2.88	ND	ND
1,2,3,6,7,8-HxCDF	ND	ND	ND	ND	0.91	ND	ND
1,2,3,7,8,9-HxCDF	ND	ND	ND	ND	ND	ND	ND
2,3,4,6,7,8-HxCDF	ND	ND	ND	ND	1.85	ND	ND
1,2,3,4,6,7,8-HpCDF	ND	ND	0.76	0.65	2.88	ND	0.24
1,2,3,4,7,8,9-HpCDF	ND	ND	ND	ND	ND	ND	ND
Percent Lipids	4	2	9.6	NA	4.3	1.3	9.2

Source: U.S. EPA (1991g).

ND = Not detected. No detection limit given.

tions of all fish tissues sampled in the reconnaissance survey are compared to the median concentrations reported for the National Bioaccumulation Study (see Table 4-10). In general, the median concentrations based on the reconnaissance survey data are generally lower, with the exception of the reconnaissance survey median concentration of 2,3,7,8-TCDF which was approximately 2 times higher than the median reported for the National Bioaccumulation Study (see Table 4-10).

In addition to 2,3,7,8-TCDD, the six other dioxin congeners and the ten furan congeners were also detected in species collected within the lower Columbia River. The frequency with which these congeners were detected in tissue varied. The only congener that was detected in all samples was 2,3,7,8-TCDF. OCDD was detected in all but one of the samples (98 percent), while the other congeners were typically detected in at least 50 percent of the samples, with the exception of 1,2,3,7,8,9-HxCDF and 1,2,3,4,7,8,9-HpCDF, which were detected in 34 and 41 percent of the samples, respectively (Table 4-6). It is instructive to note that the three most abundant congeners detected in tissue samples are the principal congeners discharged in effluent from bleached kraft pulp and paper mills (Amendola et al. 1989; Clement et al. 1989; Environmental Canada 1990).

Entry of polychlorinated dibenzodioxins and dibenzofurans (PCDDs and PCDFs) into the environment has been associated with chlorophenol production, wood-treating facilities, aerial application of phenoxy herbicides (2,4-D and 2,4,5-T) (i.e., the contaminant of concern in agent orange), effluent discharge from chlorine-bleach kraft pulp mills and chlorinated municipal sewage treatment plants, and from combustion processes including fires (Czuczwa and Hites 1984). Currently, only the five bleach kraft pulp and paper mills that discharge directly to the lower Columbia River (including the city of St. Helens that receives and treats treated pulp mill wastewater) and the wastewater treatment plant serving the city of Portland are required to monitor and report the effluent concentrations of dioxins and furans in their effluent (Tetra Tech 1991c).

U.S. EPA (1991c,d) identified chlorine bleaching pulp mills as a major source of 2,3,7,8-TCDD to the Columbia River Basin. Other potential source categories include wood-treating facilities, major municipal treatment plants, agricultural areas, industrial sites, urban areas, and release from bottom sediments. Eleven chlorine-bleaching pulp mills currently discharge to the Columbia River system. These mills are located in Canada (1), Idaho (1), Washington (4), and Oregon (3). Five major pulp and paper facilities discharge chlorine-bleach process effluent directly to the lower Columbia River below Bonneville Dam between RM 42 and RM 120 (Tetra Tech 1992c). Examination of tissue concentrations of dioxins and furans for biota collected downstream of these sources gives no clear indication that tissue concentrations are substantially elevated above those measured at other sites in the river. For example, tissue TEC concentrations of dioxins and furans in carp, crayfish, and largescale sucker collected at the two sites immediately below Bonneville Dam (stations D38^{E} and D40), which are upstream of any known source of dioxins in the lower Columbia River, are similar in magnitude to those measured at downstream stations.

4.6.2.2 Significance and Recommendations. A detailed assessment of potential impacts of crayfish and fish tissue contaminant levels on wildlife that rely directly, or indirectly, on these organisms is hampered by the lack of information on dietary contaminant levels that may pose a threat to wildlife populations. However, despite the lack of specific criteria on dietary contaminant levels on which to base assessments of impacts for most chemicals, potential impacts to wildlife can be assessed in a qualitative manner by an examination of the concentrations, relative frequency of detection, and spatial distribution of contaminants measured in fish tissue.

Adverse impacts to wildlife resulting from biomagnification of organochlorine pesticides and PCBs have been well documented. Within the lower Columbia River estuary, high levels of PCBs and DDE measured in breeding bald eagles have been suggested as one cause of the decline in breeding success and productivity of this species in the estuary (McGarigal et al. 1991). Fish-eating mammals may also be adversely affected by pesticide and PCB concentrations in prey species. Henney et al. (1981) have suggested that population declines of mink and river otters along the lower Columbia River could be due, in part, to PCB contamination resulting from consumption of contaminated fish prey.

Within the lower Columbia River, several organochlorine pesticides were detected at least once in crayfish and fish tissue (DDT, DDE, DDD, aldrin, dieldrin, mirex, dacthal, endosulfan, endrin, methoxychlor, and lindane). DDT derivatives, in particular, are pervasive throughout the lower Columbia River with concentrations of DDD, DDE, or DDT being detected in 72 out of the 73 tissue samples analyzed. The highest concentrations were measured for DDE, with concentrations of up to 480 μg/kg being measured in peamouth tissue. Other organochlorine pesticides were detected less frequently. Pesticides detected at five or more sites included aldrin, dieldrin, endosulfan I, methoxychlor, and beta-BHC. These pesticides also appear to be widespread within the lower Columbia River as they were detected in fish and crayfish collected from stations below Bonneville Dam (RM 141) to Astoria, OR (RM 15).

The state of New York is currently using fish flesh criteria, originally proposed by Newell et al. (1987), as unofficial guidelines for the protection of piscivorous wildlife. Levels have been proposed for seven of the organochlorine pesticides detected in fish tissue in the lower Columbia River (Table 4-13). Of these, seven pesticides (aldrin, dieldrin, mirex, heptachlor, DDT, DDE, and DDD), DDE was the only compound detected at levels exceeding New York State's (NYS) proposed guidelines for protection of piscivorous wildlife (see Table 4-13). DDE concentrations at or exceeding the NYS guidelines (200 μg/kg) were detected in peamouth collected at three sites in the lower Columbia River: near Astoria, OR [station D3 (RM 15)], St. Helens, OR, [station D24 (RM 85.5)], and Burke Slough [station D23 (RM 79.5)].

PCBs were detected in fish collected throughout the lower Columbia River. Although information is limited, it appears that measured concentrations may be high enough to adversely affect piscivorous wildlife. New York State's proposed guideline for PCB is 110 μg/kg for the protection of piscivorous wildlife. Eighty percent of peamouth, 67 percent of carp, and 61 percent of largescale sucker from the lower Columbia had tissue PCB concentrations that exceed NYS proposed guidelines (see Table 4-13). The maximum tissue concentration of PCB (520 μg/kg) was measured in peamouth collected near St..Helens, OR. This concentration approaches the dietary concentration of 640 μg/kg reported by Henny et al. (1981) to cause total reproductive failure in mink.

In addition to organochlorine pesticides and PCBs, concerns have been expressed about the potential impacts of dioxins on wildlife in the vicinity of the lower Columbia River. A preliminary study by the U.S. Fish and Wildlife Service found dioxin in eggs of bald eagles, gulls, terns, and cormorants nesting along the river (U.S. Fish and Wildlife Service 1991, unpublished data). The state of New York has proposed a fish flesh guideline concentration of 3 pg/g for dioxin as protective of piscivorous wildlife. Peamouth collected from three sites along a 22.5-mile stretch of the lower Columbia River had tissue concentrations exceeding 3 pg/g (see Table 4-12). These collection sites were located near St. Helens, OR, [station D24 (RM 85.5)], downstream of Longview, WA [station D19 (RM 63)], and in Burke Slough [station D23 (RM 79.5)].

TABLE 4-13. COMPARISON OF LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY TISSUE DATA WITH PROPOSED NEW YORK STATE PISCIVOROUS FISH CRITERIA
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Chemical	New York State Proposed Non-Carcinogenic Fish Flesh Criteria[a]	Species	Median Concentration[b]	Number of Samples With Exceedances	Stations with Exceedances
4,4'-DDT	200 µg/kg	Carp	3.5 µg/kg	0	
		Crayfish	1.5 µg/kg	0	
		Peamouth	12.5 µg/kg	0	
		Sturgeon	2.3 µg/kg	0	
		Largescale sucker	5.15 µg/kg	0	
4,4'-DDE	200 µg/kg	Carp	22 µg/kg	0	
		Crayfish	7.5 µg/kg	0	
		Peamouth	**111 µg/kg**	**3**	**D3, D23, D24**
		Sturgeon	10.45 µg/kg	0	
		Largescale sucker	25.50 µg/kg	0	
4,4'-DDD	200 µg/kg	Carp	4.65 µg/kg	0	
		Crayfish	1.5 µg/kg	0	
		Peamouth	15 µg/kg	0	
		Sturgeon	1.5 µg/kg	0	
		Largescale sucker	17 µg/kg	0	
Aldrin	120 µg/kg	Carp	ND[c] (1.5 µg/kg)	0	
		Crayfish	ND (1.5 µg/kg)	0	
		Peamouth	ND (12.5 µg/kg)	0	
		Sturgeon	ND (1.5 µg/kg)	0	
		Largescale sucker	ND (1.5 µg/kg)	0	
Dieldrin	120 µg/kg	Carp	ND (1.5 µg/kg)	0	
		Crayfish	ND (1.5 µg/kg)	0	
		Peamouth	ND (12.5 µg/kg)	0	
		Sturgeon	ND (1.5 µg/kg)	0	
		Larrgescale sucker	ND (1.5 µg/kg)	0	
Endrin	25 µg/kg	Carp	ND (1.5 µg/kg)	0	
		Crayfish	ND (1.5 µg/kg)	0	
		Peamouth	ND (12.5 µg/kg)	0	
		Sturgeon	ND (1.5 µg/kg)	0	
		Largescale sucker	ND (1.5 µg/kg)	0	
Heptaclor	200 µg/kg	Carp	ND (1.5 µg/kg)	0	
		Crayfish	ND (1.5 µg/kg)	0	
		Peamouth	ND (12.5 µg/kg)	0	
		Sturgeon	ND (1.5 µg/kg)	0	
		Largescale sucker	ND (1.5 µg/kg)	0	
Hexachlorocyclohexane (BHC)[d]	100 µg/kg	Carp	ND (1.5 µg/kg)	0	
		Crayfish	ND (1.5 µg/kg)	0	
		Peamouth	ND (16.25 µg/kg)	0	
		Sturgeon	ND (1.5 µg/kg)	0	
		Largescale sucker	ND (1.5 µg/kg)	0	
Mirex	300 µg/kg	Carp	ND (1.5 µg/kg)	0	
		Crayfish	ND (1.5 µg/kg)	0	
		Peamouth	ND (12.5 µg/kg)	0	
		Sturgeon	ND (1.5 µg/kg)	0	
		Largescale sucker	ND (1.5 µg/kg)	0	

TABLE 4-13. COMPARISON OF LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY TISSUE DATA WITH PROPOSED NEW YORK STATE PISCIVOROUS FISH CRITERIA

(Page 2 of 2)

Chemical	New York State Proposed Non-Carcinogenic Fish Flesh Criteria[a]	Species	Median Concentration[b]	Number of Samples With Exceedances	Stations with Exceedances
PCBs[e]	110 µg/kg	Carp	135 µg/kg	5	D28, D29, D31, D38, D40
		Crayfish	ND (50 µg/kg)	0	
		Peamouth	190 µg/kg	8	D3, D12, D15 D16 D19 D21, D23, D24
		Sturgeon	50 µg/kg	2	RM 75 (2 fish)
		Largescale sucker	150 µg/kg	12	D6, D10, D12, D20, D23, D24, D26, D28, D29, D31, D38, D40
Dioxin (2,3,7,8-TCDD Toxicity Equivalency Concentration)	3 pg/g	Carp	4.88 pg/g	4	D24, D28, D35, D40
		Crayfish	1.38 pg/g	2	D19, D28
		Peamouth	7.93 pg/g	7	D10, D15, D19 D21, D23, D24 D28
		Sturgeon	3.02 pg/g	4	RM 27, RM 49, RM 75 (2 fish)
		Largescale sucker	2.63 pg/g	4	D10, D19, D28, D38
Trichlorobenzenes	1300 µg/kg	Carp	100 µg/kg	1	D29
		Crayfish	ND (100 µg/kg)	0	
		Peamouth	ND (100 µg/kg)	0	
		Sturgeon	ND (100 µg/kg)	0	
		Largescale sucker	ND (100 µg/kg)	0	

[a] Newell et al. (1987).

[b] In cases where data were reported as nondetected, one half the detection limit was used to calculate the median concentration.

[c] Median concentration is less than the detection limit (ND).

[d] Data presented is for β-BHC.

[e] Median concentrations of PCBs were calculated by summing the concentrations of Aroclor 1254 and 1260, if either of these chemicals were reported as nondetected, one half the detection limit was used to calculate median concentration.

It should also be noted that the Columbia River has recently been identified as water quality limited due to the prediction that water column dioxin (2,3,7,8-TCDD) concentrations exceed the water column criteria for the consumption of contaminated fish and water (0.013 pg/L), and the finding that Columbia River fish tissue levels of 2,3,7,8-TCDD exceeded the human cancer risk factor of an increase of one additional cancer for a population of 1 million people for consumption of Columbia River fish (U.S. EPA 1991c,d). This prediction was based on modeling inputs of 2,3,7,8-TCDD to the Columbia River from chlorine-bleached pulp and paper mill effluents to the mainstem of the river and on analysis of the dioxin levels in fish tissue samples collected from the river (U.S. EPA 1991c,d). The U.S. EPA has developed a total maximum daily load (TMDL) that will regulate the discharge of dioxin from U.S. pulp and paper mills in the Columbia River basin to reduce the level of 2,3,7,8-TCDD below the water quality standard (U.S. EPA 1991c,d). Further investigations are being conducted by U.S. EPA Region X and the states of Oregon and Washington to provide additional information for the refinement of the TMDL and to monitor the effect of the regulatory actions that have been implemented.

The importance of historical discharges from both point and nonpoint sources is evident for fish tissue organic data. Many of the pesticides and PCBs detected have been banned or their use has been restricted, yet they have persisted and are still detectable in fish tissues of the lower Columbia River. Furthermore, the tissue concentrations of these pesticides and PCBs exceed or approach the NYS guidelines for the protection of piscivorous wildlife.

Relevant questions for further research include the following:

- What are the major sources (point and nonpoint sources) of organic compounds to the river?
- What are the effects of these organic compounds on the biota?
- Are the forms of the organic compounds in the water column available to the biota?
- Are the organic compounds detected in fish tissues in this survey the result of bioaccumulation or bioconcentration?

- Are some organic compounds and their various forms more available than others?

- Which is the most important pathway (water column or sediments) for organic contaminant exposure and accumulation?

- What is the biological turnover time of these organic compounds in fish tissue?

- How and in what forms are organic compounds transported through the river system?

- What is the fate of the organic compounds delivered to the river?

- How and in what forms are organic compounds accumulated and metabolized by the biota?

- What physical and biological factors control the variation in measured tissue concentrations of organic compounds?

- What are the forms and concentrations of organic compounds in sediments and prey items and how does this relate to the organic compound concentrations measured in fish and crayfish tissues?

- What are the species consumed, the rate of consumption, and the tissues consumed by wildlife and humans?

- What is the risk of human health impairment associated with the consumption of various quantities of the species sampled based on the reconnaissance survey fish tissue data?

- How are the organic compounds partitioned in the various tissues (i.e., skin, muscle, organs, bone) and how might this affect the evaluation of the effects of tissue contaminant levels on piscivorous wildlife and humans?

Answers to these questions are essential for identifying (1) the most important sources of specific organic compounds, and (2) the acceptable limits of the input of these contaminants into the lower Columbia River system. An integrated monitoring program of organic contaminants in the lower Columbia River, and the various point and nonpoint sources, should be performed on a seasonal basis to improve the understanding of the sources, forms, and fate of organic contaminants in the lower Columbia River. An assessment of organic compounds in various fish species and tissues in the lower river, the role of various environmental factors that control the toxic effects of these chemicals, and the degree of accumulation would also aid in further assessing the relative effects of these organic compounds on the biota of the river and the effect of the consumption of these species on wildlife and humans.

4.6.3 Identification of Potential Areas of Concern

At present it is difficult to identify areas of concern within the lower Columbia River using tissue contaminant concentrations as a basis for selection of impaired sites. This difficulty arises because there are no established tissue criteria for the protection of wildlife, or a consensus regarding concentrations in tissue that pose a concern to human health. In addition, with the exception of crayfish, all of the species are mobile; therefore, measured tissue concentrations may not necessarily reflect the location where they were captured. Despite the above caveats, it is possible to identify eight collection locations as being of potential concern due either to the presence of elevated concentrations of particular chemicals, and/or the detection of large numbers of contaminants of concern in tissue samples. These sites are identified below:

- **Station D38^E located at RM 125 near Reed Island:** Tissue concentrations of barium, cadmium, lead, nickel, silver, zinc, endrin, and beta-BHC were among the five highest measured in the lower Columbia River. This site is of special interest because there are no identified sources of these contaminants upstream within the study area (although potential sources do exist above Bonneville Dam) and this site has been used as a reference area in previous studies (Tetra Tech 1992a).

- **Station D31 located at RM 107.5 in North Portland Harbor near Hayden Island:** Tissue concentrations of barium, copper, zinc, DDE, DDD, isophorone, and Aroclor 1254 were among the five highest measured in the lower Columbia River.

- **Station D29 located near the mouth of the Willamette River at RM 101:** Tissue concentrations of DDD, aldrin, endrin and beta-BHC were among the five highest measured in the lower Columbia River. This site was also unique in that it was the only location where 12 semivolatile compounds were detected in fish tissue. Tissue concentrations of one compound, 1,2,4-trichlorobenzene, were over an order of magnitude higher than the maximum concentration measured in U.S. EPA's National Bioaccumulation Study.

- **Station D26 located near Bachelor Point at RM 92.5:** Tissue concentrations of cadmium, copper, zinc, DDT, DDE, DDD, isophorone, and gamma-BHC were among the five highest measured in the lower Columbia River. Biota collected from this site also had detectable levels of aldrin, dieldrin, malathion, and methoxychlor.

- **Station D24 located near St. Helens, OR at RM 85.5:** Tissue concentrations of lead, nickel, DDE, methyl parathion, isophorone, methoxychlor, gamma-BHC, Aroclor 1254, Aroclor 1260, and dioxins were among the five highest measured in the lower Columbia River.

- **Station D23 located in Burke Slough at RM 79.5:** Tissue concentrations of barium, DDE, DDD, dieldrin, endosulfan I, endrin, Aroclor 1254, Aroclor 1260, and dioxins were among the five highest measured in the lower Columbia River.

- **Station D19 located downstream of Longview, WA at RM 63:** Tissue concentrations of copper, DDE, DDD, isophorone, gamma-BHC, Aroclor 1260, and dioxins were among the five highest measured in the lower Columbia River.

- **Station D15 located in Wallace Slough at RM 49.5:** Tissue concentrations of barium, cadmium, lead, nickel, silver, DDT, DDE, DDD, aldrin, methoxychlor, gamma-BHC, and Aroclor 1260 were among the five highest measured in the lower Columbia River.

4.7 SUMMARY

The fish tissue data collected for the reconnaissance survey indicate the widespread occurrence of several metals, pesticides, PCBs, and dioxin and furan compounds in fish that inhabit the lower Columbia River. The reconnaissance survey results were also generally similar to historical measurements of tissue concentrations of metals and organic compounds measured in national surveys conducted by the U.S. Fish and Wildlife Service and the U.S. Environmental Protection Agency. It is difficult to assess the potential effect of the measured tissue concentrations of metals and organic compounds due to the lack of established effects-based regulatory levels for these substances in fish tissues. The maximum levels of mercury in samples of white sturgeon and peamouth (0.35 and 0.23 mg/kg wet weight, respectively) were close to the Food and Drug Administration (FDA) action level for mercury in fish of 1 mg/kg.

Potential adverse effects to wildlife were also suggested based on comparison of the reconnaissance survey fish tissue concentrations for the pesticide DDT, polychlorinated biphenyl compounds (PCBs), and dioxins, to New York's guideline fish tissue concentrations for the protection of piscivorous wildlife. The designation of the Columbia River as water quality limited, due to an assessment by the U.S. Environmental Protection Agency (U.S. EPA 1991c,d) of the human health risk due to the levels of dioxin in water and fish tissues, also indicates concern for the human health effects of the consumption of fish from the lower Columbia River.

Although potential point sources were identified for the metals and organic compounds detected in the reconnaissance survey tissue samples, nonpoint and in-place sources of these metals are also likely sources of these constituents in the lower Columbia River. The data on the relative contribution of point, nonpoint, and in-place pollutant sources is extremely limited (Tetra Tech 1992c). Furthermore, the limited nature of a reconnaissance survey does not allow for the definitive identification of specific pollution sources.

5.0 BENTHIC COMMUNITY ASSESSMENT

5.1 INTRODUCTION

Benthic communities have been widely used in pollution impact studies and as part of long-term environmental monitoring programs in marine, estuarine, and freshwater environments. Decreases in the number of taxa, shifts in community composition, and changes in abundance have all been documented responses to physical and chemical stresses in aquatic environments. While benthic communities exhibit a high degree of natural variability, comparison with communities from reference or control areas can assist in clarifying the types of impacts a benthic community may be experiencing at a given point in time.

Historical studies evaluating benthic communities in the lower Columbia River have been conducted mostly in the estuarine portions of the river. A series of ecological investigations were sponsored by the Columbia River Estuary Data Development Program (CREDDP) in the early 1980s in the first 30 miles of the river. Studies included examination of the productivity of benthic and epibenthic organisms in response to changes in physical features (salinity, current velocity, sediment type) of the estuary, community composition of salmonid prey species, and food web structure. No other program has matched the scope of the CREDDP-sponsored investigations. Studies within the freshwater portions of the river have been very limited in scope and areal extent (see Tetra Tech 1992a for a review of these studies). Benthic community structure has been used in the lower Columbia River to evaluate local impacts from specific activities or to examine prey species for target fisheries resources. In most of these investigations in both the estuary and the river, the scope of the sampling program was not adequate to evaluate the overall water quality of the river.

The Bi-State Program directed inclusion of a benthic invertebrate sampling program in the lower Columbia River reconnaissance survey as an element of a broad-scale characterization of the water quality. The objectives of the benthic sampling program were:

- To achieve a broad-scale characterization of the benthic invertebrate communities in the lower Columbia River.
- To use the benthic invertebrate community data, along with physical, chemical, and other biological data, to establish ecological zones.
- To determine whether benthic invertebrate communities or individual taxa are useful indicators of environmental stress in specific ecological zones in the lower Columbia River.

5.2 SAMPLING LOCATIONS

A total of 54 stations in the lower Columbia River were sampled to assess benthic community structure (Figures 1-1 through 1-4). Benthic samples were collected concurrently with, and in the same location as, sediment chemistry samples (Table 3-1) to achieve two objectives. These objectives are: first, to obtain a broad-scale characterization of benthic communities in the study area, and second, to allow analysis of the relationship between benthic community structure and sediment chemistry.

5.3 SAMPLING METHODS

Benthic sampling was conducted from the R/V Brendan D II using a modified van Veen (0.06 m^2) grab sampler. Three replicate samples were collected at each station following adequate sediment penetration by the grab; the samples were screened (0.5 mm mesh size) in the field. Sampling methodologies and criteria for sample acceptance followed those outlined in the Puget Sound Protocols (Tetra Tech 1986). All organisms, sediments, and debris retained on the screen were preserved in double plastic bags with 10 percent buffered formalin in river water. All samples were shipped to the EVS Environmental Consultants benthic laboratory for benthic organism analysis.

5.4 LABORATORY METHODS

Upon arrival at the lab, all samples were inventoried and checked against chain-of-custody forms. If a sample consisted of multiple containers, all containers were located and processed as a group. Samples were held in formalin for a minimum of 24 hours after collection, to ensure adequate fixation of the organism tissues, and then rescreened. During the second screening, samples were gently rinsed with fresh water to remove the formalin from the sediments. A smaller mesh size (0.25-mm) was used during the rinsing process than was used during field screening to ensure retention of animal fragments necessary for complete identifications. To maximize washing efficiency and prevent loss of material, screens were only partially filled during the rinsing process. All material retained on the screen for each sample was transferred to a plastic jar, covered with 70 percent ethanol, and lightly agitated to ensure mixing of the alcohol with the contents. All internal and external labels were transferred to the sample jars. Of the three replicate samples collected from each site, one sample was chosen at random for taxonomic processing, and the remaining two samples were archived.

Standard techniques were used to sort organisms from the sediments (Tetra Tech 1986). Each sample was sorted in its entirety by a single person to facilitate quality assurance and quality control (QA/QC) checks. The larger (readily identifiable) organisms were removed first. Smaller organisms within the remaining sediments were sorted by placing a 5 mL fraction of the sample in a petri dish and systematically scanning the dish using a 10x power dissecting microscope. All animals and fragments were removed with forceps during the scan. Each petri dish was sorted twice to ensure compliance with quality control criteria. Organisms were sorted into major taxonomic groups (i.e., annelids, arthropods, molluscs, and miscellaneous taxa); each group was placed in a separate vial containing 70 percent ethanol.

5.4.1 Taxonomic Analyses

Taxonomic identification and enumeration did not occur until all sorted samples satisfied QA/QC program requirements (Tetra Tech 1986). All organisms were enumerated and identified to the lowest practical taxonomic level, generally genus or species. The following individuals performed the taxonomic identifications within their area of expertise: Mr. Gary Rosenthal (marine annelids); Mr. Robert Wisseman and Ms. Janey Gaventa (freshwater annelids, arthropods, and miscellaneous taxa); Mr. Jeff Cordell (marine and freshwater arthropods); Ms. Julia Schroeder (marine molluscs); and Mr. Terry Frest (freshwater molluscs). If animal fragments were present, only fragments representing the anterior portion of an organism were counted. Nematodes retained on the 0.5 mm screen were included in the abundance summaries and treated as a single taxa. Because of the small size of nematodes, a portion of the total numbers of these taxa may have passed through the screen during the sieving process. Therefore, the reported numbers of nematodes should only be considered as an estimate.

5.4.2 Quality Assurance and Quality Control

Quality assurance and quality control procedures for both sorting and identifying animals were rigorously followed as outlined in the Puget Sound Protocols (Tetra Tech 1986). Sorting efficiency and accuracy were checked by reprocessing 20 percent (by volume) of the remaining sediment residue after initial sorting was completed. Reprocessed samples were scanned with a dissecting microscope (25x power) by someone other than the original sorter. Samples passed QA/QC criteria if the number of individuals found in the sediment residue was less than 5 percent of the total number of organisms found in the original sample. If the number of organisms found was greater than 5 percent of the total number, the entire sample was resorted. If a sample required complete resorting, then all other work performed by the sorter responsible for the error was also checked.

Taxonomic verification for the marine samples was achieved by sending 5 percent of the samples to a qualified regional expert, Mr. Howard Jones of Marine Taxonomic Services, for independent identification. Taxonomic verification of selected arthropods occurring in freshwater samples was performed by Mr. Jeff Cordell. Any discrepancies in taxonomic classification were corrected before proceeding with data analysis.

5.4.3 Analysis of Benthic Community Structure

Benthic community structure was used to evaluate the health of benthic communities in the lower Columbia River. Nematodes, although considered meiofauna and not considered to be macroinvertebrates, were included in the analysis of benthic community structure because these organisms represent a potentially important food source within the sediments for deposit-feeding organisms. Differences in benthic communities among stations or between stations and reference locations were identified on the basis of specific community attributes (i.e., species abundance, major taxa abundance, species richness) or habitat characteristics (e.g., sediment grain size, salinity).

Consecutive steps were taken to explore patterns in benthic community structure in the lower Columbia River. First, ecological indices (i.e., richness and abundance) were calculated for each sample to reduce the complex biological data to simple numerical descriptors. Second, differences in ecological indices between stations that had been grouped by habitat type (e.g., similar salinity and sediment grain size) were examined using analysis of variance (ANOVA) techniques. Classification analyses were performed to identify stations with similar species compositions. Correlations and regressions were then calculated to examine relationships among ecological, chemical, and physical variables. Finally, reference stations within the lower Columbia River were identified, and differences in benthic community attributes between stations and reference locations were examined to identify potential areas of concern.

5.4.3.1 Descriptive Statistics and Biological Indices. Statistical and graphical analyses were performed using the computer programs SYSTAT (Wilkinson 1989) and CLUSTER (Nemec 1988). Replicate data for richness and abundance at each station were not available, thereby precluding between-station comparisons. The distribution of total number of taxa (richness) and total number of individuals (abundance) was therefore examined using frequency distributions and plots. The central value and variability associated with richness and abundance were estimated using the median and inter-quartile range (IQR; 75th percentile minus the 25th percentile value). Outliers or anomalous data are commonly identified by screening ranked data for values that exceed 1.5 times the IQR above the 75th percentile (Moore and McCabe 1989).

Stations were also grouped according to habitat characteristics (i.e., salinity and sediment grain size); basic descriptive statistics (i.e., mean, variance, standard deviation, coefficient of variation, and standard error) were calculated for richness and abundance for each group. In addition, the number of individuals in each major taxon (annelids, arthropods, molluscs, and miscellaneous taxa) were examined for each station.

5.4.3.2 Differences Among Habitats. Relationships among stations grouped according to habitat characteristics were examined using ANOVA methods. Independent *t*-tests were used because only two-sample comparisons (e.g., richness vs. salinity) were made. The independent *t*-test procedure is based upon the assumption that the data are approximately normally distributed, but does not assume that the samples have equal variances. To test the assumption of normality, the distributions of abundance and richness data were examined using normal probability plots. Using the SYSTAT PROB'Y procedure, the distributions of richness and abundance data were plotted against theoretical normal distributions (Figure 5-1). Plots resulting in an approximate straight line have a normal distribution. Some departures from normality were suggested by the plot for abundance data. The distribution of abundance data was examined further using a log transformation [i.e., log (x+1) where x equals abundance]. Log-transformed abundances were again plotted against a normal theoretical distribution (Figure 5-1). Because log transformation improved the distribution of abundance data, all statistical analyses using abundance data were conducted with log-transformed data.

A series of *t*-tests were conducted to determine whether statistically significant differences existed between stations grouped by habitat characteristics within the study area. As part of the *t*-test procedure, the probability was calculated for the paired variables to determine which station groups were significantly different from other station groups. A probability of $P \leq 0.05$ was used as the experiment-wise significance level in each of these tests. Therefore, all values less than or equal to a probability of 0.05 were considered significantly different.

5.4.3.3 Classification Analyses. Classification analyses were used to group stations with similar community composition. Classification analysis is a commonly used, multivariate statistical approach that results in a visual representation of among-station relationships. First, a classification analysis was conducted for all stations in the river. Then, because of similarities identified in the first analysis, stations were further grouped by salinity regime (i.e., estuarine, freshwater) and separate classification analyses were conducted for each group. The Bray-Curtis similarity index (Boesch 1977) was selected for development of the similarity matrix. This index has been extensively used in ecological investigations of benthic communities (Boesch 1977) and is a measure of the similarity between stations. Values of this index are largely determined by abundant taxa (i.e., numerically dominant taxa). Taxa present in low abundances (rare taxa) become relatively unimportant, and in some cases, the index may reflect abundances of only one or two numerically dominant taxa (Boesch 1977). To minimize the effect of dominant taxa, log-transformed abundance data at each station were used to calculate an index of similarity among station groups. Before the classification analyses were conducted, each data matrix was reduced by excluding taxa with fewer than five individuals in the entire data set.

5.4.3.4 Correlation and Regression Analyses. Relationships among ecological variables and habitat characteristics (salinity, sediment fines, total organic carbon) were examined using correlation and

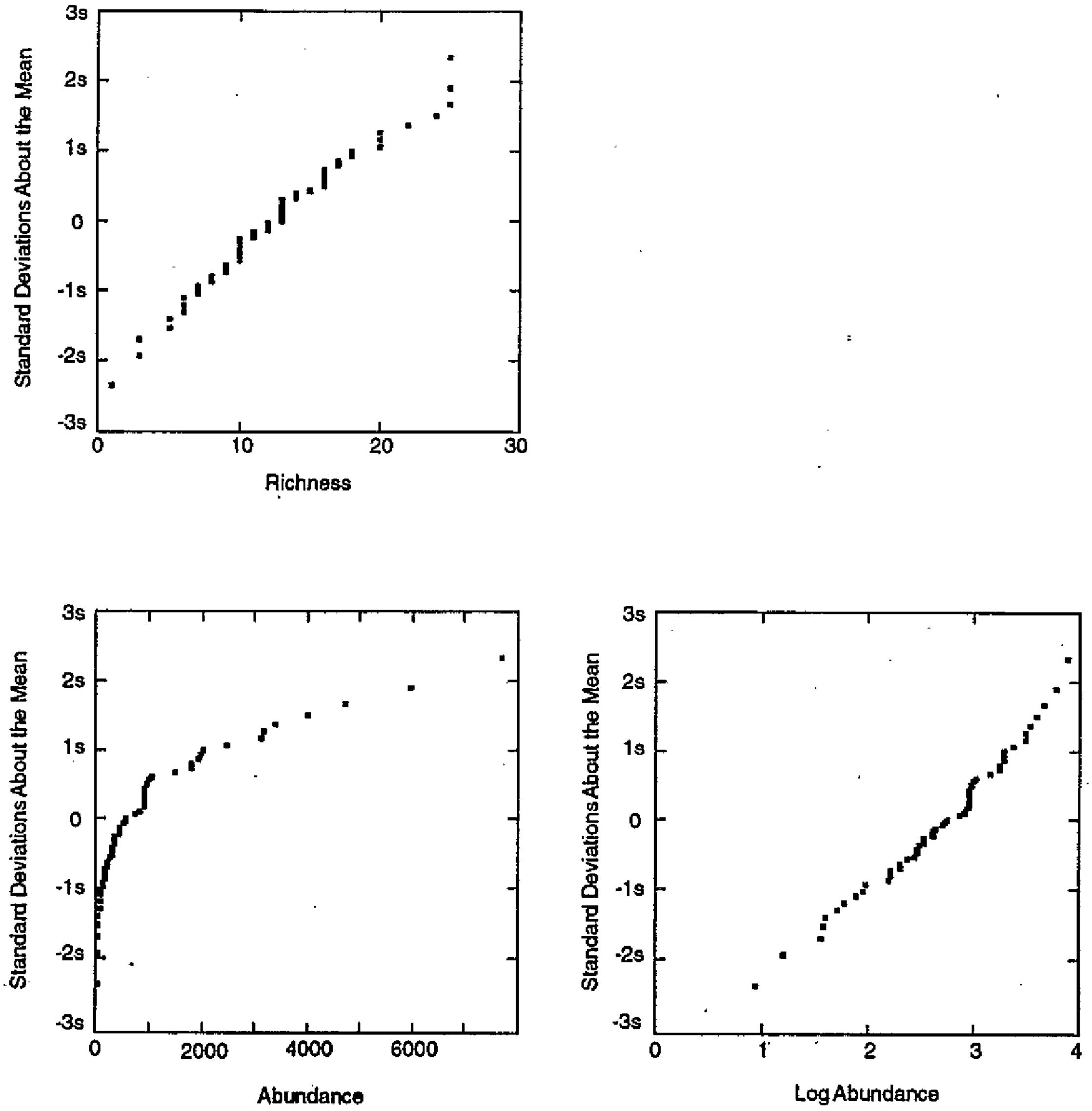


Figure 5-1. Normal and log-transformed probability plots examining the distributional attributes of richness and abundance data at 54 stations in the lower Columbia River.

regression analyses. Correlation analysis estimates the intensity or the strength of a relationship between two variables, but involves no assumption of dependency between the variables (i.e., both variables have a describable relationship, but are independent of one another). The regression analysis determines the degree to which one variable controls the value of another. A scatter plot matrix (SYSTAT SPLOM procedure) was used to illustrate the relationships among ecological variables and habitat characteristics. Only linear correlation and regression analyses were conducted; it is possible that other types of relationships may exist.

The Pearson correlation coefficient was used as a measure of the strength of the linear association among the ecological and physical or chemical variables. Bonferroni's probability (SYSTAT CORR procedure) was computed to test the significance of the correlation. Regression analyses were used to test the significance of the relationship between variables, assuming a dependent relationship.

5.4.3.5 Identification of Ecological Zones. Physical habitat characteristics and community composition were used to establish ecological zones in the lower Columbia River. Salinity, sediment grain size, and the distribution and composition of numerically dominant taxa were used to describe major zones within the river. Absolute physical boundaries of the zones were not identified because of the changeable nature of habitat characteristics.

5.4.3.6 Identification of Areas of Concern. Benthic community attributes (i.e., richness and abundance) for all stations were compared with reference values that were derived from the reconnaissance survey data. First, richness and abundance data were ranked separately and values greater than or equal to the 80th percentile value for each variable (i.e., stations with the greatest number of taxa and highest total number of organisms) were used to represent reference conditions. Sediment chemistry values at the stations identified as candidate reference sites were evaluated. Stations with elevated sediment chemical concentrations (Section 3.0) were excluded from future consideration as benthic reference sites. The median values for reference richness and abundance were calculated from the selected reference station data. Then, the richness and abundance values from all stations were divided by reference values to evaluate relative differences in benthic community structure at each station. Stations with richness and abundance less than or equal to 50 percent of the reference values were considered potentially impacted communities. This approach follows guidelines for identifying biological impacts developed as part of the Washington State Sediment Management Standards (WAC 173-204 1991).

5.5 RESULTS

Samples were collected from a total of 54 stations in the lower Columbia River. A total of 63,021 benthic infaunal organisms belonging to 114 taxa were identified from the 54 samples analyzed. Original benthic community data are presented for each sample in Appendix E (under separate cover). Total abundance and richness varied widely throughout the river. Benthic community variability may be attributed to the effects of sediment grain size, sediment organic carbon content, salinity, and habitat stability. Accordingly, results are presented for both the entire river and by habitat type.

5.5.1 Taxonomic Analyses

Forty percent of all organisms found were identified to species, 31 percent were identified to genus, and 30 percent were identified to family or a higher taxonomic level. Examples of the classification of benthic organisms are provided in Table 5-1.

5.5.2 Habitat Characteristics

Conventional chemical and physical variables including salinity of the overlying water, sediment grain size, and total organic carbon (TOC) of the sediments were used to characterize habitats sampled in the lower Columbia River. These data are presented in Tables 5-2 and 5-3. Habitats were classified as either estuarine or freshwater on the basis of near-bottom salinity measured during the water quality survey. Presence of euryhaline (salinity-tolerant) benthic taxa was used to further delineate the estuarine-riverine habitat boundary.

In the lower Columbia River, salinity ranged from approximately 32 ppt at the mouth of the river to < 1 ppt at RM 22 (station W9) near Grays River (see Section 2.6.1.2). Euryhaline species were present from the mouth of the estuary up to approximately RM 27 (Station D8). The habitats up through RM 27 were characterized as estuarine, and included 11 sampling stations. The habitats upstream of RM 27 were characterized as freshwater, and included 43 sampling stations.

The grain size distribution at each station was examined because of its documented effect on benthic community structure. In the lower Columbia River, sediments tend to be coarse and distributed among various sand size fractions. However, material finer than 100 μm in size is often transported as

TABLE 5-1. SELECTED EXAMPLES OF INFAUNAL TAXON CLASSIFICATION.

PHYLUM	CLASS	ORDER	FAMILY	SPECIES	COMMON NAME
				Scientific name	
Annelida	Polychaeta	Capitellida	Maldanidae	*Maldane sarsi sarsi*	Bamboo worm
Arthropoda	Crustacea	Amphipoda	Corophiidae	*Corophium salmonis*	Amphipod
Arthropoda	Insecta	Diptera	Chironomidae	*Chironomus spp.*	Midges
Mollusca	Gastropoda	Basommatophora	Ancylidae	*Ferrissia parellelus*	Freshwater limpet
Mollusca	Bivalvia	Myoida	Myidae	*Mya arenaria*	Soft-shell clam

TABLE 5-2. NEAR-BOTTOM SALINITY AT NINE RECONNAISSANCE SURVEY WATER SAMPLING STATIONS IN THE LOWER COLUMBIA RIVER.

Station	River Mile	Salinity (ppt)
W1	0	32
W2	2	15
W3	3	16
W4	11	24
W5	13	6
W6a	13	20
W6b	13	26
W6c	13	10
W7	13	6
W8a	19	10
W8b	19	10
W8c	19	1
W9	22	<1
W10-W45	23-146	<1

TABLE 5-3. RICHNESS, ABUNDANCE, AND SEDIMENT CONVENTIONAL CHARACTERISTICS AT EACH OF THE 54 BENTHOS SAMPLING STATIONS IN THE LOWER COLUMBIA RIVER

(Page 1 of 2)

Station[a,b]	River Mile	Taxa Richness (#taxa/0.06 m^2)	Total Abundance (#individuals/0.06 m^2)	Sediment Texture (% < 100 μm)	Total Organic Carbon (%)
D2	2	15	944	98	1.63
D4	6	20	1,997	82	1.13
D1	8	22	3,113	76	1.36
E1	8	10	60	4	0.13
D3	13	10	911	68	0.60
E2^{D}	16	13	174	24	0.10
D5^{E}	21	12	7,693	19	0.37
D6	21	14	1,921	26	0.46
D7	22	10	4,723	32	0.35
E3	22	8	80	14	0.21
D8	27	16	3,411	50	0.26
D11	29	25	5,960	70	0.80
E4	30	5	338	2	0.05
D9	34	8	352	25	0.51
D10	38	18	1,790	54	0.79
D12	40	25	2,014	94	0.77
D14	42	12	1,473	77	0.26
D13	43	13	516	89	0.37
E5	46	3	40	2	0.02
D15	50	14	434	43	0.68
D16	58	7	316	98	0.73
E6^{D}	58	10	295	23	0.31
D17	59	20	903	73	0.44
D18	62	25	931	32	0.69
D19	63	9	578	57	0.18
E7	67	5	53	3	0.02
D21	70	9	445	61	0.87
D20	71	20	4,027	84	0.85
D22	76	16	919	76	1.54
E8	77	13	1,002	8	0.17

TABLE 5-3. RICHNESS, ABUNDANCE, AND SEDIMENT CONVENTIONAL CHARACTERISTICS AT EACH OF THE 54 BENTHOS SAMPLING STATIONS IN THE LOWER COLUMBIA RIVER
(Page 2 of 2)

Station[a],[b]	River Mile	Taxa Richness (#taxa/0.06 m^2)	Total Abundance (#individuals/0.06 m^2)	Sediment Texture (% < 100 μm)	Total Organic Carbon (%)
D23	80	16	3,176	84	0.68
E9^{D}	83	13	890	55	0.68
D24	85	16	1,802	71	0.75
D25	88	17	919	80	0.51
D26	92	6	97	23	0.19
D27	94	11	421	21	0.41
D28	99	17	912	34	0.66
E10^{D}	100	13	160	26	0.38
D29	101	10	289	21	0.41
D30	103	13	1,053	69	0.58
E11^{D}	104	12	742	41	0.64
D31	106	16	538	41	0.43
D32^{E}	108	9	210	18	0.24
D33	109	10	836	38	0.48
D34^{E}	112	10	90	17	0.21
E12	114	1	37	<1	0.04
D35	118	24	2,444	44	4.06
D36	118	18	248	28	0.73
D37	121	11	303	50	0.47
D38^{E}	124	3	9	16	0.07
E13	126	6	204	3	0.04
D39	128	7	38	30	0.06
E14	137	13	174	1	0.08
D40	142	6	16	36	0.45

[a] Stations with a superscript "E" or "D" were reclassified as coarse-grained or fine-grained sediment stations, respectively (see Section 3.6.1.2).

[b] Shaded areas indicate coarse-grained stations.

suspended material in the water column (Conomos and Gross 1972; Sherwood et al. 1984) (see Sections 3.6.1.2 and 3.7.1 for further details on sediment characteristics). While no data were available to clearly use the grain-size data to distinguish actual depositional areas from less stable locations, the presence of finer sediments was thought to be indicative of more stable, depositional areas within the river. Throughout the river, the percent of sediments finer than 100 μm ranged from <1 to 98 percent. Grain size data were examined for samples collected in areas of the river predicted to be coarse-grained prior to the reconnaissance survey. Most of these stations had less than 20 percent of sediments finer than 100 μm. Presence of this sediment size fraction in amounts greater than 20 percent of the total sample weight was, therefore, used to identify depositional or fine-grained habitats in the river. A total of 41 fine-grained and 13 coarse-grained stations were sampled on the basis of this classification. Nine stations were reclassified from the original sampling plan: Stations D5, D32, D34, and D38 were reclassified as coarse-grained sediment stations; stations E2, E6, E9, E10, and E11 were reclassified as fine-grained sediment stations. These changes will be noted in the text by using the superscript "^{D}" or "^{E}" (e.g., E2^{D}).

Although the organic carbon content of the sediments also affects benthic community composition, the TOC content of the sediments was low [i.e., all but one station (station D35 in Camas Slough, 4.1 percent TOC) had less than 1.6 percent sediment TOC] and was not used to further classify habitat types.

5.5.3 Benthic Community Characteristics

Summary descriptive statistics for abundance and richness variables were used to simplify the examination of the lower Columbia River benthic community data. These results are presented in the following sections.

5.5.3.1 Descriptive Biological Indices. Abundance and richness data for each sample collected are summarized in Table 5-3. Abundance, expressed as the number of individuals per 0.06 m^2, ranged from 9 individuals (station D38^{E}) to 7,693 individuals (station D5^{E}) in the study area. The number of taxa per 0.06 m^2 ranged from 1 (station E12) to 25 (stations D11, D12, and D18). Abundances and taxa richness at each station are plotted in Figure 5-2. Overall, freshwater stations appeared to have relatively lower abundances and relatively fewer taxa compared to the estuary. Throughout the estuary, over 60 percent of the stations had less than 2,000 individuals per 0.06 m^2 and fewer than 16 taxa. Stations D1, D5^{E}, D7, and D8 had the greatest abundances of benthic organisms in the estuary, and stations D1 and D4 had the highest number of taxa. In the freshwater habitats, over 50 percent of the stations had less than 500

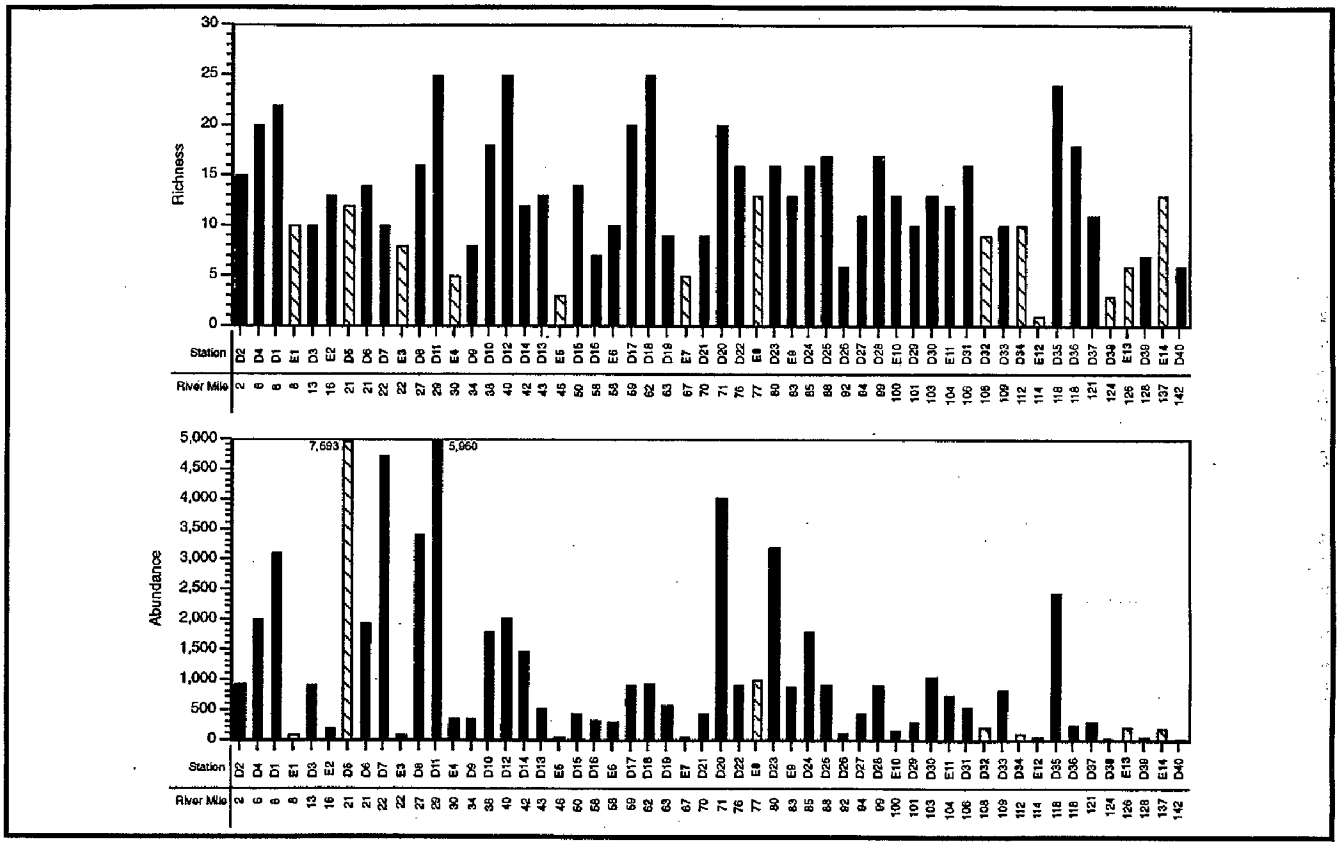


Figure 5-2. Richness and abundance per 0.06m^2 at each of the 54 sampling stations in the lower Columbia River. Hatched bars indicate coarse-grained habitats.

individuals per 0.06 m^2 and fewer than 13 taxa. Stations D11, D12, D20, D23, and D35 had the highest abundances, and stations D11, D12, D18, and D35 had the highest numbers of taxa.

Average abundance and richness values were also calculated for the estuarine and freshwater stations that were grouped according to fine- and coarse-grained sediment characteristics (Table 5-4). Few differences were apparent in the estuary, when comparing richness and abundance by sediment type. In the estuary, mean abundance and richness per 0.06 m^2 ranged from 2,611 individuals and 10 taxa at the coarse-grained stations to 2,149 individuals and 15 taxa at the fine-grained stations. Greater differences appeared to occur between sediment types in the freshwater portions of the river. Mean abundances and richness (per 0.06 m^2) in the freshwater habitats of the river ranged from 216 individuals and 7 taxa at the coarse-grained stations to 1,086 individuals and 14 taxa at the fine-grained stations..

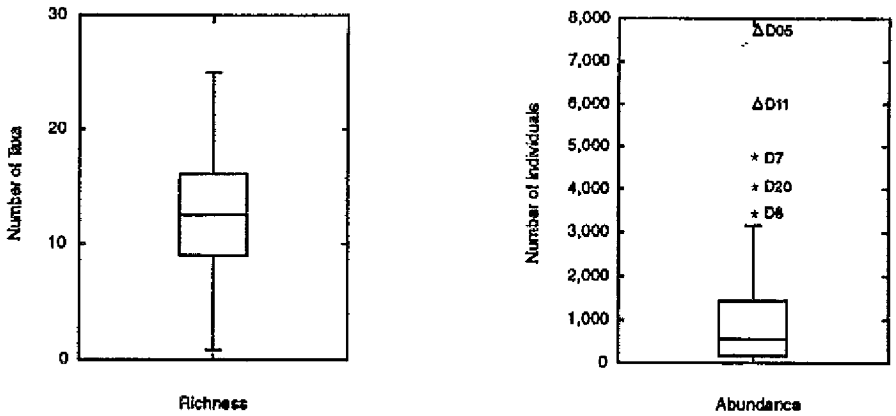
Distributional analyses were also used to characterize the richness and abundance data for the lower Columbia River. Median and inter-quartile ranges (IQR) were calculated to identify anomalously high or low values (i.e., outliers). Abundances and richness that exceeded a value 1.5 times the IQR were considered potentially high; the stations where these values occurred are identified in Figure 5-3. Although no stations were identified as outliers based on richness, stations $D5^E$, D11, D7, D20, and D8 had abundances that exceeded the upper IQR value for this variable.

5.5.3.2 Abundance of Major Taxa. Abundances of major taxa groups (i.e., annelids, arthropods, molluscs, and miscellaneous taxa) at all stations are summarized in Table 5-5 and Figures 5-4 through 5-7. Annelids (i.e., oligochaetes and polychaetes) occurred at 50 of the 54 stations and were the most abundant taxonomic group at 25 stations. Arthropods (i.e., crustaceans, insects, and arachnids) were present at 53 stations and were the most abundant taxonomic group at 15 stations. In most cases arthropod taxa were represented by members of the crustacean class, with the exception of 10 freshwater stations where insects were relatively more abundant. Molluscs (i.e., bivalves and gastropods) occurred at 51 stations and were the most abundant taxonomic group at 9 stations. Few miscellaneous taxa were observed in the estuary, and these consisted primarily of nematodes. Nematodes were widely distributed in the river, accounted for 10,481 individuals in the overall abundance total, and were the most abundant taxa at five stations.

TABLE 5-4. MEAN RICHNESS AND ABUNDANCE OF BENTHIC INFAUNAL ORGANISMS FOR ESTUARINE AND FRESHWATER FINE-GRAINED AND COARSE-GRAINED HABITATS IN THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY.

	RICHNESS (#taxa/0.06 m^2)		ABUNDANCE (#individuals/0.06 m^2)	
	Mean	S.D.	Mean	S.D.
<u>Estuarine Stations</u>				
Fine-Grained	15	4	2,149	1,517
Coarse-Grained	10	2	2,611	4,401
<u>Freshwater Stations</u>				
Fine-Grained	14	6	1,086	1,262
Coarse-Grained	7	4	216	295

S.D. = one standard deviation.



* Concentration exceeds 1.5 times IQR.

Δ Concentration exceeds 3.0 times IQR.

Figure 5-3. Distributions of richness and abundance data at 54 stations in the lower Columbia River.

TABLE 5-5. ABUNDANCES OF MAJOR TAXONOMIC GROUPS AT EACH OF THE 54 STATIONS IN THE LOWER COLUMBIA RIVER SAMPLED DURING THE RECONNAISSANCE SURVEY
(Page 1 of 3)

		Major Taxa Abundances (Number of Individuals/0.06 m^2)								
		Annelida		Arthropoda			Mollusca		Miscellaneous	
Station[a,b]	River Mile	Oligochaeta	Polychaeta	Arachnoidea	Crustacea	Insecta	Gastropoda	Bivalvia	Nematoda	Other
D2	2	149	565	0	9	0	0	217	4	0
D4	6	0	668	0	908	0	0	207	214	0
D1	8	2,109	584	1	89	0	0	267	63	0
E1	8	2	22	0	19	0	0	13	4	0
D3	13	454	177	0	2	0	0	190	88	0
E2[D]	16	91	16	0	22	0	0	42	3	0
D5[E]	21	62	42	0	7,296	1	0	21	270	1
D6	21	137	10	0	1,459	15	12	43	245	0
D7	22	112	46	0	4,412	1	2	73	77	0
E3	22	3	1	0	46	4	0	0	26	0
D8	27	105	12	4	1,906	58	233	2	1,091	0
D11	29	3,607	2	4	135	303	4	273	1,631	1
E4	30	0	0	0	328	0	0	5	5	0
D9	34	40	0	0	272	9	4	22	5	0
D10	38	738	0	0	584	21	73	97	277	0
D12	40	1,354	0	3	39	87	8	33	470	20
D14	42	1,335	3	0	72	13	1	5	23	21
D13	43	278	7	0	146	25	26	22	12	0
E5	46	0	0	0	0	0	0	17	23	0
D15	50	175	1	0	200	23	0	14	20	1
D16	58	295	0	0	1	15	0	3	2	0

TABLE 5-5. ABUNDANCES OF MAJOR TAXONOMIC GROUPS AT EACH OF THE 54 STATIONS IN THE LOWER COLUMBIA RIVER SAMPLED DURING THE RECONNAISSANCE SURVEY
(Page 2 of 3)

		Major Taxa Abundances (Number of Individuals/0.06 m^2)								
		Annelida		Arthropoda			Mollusca		Miscellaneous	
Station^{a,b}	River Mile	Oligochaeta	Polychaeta	Arachnoidea	Crustacea	Insecta	Gastropoda	Bivalvia	Nematoda	Other
E6^{D}	58	8	0	0	119	8	0	132	27	1
D17	59	650	0	0	20	32	15	132	53	1
D18	62	167	0	7	414	13	64	155	111	0
D19	63	381	0	0	125	3	43	10	16	0
E7	67	2	0	0	3	44	0	4	0	0
D21	70	353	0	0	7	4	1	2	76	2
D20	71	2,142	111	7	224	232	0	46	1,260	5
D22	76	631	0	3	74	32	0	10	167	2
E8	77	62	0	0	372	54	0	381	133	0
D23	80	1,112	0	2	214	39	0	45	1,764	0
E9^{D}	83	828	0	0	2	19	0	27	14	0
D24	85	1,479	0	0	118	76	0	18	106	5
D25	88	606	0	4	13	26	0	5	252	13
D26	92	3	0	0	48	0	0	45	1	0
D27	94	27	0	5	108	1	0	172	65	43
D28	99	262	0	3	178	34	0	42	390	3
D10^{D}	100	12	0	0	7	35	0	93	13	0
D29	101	27	0	2	97	6	0	36	116	5
D30	103	655	1	0	62	18	0	73	244	0
E11^{D}	104	365	1	0	31	17	0	37	288	291
D31	106	302	2	5	25	31	1	56	115	116

TABLE 5-5. ABUNDANCES OF MAJOR TAXONOMIC GROUPS AT EACH OF THE 54 STATIONS IN THE LOWER COLUMBIA RIVER SAMPLED DURING THE RECONNAISSANCE SURVEY
(Page 3 of 3)

Station[a,b]	River Mile	Major Taxa Abundances (Number of Individuals/0.06 m^2)								
		Annelida		Arthropoda			Mollusca		Miscellaneous	
		Oligochaeta	Polychaeta	Arachnoidea	Crustacea	Insecta	Gastropoda	Bivalvia	Nematoda	Other
D32^E	108	5	1	0	121	2	0	63	18	0
D33	109	138	0	0	169	12	0	106	411	0
D34^E	112	4	0	0	15	5	0	61	4	1
E12	114	0	0	0	0	37	0	0	0	0
D35	118	1,996	0	3	89	79	14	166	92	5
D36	118	40	0	5	21	34	0	76	70	2
D37	121	156	1	2	30	7	0	21	85	1
D38^E	124	7	0	0	0	1	0	0	1	0
E13	126	0	0	0	18	28	0	127	31	0
D39	128	2	0	0	0	5	0	29	2	0
E14	137	3	0	1	25	13	15	109	0	8
D40	142	3	0	0	6	1	0	1	3	2

[a] Stations with "E" or "D" were reclassified as coarse-grained or fine-grained sediment stations, respectively (see Section 3.6.1.2).

[b] Shaded areas indicate coarse-grained stations.

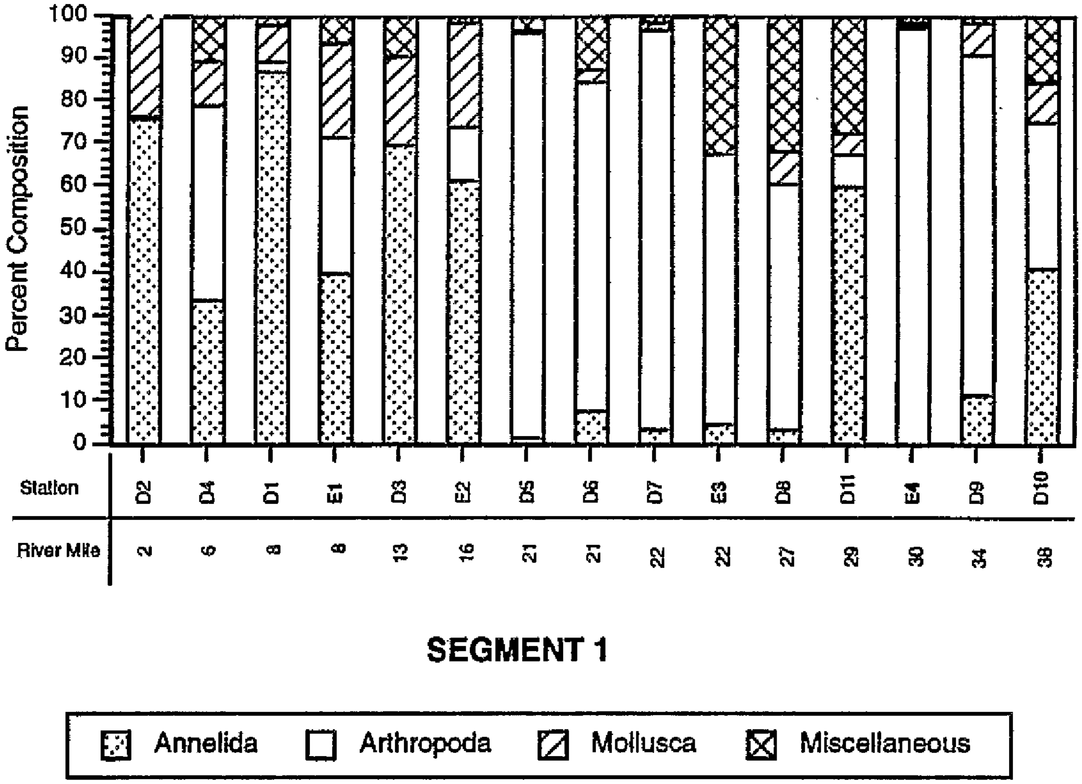


Figure 5-4. Percent composition of major taxa groups at 15 stations in Segment 1 of the lower Columbia River. Bolded stations were coarse-grained habitats.

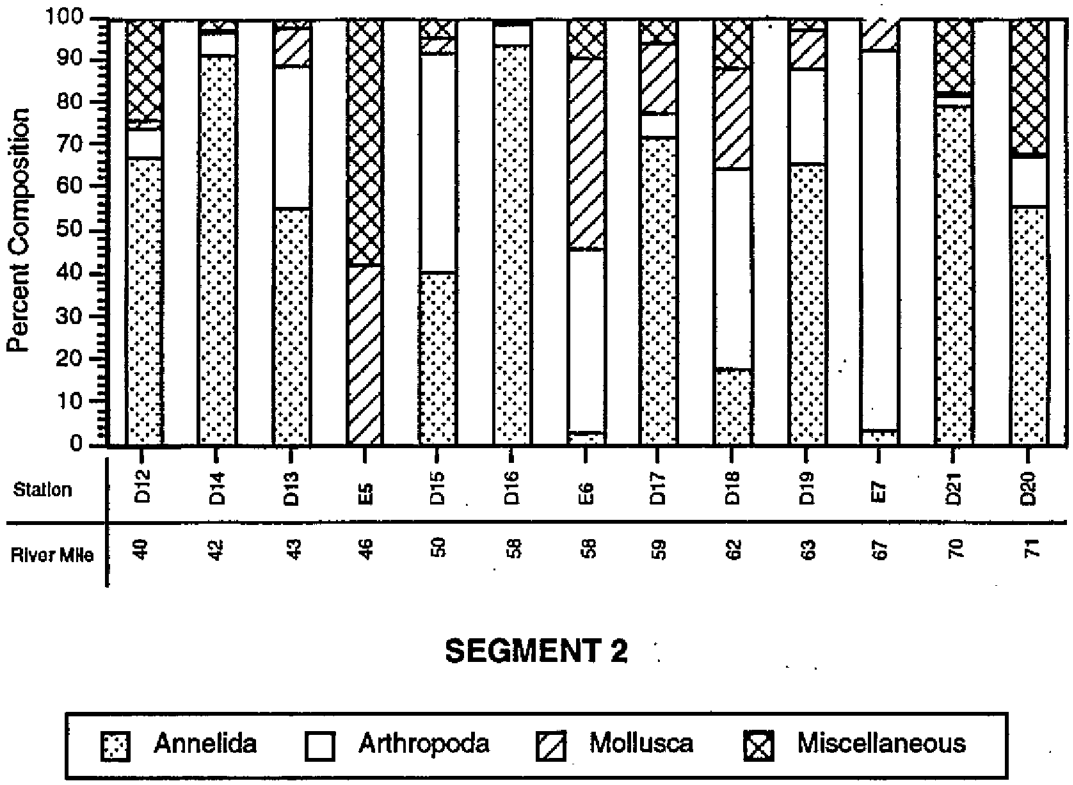


Figure 5-5. Percent composition of major taxa groups at 13 stations in Segment 2 of the lower Columbia River. Bolded stations were coarse-grained habitats.

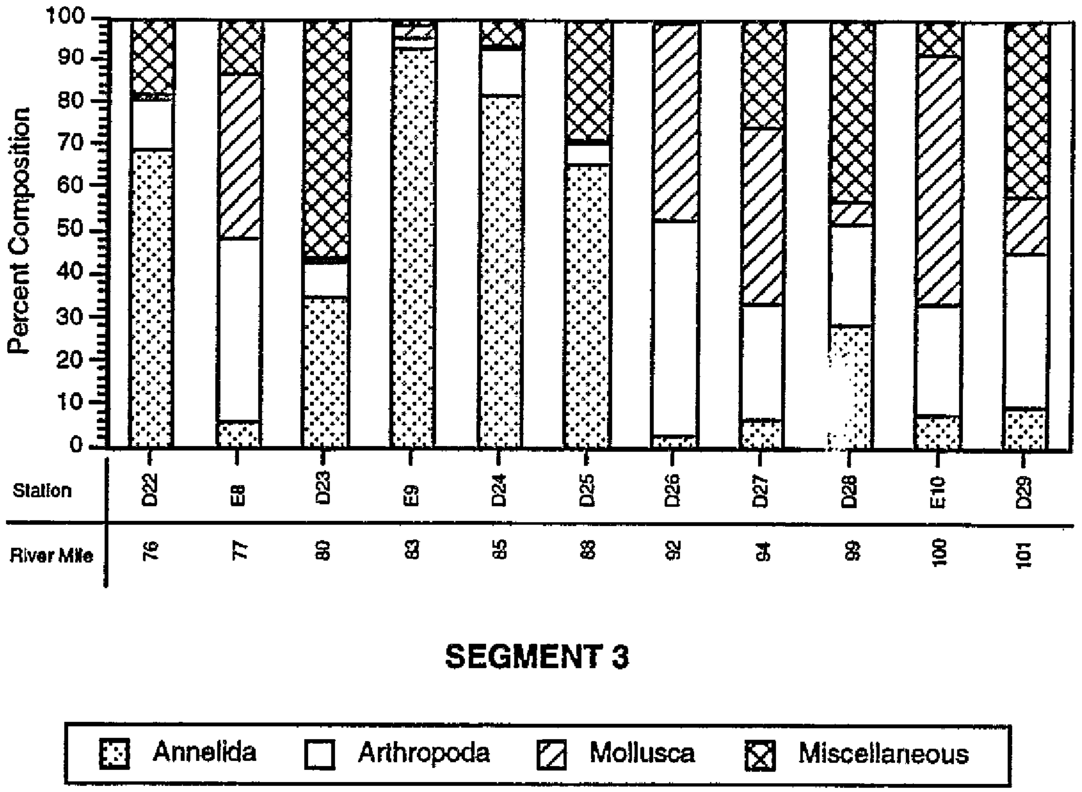


Figure 5-6. Percent composition of major taxa groups at 11 stations in Segment 3 of the lower Columbia River. Bolded stations were coarse-grained habitats.

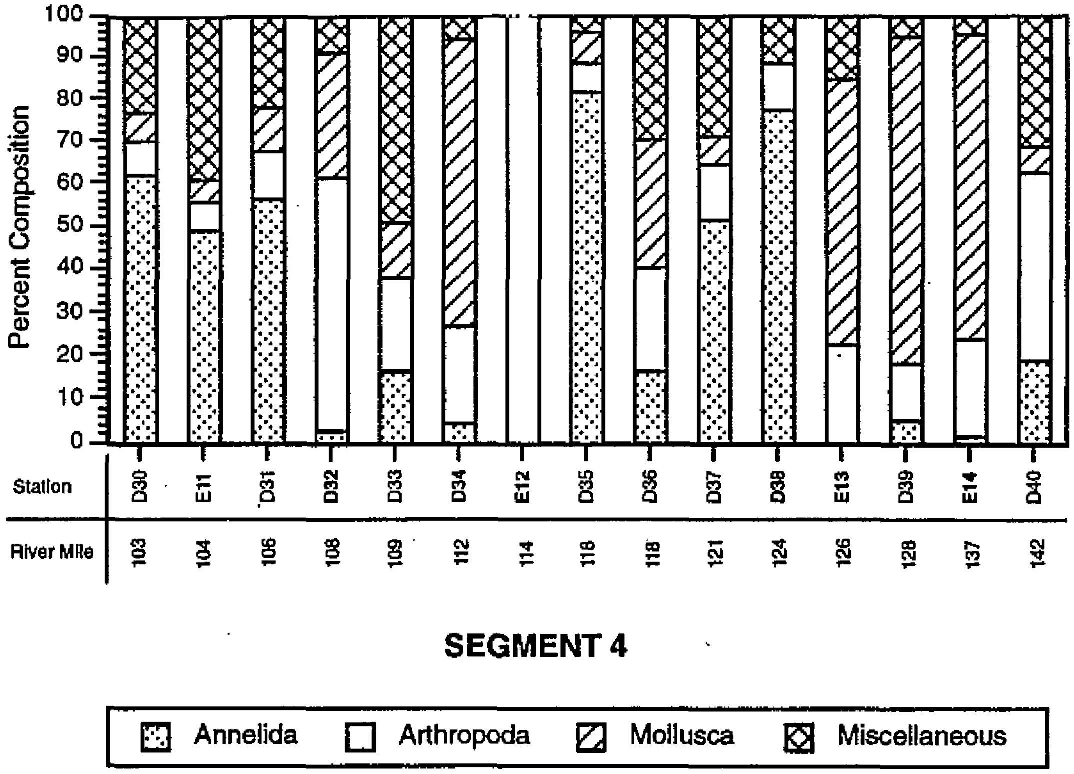


Figure 5-7. Percent composition of major taxa groups at 15 stations in Segment 4 of the lower Columbia River. Bolded stations were coarse-grained habitats.

Major taxa abundance was examined further by grouping stations according to salinity regime (estuarine or freshwater). Within the estuary, polychaetes dominated the higher salinity areas downstream of RM 13 (station D3). Bivalve molluscs and crustaceans were also abundant at some stations in the higher salinity areas of the estuary, while insects, nematodes, and gastropod molluscs were absent. As salinity decreased, crustaceans became the most abundant taxa at the estuarine stations, and bivalve and polychaete abundances decreased. Nematode abundances appeared to increase with decreasing salinity. Oligochaetes were present, if not abundant, at most estuarine stations.

Abundant major taxa in the freshwater areas of the river included oligochaetes, crustaceans, and bivalves. Oligochaetes were the most abundant taxa at 20 of the 43 freshwater stations. Oligochaetes are often indicative of organically enriched sediments. However, these taxa are a highly adaptive, diverse group and can be found in sediments ranging from sands to muds (Thorp and Covich 1991). Crustaceans and bivalve molluscs were the next most abundant groups, each dominating the total abundance at nine freshwater stations. Crustaceans in the freshwater areas of the river were primarily represented by one species, *Corophium salmonis*. This species is a tube-dwelling amphipod, capable of forming dense tube stands in sand and mud flats. The bivalve, *Corbicula fluminea*, represented the majority of molluscs in the freshwater habitats. Both these taxa are highly adapted to life in more dynamic environments and occur in very high densities. Nematodes were present, if not abundant, at many of the freshwater stations and were numerically dominant at five stations. Nematodes are an ecologically diverse group that have adapted to a wide variety of habitats in estuarine and freshwater environments. Insects were also relatively abundant in the freshwater portions of the river and were primarily represented by chironomids (freshwater midges). Chironomids are generally considered to be pollutant-tolerant (Burton 1991) and were found at 41 stations in the river. At station E12, these taxa represented 100 percent of the taxa present at the station. Polychaetes and gastropods were among the rarest taxa groups in the freshwater reaches of the river.

5.5.4 Differences Among stations

Because of the influence of habitat characteristics on community structure, differences or similarities in community indices were explored among habitat types. Statistical tests using both univariate and multivariate techniques were used to delineate these differences in benthic community structure; the results are presented in the following sections.

5.5.4.1 Community Indices. Comparisons of the sample means pooled by habitat type were made using *t*-tests to evaluate the effect of habitat on benthic community attributes. Probabilities less than 0.05 were considered significant, indicating that the communities were unlikely to be the same. Results using abundance and richness data indicated that there were significant differences among fine-grained and coarse-grained habitats in mean richness, mean total abundance, mean annelid abundance, and mean miscellaneous taxa abundance. Results of all other comparisons were not statistically significant. Probabilities of significant differences among habitats based on benthic attributes are presented in Table 5-6.

Pooling stations from throughout the river, fine-grained stations had significantly ($P \leq 0.05$) greater numbers of taxa compared to coarse-grained stations. Significant differences in mean abundances pooled by sediment type occurred only within the freshwater portions of the river. Annelid and miscellaneous taxa abundance were also significantly higher at fine-grained stations compared to coarse-grained stations in the freshwater reaches of the river. No significant differences were identified in the estuary for any comparison of abundance by grain size. No significant differences were found in arthropod or molluscan abundance between fine-grained and coarse-grained stations throughout the river. The lack of significant relationships between benthic indices and grain size in this estuary is not conclusive because of the small number of samples collected in this area of the river.

5.5.4.2 Community Composition. The dendrograms illustrating the results of the cluster analysis for the estuarine and freshwater stations are presented in Figures 5-8 and 5-9. Stations were considered members of the same group or cluster if the similarity between stations was greater than or equal to 60 percent. Overall the results of the cluster analysis reflected the effect of salinity and grain size characteristics on benthic community structure.

Within the estuary, two major clusters were identified among the fine-grained stations, with the coarse-grained stations consisting of highly dissimilar communities. Stations D5^E, D6, D7, and D8 in the upper estuary formed the first cluster with greater than 71 percent similarity; stations D1, D2, and D3 in the lower estuary formed the second cluster with 64 percent similarity. Station D4 was linked with this second cluster but at a similarity of only 50 percent. The first and second clusters were linked at less than 30 percent similarity suggesting that communities in the upper estuary were different from those in the lower estuary. Stations E1, E2^D, and E3 were the coarse-grained estuary stations and were the least similar to all other estuarine stations and to each other. The mean total abundance for the group of

TABLE 5-6. PROBABILITY (P) OF SIGNIFICANT DIFFERENCES BETWEEN HABITATS BASED ON TOTAL RICHNESS, TOTAL ABUNDANCE, ANNELID ABUNDANCE, AND MISCELLANEOUS TAXA ABUNDANCE.

	TOTAL RICHNESS		
	All Stations	Estuarine Stations	Freshwater Stations
Fine-Grained	Coarse-Grained <0.0001	Coarse-Grained 0.031	Coarse-Grained <0.0001

	TOTAL ABUNDANCE		
	All Stations	Estuarine Stations	Freshwater Stations
Fine-Grained	Coarse-Grained 0.005	Coarse-Grained NS	Coarse-Grained 0.003

	ANNELID ABUNDANCE		
	All Stations	Estuarine Stations	Freshwater Stations
Fine-Grained	Coarse-Grained <0.0001	Coarse-Grained NS	Coarse-Grained <0.0001

	MISC. TAXA ABUNDANCE		
	All Stations	Estuarine Stations	Freshwater Stations
Fine-Grained	Coarse-Grained 0.003	Coarse-Grained NS	Coarse-Grained 0.002

NS: Not significant at $P<0.05$.

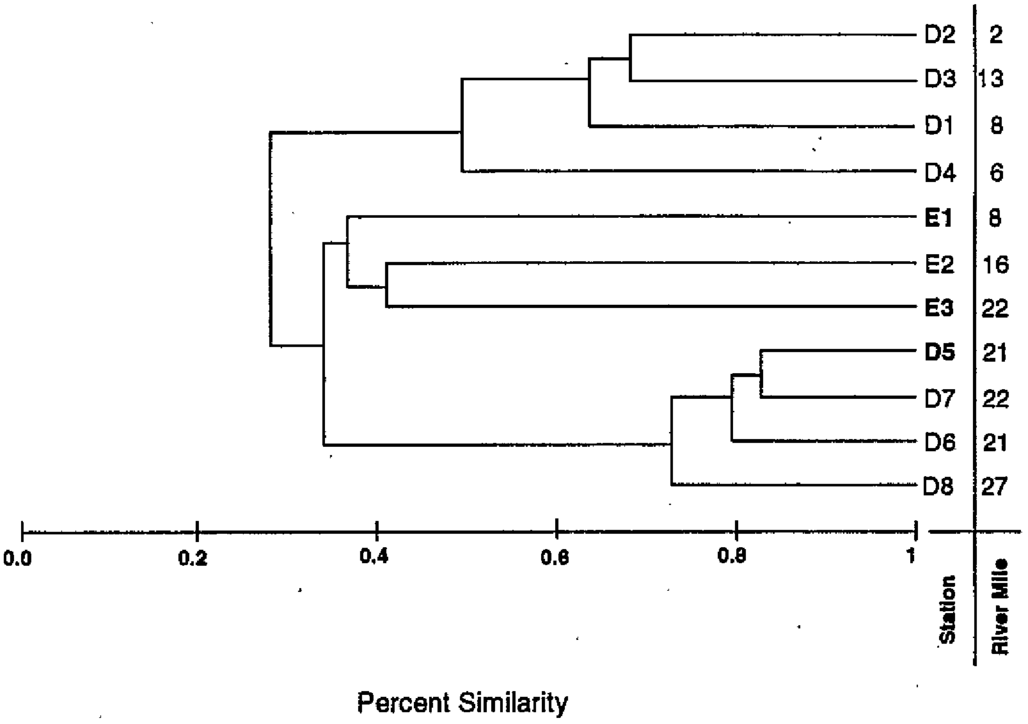


Figure 5-8. Dendrogram resulting from a Bray-Curtis classification analysis of the benthic community data at 11 marine and estuarine stations in the lower Columbia River. Bolded stations were coarse-grained habitats.

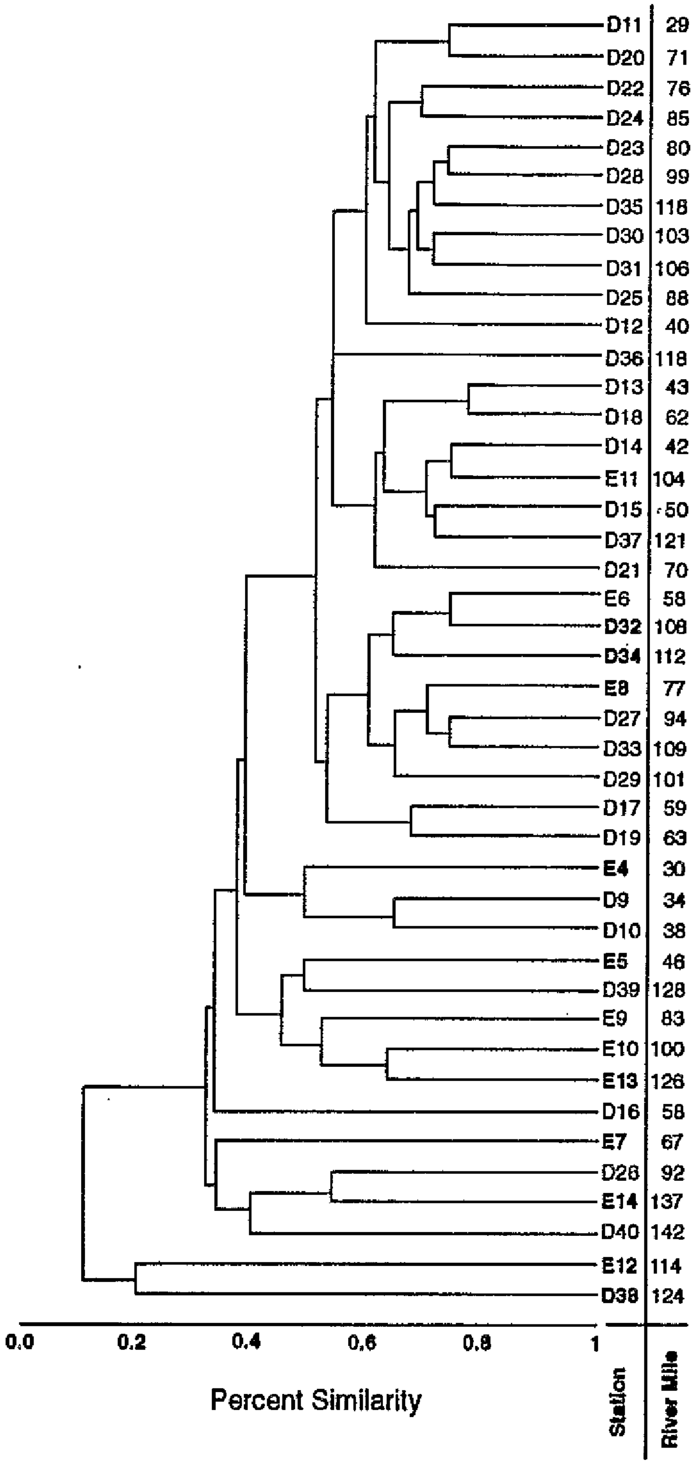


Figure 5-9. Dendrogram resulting from a Bray-Curtis classification analysis of the benthic community data at 43 freshwater stations in the lower Columbia River. Bolded stations were coarse-grained habitats.

stations in the estuary with the greatest similarity (stations D5^E, D6, D7, and D8) was greater than 4,400 individuals per 0.06 m^2. These estuarine stations were characterized by lower salinities, sandier substrates, and the presence of euryhaline taxa. The communities at these stations were dominated by the crustacean *Corophium salmonis*, nematodes, and oligochaetes. Stations D1, D2, D3, and D4 had a relatively lower mean total abundance (1,700 individuals per 0.1 m^2) than the first cluster. These estuarine stations occurred closest to the mouth of the river and were characterized by high salinities, very fine-grained sediments and the presence of marine taxa. Dominant taxa at these stations included the polychaete *Hobsonia florida* and the bivalve *Macoma balthica,* as well as oligochaetes and nematodes. Oligochaetes were found throughout the estuary, but were absent at station D4, which may have contributed to its lower percent similarity with other members of the second cluster. Several polychaetes (*Spio* spp. and *Eteone spilotus*) and crustaceans (*Hemileucon* spp. and *Eohaustorius estuarius*) were characteristic of the estuarine stations but were dominant only at stations E1, E2^D, and E3.

For the freshwater reaches of the river (Figure 5-9), three major clusters were formed by 26 of the 43 stations. Stations D13, D14, D15, D18, D21, D37, and E11^D formed the first cluster with 62 percent similarity; stations D11, D12, D20, D22, D23, D24, D25, D28, D30, D31, and D35 formed the second cluster with 60 percent similarity. Station D36 was linked with the second cluster at 55 percent similarity. The first and second clusters were linked at less than 55 percent similarity. The third cluster was formed by stations D27, D29, D32^E, D33, D34^E, E6^D, and E8 with a similarity of 61 percent. The remaining 17 freshwater stations were fairly dissimilar to most other stations. Several small clusters were formed by stations D17 and D19; stations D9, D10, and E4; and stations D39, E5, E9^D, E10^D, and E13 among the remaining stations. However, these groups were not linked with the other clusters at greater than 60 percent similarity. The remaining stations (D16, D26, D38^E, D40, E7, E12, and E14) were the least similar to all other freshwater stations and to each other.

Community composition among all freshwater stations was relatively similar with oligochaetes, nematodes, *Corbicula fluminea* and *Corophium salmonis* representing the dominant taxa at most stations. Results of the cluster analysis indicated a gradual change in abundance of these dominant taxa between the stations of the first, second, and third clusters. For these three freshwater station clusters, the mean total abundance appeared to be high (nearly 2,000 individuals per 0.06 m^2). The mean total abundance for the remaining stations was lower, at only 300 individuals per 0.06 m^2. Coarse-grained stations represented many of the remaining stations that did not show great similarity with most other stations.

The majority of the freshwater coarse-grained stations had fewer taxa and total abundances compared with the freshwater fine-grained stations.

5.5.4.3 ***Relationship Among Biotic and Abiotic Variables.*** Correlations of benthic community variables (i.e., total abundance, richness, and major taxa abundance), habitat characteristics (i.e., sediment fines and TOC), and metals concentrations were examined. Regression analyses were used to test the significance of the relationship between biological and habitat or chemical variables. The regressions were compared on the basis of the significance of the regression (P); the correlation coefficient (r), which provides a measure of the degree of association between the two variables; and the coefficient of determination (r^2), which is a measure of the total variation in the dependent (i.e., biological) variable that is explained by the independent (i.e., physical or chemical) variable. Stronger relationships are indicated by probabilities less than 0.05, and higher r, and r^2 values. Correlation coefficients, coefficients of determination, and probability values for all correlations are presented in Table 5-7. The correlation scatter plots for variables with significant relationships are presented in Figure 5-10.

Throughout the river, richness, abundance, and annelid abundance were positively correlated with sediment fines and TOC ($P \leq 0.05$). In addition, miscellaneous taxa (primarily nematodes) abundance was positively correlated with sediment fines. However, the coefficient of determination, r^2, indicated that only 19 to 33 percent of the variation in the benthic community variables was explained by TOC concentrations. While the correlation is still considered significant, it is possible that a relationship other than one of linearity may exist between these variables or that another variable explains more of the variation. Significant correlations for which the physical variables explained most of the variations (i.e., $r^2 > 0.65$) in the benthic data occurred only in the case of percent sediment fines and annelid abundance.

Relationships between benthic community variables and habitat attributes were examined further by grouping stations according to salinity. For the estuarine stations, annelid abundance was significantly ($P \leq 0.05$) and positively correlated with sediment fines and had a strong linear association. Richness, abundance, and annelid abundance were significantly ($P \leq 0.05$) correlated with sediment fines and TOC in the freshwater reaches of the river. In addition, miscellaneous taxa abundance was correlated with sediment fines. However, only 22 to 31 percent of the variation in benthic community variables was explained by TOC concentrations in the sediments. Sediment fines was the only physical variable which explained greater than 65 percent of the variation in a biological variable (i.e., annelid abundance).

TABLE 5-7. CORRELATION COEFFICIENTS (r), COEFFICIENTS OF DETERMINATION (r^2), AND SIGNIFICANCE LEVELS (*P*) FOR CORRELATIONS AMONG BIOTIC AND ABIOTIC VARIABLES.

	Taxa Richness			Total Abundance			Annelid Abundance			Misc. Taxa Abundance		
	r	r^2	*P*	r	r^2	*P*	r	r^2	*P*	r	r^2	*P*
<u>All Stations</u>												
Sediment fines	0.554	0.307	<0.0001	0.439	0.192	<0.0001	0.829	0.687	<0.0001	0.419	0.176	0.045
TOC	0.576	0.331	<0.0001	0.572	0.327	0.025	0.563	0.317	<0.0001	0.295	0.087	NS
<u>Estuarine Stations</u>												
Sediment fines	0.658	0.433	NS	0.392	0.154	NS	0.830	0.689	0.024	0.091	0.008	NS
TOC	0.681	0.464	NS	0.340	0.116	NS	0.773	0.598	NS	-0.061	0.004	NS
<u>Freshwater Stations</u>												
Sediment fines	0.541	0.293	0.003	0.638	0.407	<0.0001	0.846	0.716	<0.0001	0.499	0.249	0.010
TOC	0.561	0.314	0.001	0.470	0.221	0.022	0.535	0.287	0.003	0.360	0.130	NS

NS: Not significant at $P<0.05$.

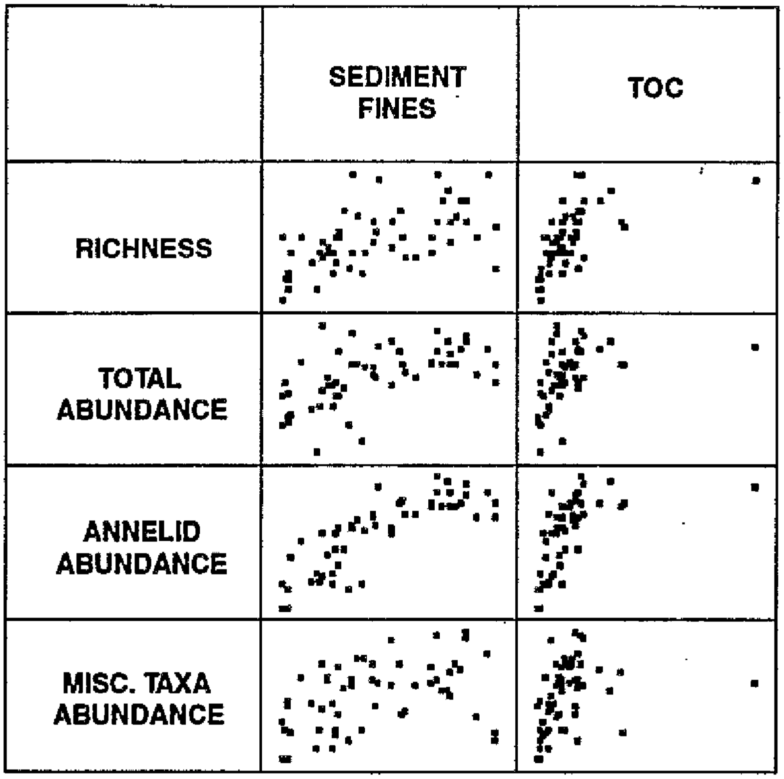


Figure 5-10. Relationship between habitat characteristics and benthic community attributes.

The relationship among benthic community indices and metals (i.e., As, Ba, Be, Cd, Cr, Cu, Pb, Hg, Ni, Ag, and Zn) concentrations was also examined. No significant correlations were found that would indicate that benthic abundances and richness decreased with increasing sediment metals concentrations. This may be due to the very strong effect habitat characteristics have on benthic community structure. To further examine relationships between benthic community indices with sediment metals, the correlation between the abundance of two potential indicator taxa, *Corophium salmonis* and *Corbicula fluminea*, and sediment metals was examined. No significant correlations were found between indicator taxa abundance and concentrations of trace elements. Contaminant concentrations in the sediments may have an effect on benthic organisms, but the strong role that habitat stability and salinity appear to play may have obscured detection of any chemical effect.

5.5.4.4 Delineation of Ecological Zones. Salinity was the dominant factor in establishing ecological zones in the lower Columbia River. Two main zones were identified: the estuarine zone (> 1 ppt) and the riverine zone (< 1 ppt). Within the estuary, there was some evidence that a transitional ecological zone may exist. Taxa present in the lower salinity areas (1 to 15 ppt salinity) in the upper estuary were often distinct from the taxa found in areas with more marine conditions (> 15 ppt salinity) in the lower estuary, reflecting the different tolerances to salinity fluctuations. This delineation was also suggested by the results of the cluster analysis. However, no further division of the estuary zone was made because too few stations were sampled.

While grain size appeared to affect benthic community abundances in the freshwater reaches of the river, community composition between sediment types was very similar. Therefore, no further delineation of ecological zones based on grain size were identified in the freshwater zone of the river. Sediment characteristics may also play a role in structuring benthic communities in the estuary, but again too few stations representing coarse-grained habitats were sampled, so no further delineation of ecological zones was made in this study.

5.5.4.5 Comparison with Columbia River Reference Area Data. To identify reference areas in the lower Columbia River, stations were first grouped according to salinity type (estuarine or freshwater). Next, because the results of the *t*-tests indicated significant differences in richness and abundance between the freshwater fine-grained and coarse-grained stations, separate reference stations were selected for the fine-grained and coarse-grained freshwater habitats. Even though significant differences in richness occurred between the estuarine fine-grained and coarse-grained stations, no separate reference stations could be identified for each habitat type because there were only three coarse-grained stations, which could not be further separated. Finally, the richness and abundance data from each group of stations were ranked. Stations representing the upper 80th percentile value for richness and abundance were initially considered as candidate reference stations (i.e., highest richness and abundance values). Levels of contaminants at the candidate stations were then examined. Stations D24 and D35 were originally identified as freshwater reference stations, but they were dropped from further consideration because of the elevated concentrations of a number of contaminants at these two stations. In addition, anomalously high TOC values were also found in station D35 sediments making this station unlike any other station sampled.

High abundances are not necessarily indicative of reference conditions. Benthic communities are known to respond to organic enrichment by increasing abundances of opportunistic taxa with a concomitant loss of richness (Pearson and Rosenberg 1978). Abundances at candidate reference stations were further examined to address these considerations. Richness and abundances were highly correlated, which allowed identification of anomalous richness and abundance values on the basis of a regression analysis using these two variables. Stations D5^E and D7 were identified as outliers (i.e., having anomalously high abundances relative to richness). While these two stations had extremely low TOC in the sediments, some other physical characteristics allowed the communities at these stations to be dominated by only a few, highly adaptive taxa (i.e., *Corophium salmonis* and nematodes). These stations were considered potentially anomalous stations and were dropped from consideration as estuarine reference stations. These two stations were also identified as outliers as part of the distributional analysis (abundances were more than 1.5 times the IQR above the 75th percentile). Percentile values were recalculated using the remaining data (i.e., excluding stations D5^E, D7, D24, and D35), and the median value of the upper 80th percentile was used to represent reference conditions. Final reference stations and median reference values for richness and abundance are identified in Table 5-8. Those having 50 percent or fewer taxa or individuals compared to reference were considered potentially stressed stations, without regard to the causative factors.

Overall, 25 stations were identified as having less than 50 percent of the richness or abundance values used to represent reference conditions. In the estuary, five benthic sampling stations were identified as

TABLE 5-8. MEDIAN RICHNESS AND ABUNDANCE VALUES FOR REFERENCE STATIONS SAMPLED IN THE LOWER COLUMBIA RIVER RECONNAISSANCE SURVEY.

RICHNESS (#taxa/0.06 m^2)		ABUNDANCE (#individuals/0.06 m^2)	
	Median Value		Median Value
Estuarine Stations		Estuarine Stations	
D1, D4	21	D1, D8	3,262
Freshwater Stations		Freshwater Stations	
Coarse-Grained		Coarse-Grained	
E8, E14	13	E4, E8	670
Fine-Grained		Fine-Grained	
D10, D11, D12, D17, D18, D20, D36	20	D10, D11, D12, D14, D20, D23, D30	2,014

having depauperate benthic communities based on low abundances, and one additional station was identified as having significantly low richness compared to reference (Figure 5-11). Communities at stations D3, E1, and E3 were depauperate with few taxa present compared to reference. In addition, stations D2 and E2^D had depressed abundances, and station D7 had low richness. Percent abundance for the depauperate communities in the estuary ranged from 2 to 29 percent of the reference abundance. Percent richness at low-diversity stations ranged from 38 to 48 percent of the reference richness for the estuary.

The benthic communities at eight of the freshwater coarse-grained stations were identified as depauperate, and communities at six stations were identified as having significantly lower diversity compared to reference (Figure 5-12). On the basis of low total abundance and richness, stations D38^E, E4, E5, E7, E12, and E13 were identified as having substantially different community indices compared to reference conditions for freshwater coarse-grained habitats. Low abundances also occurred at stations D32^E, D34^E, and E14. For these stations, percent abundance ranged from 1 to 50 percent of the reference abundance. Percent richness ranged from 8 to 46 percent of the reference richness for this habitat type. In the freshwater fine-grained habitats, 24 of the 33 stations sampled were identified as having depressed abundances, but only 9 stations were identified as having low richness (Figure 5-13) compared to reference. Stations D9, D16, D19, D21, D26, D29, D33, D39, D40, and E6^D had both low abundance and low richness values compared to reference. Depressed abundances were also identified at stations D13, D15, D17, D18, D22, D25, D27, D28, D31, D36, D37, E9^D, E10^D, and E11^D. Overall, only stations D24 and D35 exceeded the reference abundance values for the freshwater fine-grained habitats. Percent abundance for the depauperate freshwater fine-grained stations ranged from <1 to 46 percent of the reference abundance. Percent richness ranged from 30 to 50 percent of the reference richness.

5.6 DISCUSSION

Benthic communities in the study area reflect the dynamic nature of the aquatic environment in the lower Columbia River. Habitat characteristics (e.g., salinity, sediment grain size, and habitat stability) appear to strongly influence community composition throughout the river. Estuarine benthic communities are very different from riverine communities, in both species composition and total taxa abundances. Taxa richness between the estuary and the river appears to be similar. Community structure in the estuary

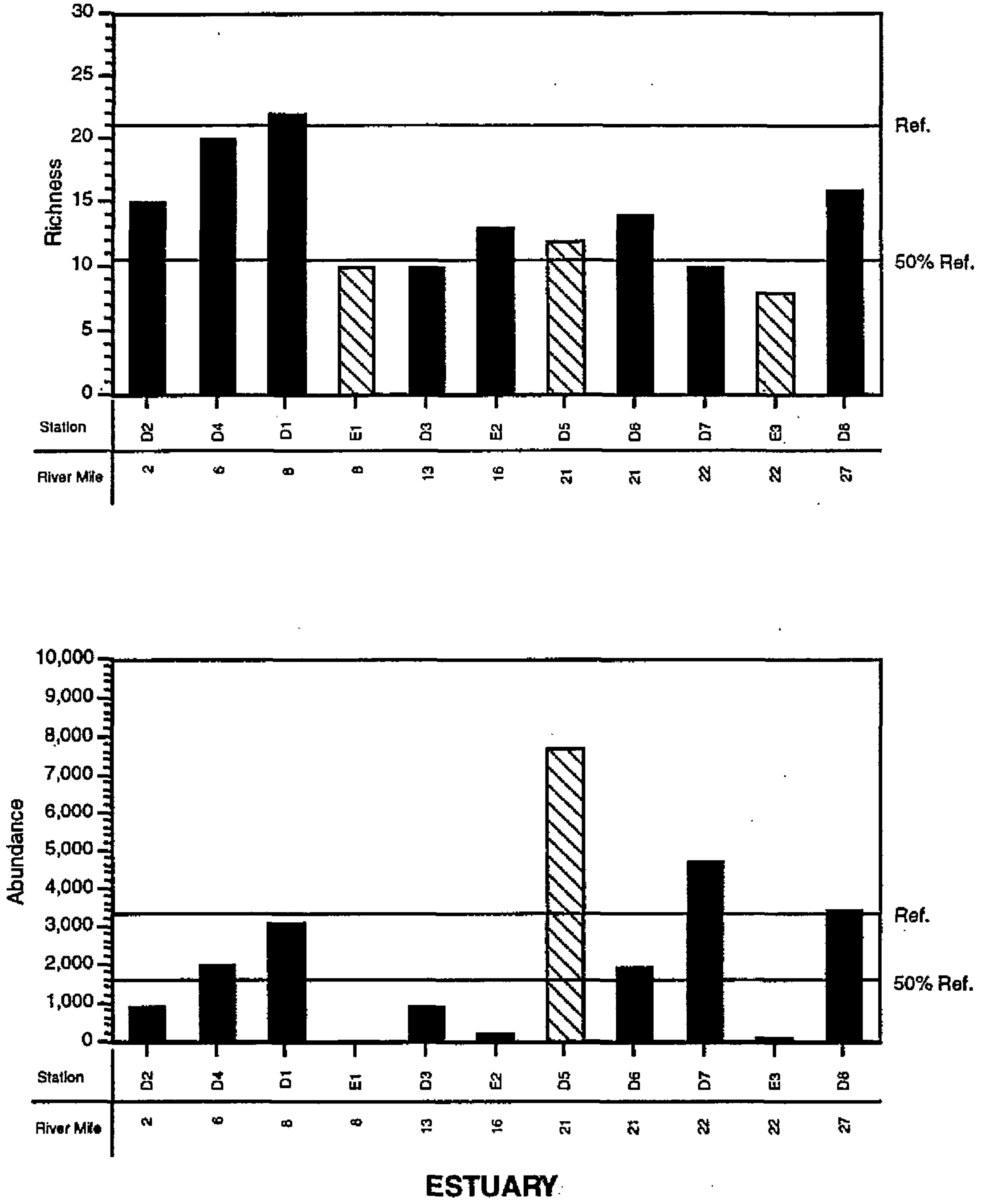


Figure 5-11. Comparisons between richness and abundance data for estuarine stations and median reference values. Hatched bars indicate coarse-grained habitats.

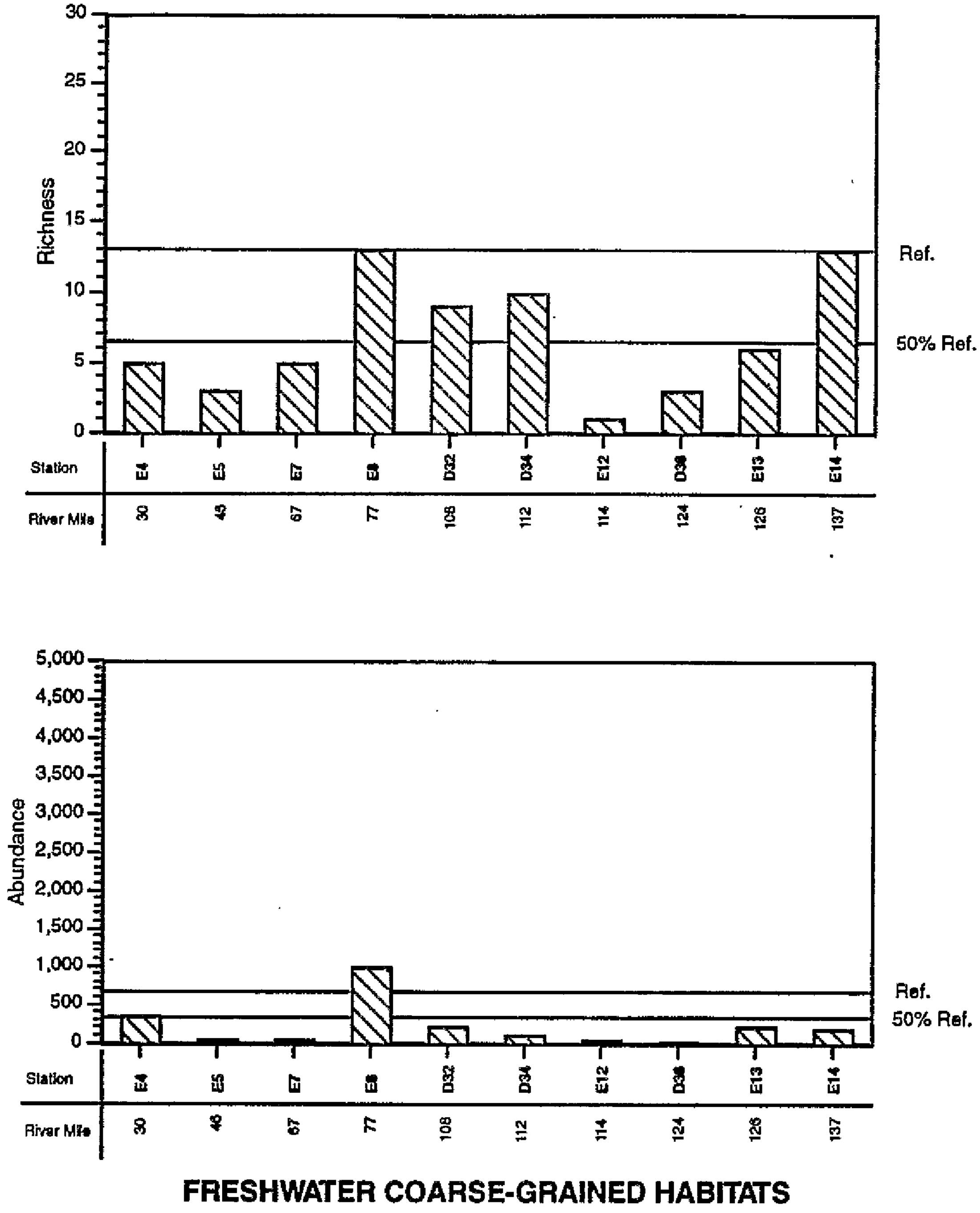


Figure 5-12. Comparisons between richness and abundance data for freshwater coarse-grained stations and median reference values.

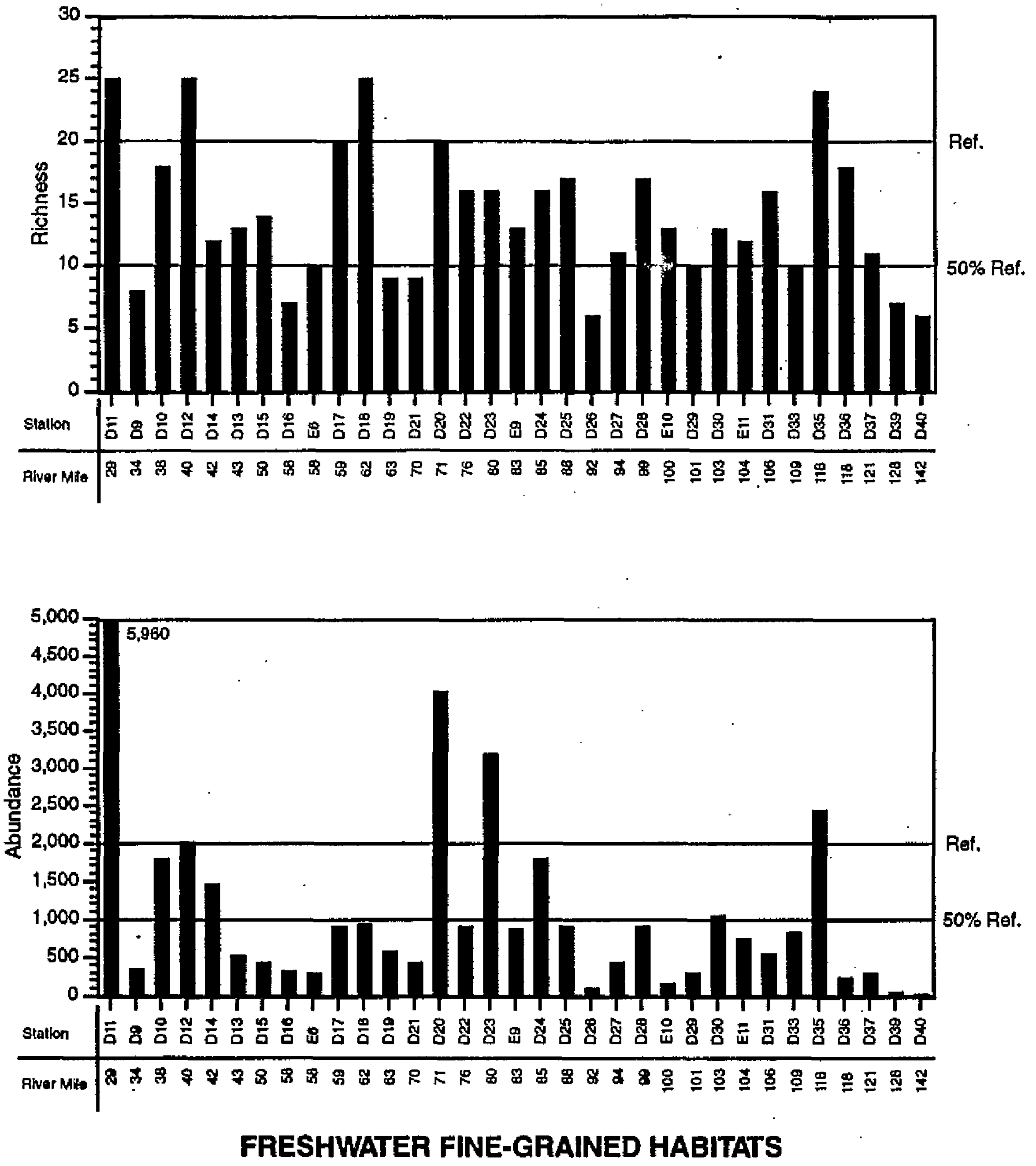


Figure 5-13. Comparisons between richness and abundance data for freshwater fine-grained stations and median reference values.

appears to be primarily affected by salinity, although too few data were available to fully test the effect of grain size in the estuary. Stations near the river mouth and in areas of higher salinity were characterized by marine taxa. Taxa that are tolerant of salinity fluctuations or intermittent freshwater conditions were found at upper estuary stations in areas with lower salinities.

Grain size appears to have a lesser effect than does salinity on community structure in the estuary. Average taxa richness and abundances were very similar between communities in fine-grained and coarse-grained habitats in the estuary. Community composition also appeared to respond to salinity, as well as to sediment characteristics. In fine-grained sediments in areas with higher salinity, the polychaetes *Hobsonia florida, Eteone spilotus*, several spionids, and the bivalves *Macoma balthica*, and *Mya arenaria* were among the dominant taxa. These taxa were present in the coarser sediments in higher salinity areas but were not as abundant. Several other taxa, including the amphipods *Grandifoxus grandis* and *Eohaustoris estuarius*, were among the numerically dominant taxa at these coarse-grained stations. In lower salinity areas with mixed sediments, *Corophium salmonis* and *Corbicula fluminea* were among the dominant taxa. Oligochaetes and nematodes were dominant at all fine-grained stations, regardless of salinity.

Within the freshwater reaches of the river, sediment grain size appears to be the dominant factor affecting community richness and abundance. Few taxa were found at the coarse-grained riverine stations and abundances were low compared to the fine-grained riverine stations. Coarser sediments in the lower Columbia River tend to be indicative of unstable habitats. Under most conditions, coarse sands are carried down river by the force of the river currents, and therefore benthic habitats are neither consistent nor persistent.

5.6.1 Comparison With Historical Data

The importance of salinity in structuring benthic communities in the estuarine portion of the river has been noted in several studies (e.g., Haertel and Osterberg 1967; Higley et al. 1983; Simenstad 1984; Amspoker and McIntire 1986). Simenstad (1984) summarized the results of the Columbia River Estuary Data Development Program (CREDDP) studies of epibenthic zooplankton in the lower Columbia River estuary and concluded that circulation patterns, salinity intrusion, and the location of the turbidity maximum were important factors in structuring these communities.

The importance of the dynamic nature of sediment resuspension, scouring, transport, and deposition have also been noted as important factors that control the structure of benthic communities in the estuarine portion of the river (e.g., Higley et al. 1983; Simenstad 1984; Amspoker and McIntire 1986; Hinton et al. 1990). Simenstad et al. (1990) estimated that 9.7 million metric tons of sediment are delivered to the estuary each year, much of which (primarily the coarser fraction) may be retained in the estuary (Sherwood et al. 1984). High peak flows [spring freshets of about 12,000 m^3/s (424,000 cfs)], which although lower than those prior to the construction of dams, allow for the transport of both fine sands and silts in the water column and coarse sands as bedload (Simenstad et al. 1990). Very high winter peak flows (which are not attenuated by dams along the mainstem of the river) also occur below the confluence of the Willamette River during the fall and winter months, due to heavy rainfall runoff from the Cowlitz and Willamette river drainage basins during these seasons.

The most comprehensive study of the estuary's benthic infauna was summarized by Holton et al. (1984) who assessed the relationship of benthic community structure (using a stratified-random sampling design) in relation to the *a priori* designation of various habitat types (e.g., main channel center, main channel side, minor channel, protected flat, unprotected flat, and marsh channel) and the degree to which benthic community structure corresponds to measured habitat properties such as percent fine-grained sediments and percent sediment TOC. Based on discriminant analysis, benthic community structure was most diverse and most closely fit the original definition of habitats on the basis of physical characteristics (93 percent of the samples were correctly classified) (Holton et al. 1984). The samples collected in the transition zone fit 74 percent of the original habitat classifications and 63 percent of the samples were correctly classified in the freshwater zone. Relationships between sediment grain size and sediment TOC were also apparent, but these relationships were complex due to the occurrence of fine sediments with a relatively high organic content in the deep channel bottoms of the transition and freshwater portions of the estuary, as well as in shallow protected mudflat areas (Holton et al. 1984). Simenstad et al. (1984) also noted that sediment depositional areas in the estuary occur in deep channel areas of the upper portion of the estuary in association with the turbidity maximum and in quiescent bays and backwaters. This complexity in the estuary may explain the lack of a significant relationship between sediment fines and community variables noted in the more limited benthic invertebrate sampling performed in the estuary as part of the reconnaissance survey.

Although the benthic communities of the estuary have been relatively well studied (primarily due to the CREDDP studies and studies related to dredging and disposal activities), studies of the benthic communities of the freshwater portion of the lower river have been limited in both extent and scope (Tetra Tech 1992a). Although some studies have included measurements of sediment characteristics (i.e., grain size, percent volatile solids, and/or sediment TOC), no attempt has been made to relate sediment grain size to benthic community characteristics such as abundance or richness (Tetra Tech 1992a). However, the results of the reconnaissance survey indicate that in the freshwater portion of the river, the portion of fine sediments is an important control of the abundance and richness of the benthic infauna.

The unique character of the marine water-influenced benthic community confined to the area of the mouth of the river, and the general dominance of *Corbicula fluminea* and *Corophium salmonis*, have also been observed in both historical marine (e.g., Higley et al. 1983; Simenstad 1984; Holton et al. 1984; Hinton et al. 1990) and freshwater studies (e.g., McCabe and Hinton 1990a,b; McCabe et al. 1990). Few historical studies have identified all of the taxa in the samples collected to species, especially the larval insect fauna (see Tetra Tech 1992a for a review of these studies). However, one study conducted in the freshwater portion of the lower Columbia River along Cottonwood Island identified a maximum of 19 taxa in a single 0.1 m^2 van Veen grab sample (McCabe et al. 1990). A maximum of only nine benthic invertebrate taxa were identified at five stations sampled along the Cathlamet Ferry route between Puget Island and Westport Slough (McCabe and Hinton 1990a). This is consistent with the maximum of 25 taxa identified in a single sample collected for the reconnaissance survey. The density of organisms reported in this study is also consistent with the densities of benthic invertebrates reported in studies of the estuary and in the freshwater reaches of the river (see Tetra Tech 1992a for a review of these studies).

No historical studies have attempted to relate benthic community characteristics to pollutant levels measured in the river's sediments. That the reconnaissance survey results did not indicate a relationship between contaminant levels and community variables such as richness and abundance may be due to the limited number of sampling locations that were distributed throughout several habitat types in the study area. For example, analyses of sediment samples collected from station D35 in Camas Slough indicated that several metals and organic compound concentrations exceeded effects-based reference levels adopted for this study, indicating potential effects on aquatic biota. However, abundance at this station was relatively high, consisting primarily of oligochaetes, and a relatively high number of taxa (24) were identified. However, other habitat variables such as the volume of debris in the sample (station D35 was the location of a log-storage area) could confound the relationship of contaminant levels with community variables.

5.6.2 Significance and Recommendations

Dominant taxa (i.e., oligochaetes, nematodes, *Corbicula fluminea* and *Corophium salmonis*) that occur in the river habitats are characterized by highly adaptive lifestyles. These taxa typically feed on organic material in the sediments. However, Columbia River sediments tend to be very low in TOC content in the areas sampled during the reconnaissance survey. It is highly likely that these organisms have adapted to feeding on an organic flocculent layer that is constantly moving along the bottom of the river (i.e., they are feeding on organic material not incorporated into the sediments). Oligochaetes are a diverse group and can be found in sediments ranging from sands to muds (Thorp and Covich 1991). Nematodes are also an ecologically diverse group, and have adapted to a wide variety of habitats in estuarine and freshwater environments. These taxa often represent significant portions of freshwater benthic communities and provide food for many other taxa (e.g., crayfish prey on many types of nematodes). The amphipod *Corophium salmonis* and the bivalve *Corbicula fluminea* also have highly adaptive strategies for living in more dynamic environments. While these two species are sensitive to physical and chemical stresses, they are able to rapidly recolonize through various reproductive and dispersion strategies. These taxa may represent important food sources for other invertebrates, fish, and wildlife. Chironomids (freshwater midges) were found throughout the freshwater portions of the river and were among the dominant taxa at many stations. Chironomids are generally tolerant of a wide range of environmental quality, and members of this group have adapted to living in very different habitats.

Following the original approach developed by Tetra Tech (1992a), 25 stations in both the estuary and freshwater portions of the river were identified as depauperate or lacking diversity on the basis of lower benthic community abundances and richness compared to reference conditions. This approach was based on the assumption that contaminant concentrations and benthic community structure would be highly correlated. However, no significant correlations were found between metals concentrations and taxa richness, total abundance and selected taxa abundance. At those stations identified as potential areas of concern on the basis of anthropogenically enriched chemical concentrations or concentrations above sediment quality guidelines, total taxa abundances and richness were usually greater than values used to identify depauperate benthic communities. Benthic community structure is more likely a function of physical habitat characteristics and the changes in habitat on both a temporal and spatial scale. Grain size distributions, salinity, and flow velocity change according to the tidal cycles, the amount of water released at Bonneville Dam and from the Willamette and Cowlitz rivers, due to seasonal rainfall or snowmelt. All these factors affect the rates and direction of flow in the river, and the amount of sediment being actively transported or deposited. These factors, in turn, control habitat characteristics and stability. The lack of persistence and stability in benthic habitats in the majority of the study area—rather than any contaminant effect—may have contributed to the low abundance and richness reported for many stations in the river.

The lack of correlation between community structure and metals concentrations may affect the use of benthic community indicators in evaluating the health of the river. Although benthic communities can be used to evaluate localized conditions in the river, physical factors tend to drive community responses and obscure any potential chemical effects. Use of benthic communities as biological indicators for long-term monitoring in the lower Columbia River is examined in more detail in the final reports for Task 4, *Review of Biological Indicators to Support Monitoring Recommendations on a Biological Monitoring Approach* and *Recommended Biological Indicators for the lower Columbia River* (Tetra Tech 1992d,e).

5.7 SUMMARY

Benthic community data collected for this study indicate that the lower Columbia River benthic communities largely reflect the dynamic nature of the river environment. Habitat characteristics (i.e., salinity, grain size, and habitat stability) appear to greatly influence the specific characteristics of the benthic communities at each area sampled. Two major ecological zones are evident from the benthic data: an estuary zone and a freshwater zone. The estuary zone appears to be further subdivided into a marine-related species assemblage and an euryhaline (transitional) assemblage. Sediment grain size distribution did not appear to greatly influence community abundance in this zone, but too few data were collected representing coarse-grained habitats to fully test this effect.

In contrast to the estuary zone, the communities in the freshwater zone tended to be influenced by sediment grain size and habitat stability. Community indices such as taxa richness and abundance differed significantly between fine- and coarse-grained sediment stations in this zone. Only seven taxa were dominant along all stations within the freshwater zone. The dominant taxa are characterized by highly adaptive and opportunistic lifestyles.

Community indices (taxa richness and abundance) at stations in the estuary and freshwater zones were compared to derived, within-system reference conditions. Depressions in both taxa richness and abundance indicated that 19 stations had community indices that were substantially below reference conditions. Of these stations, three were located in the estuary, six in freshwater coarse-grained sediments, and 10 in freshwater fine-grained sediments. These depressions do not appear to be related to sediment contaminant (i.e., metals) concentrations because no significant correlations were found between metals concentrations and taxa richness, total abundance and indicator taxa abundance at these stations. Benthic community structure is more likely a function of physical habitat characteristics or habitat stability than it is a function of sediment contamination.

The lack of significant correlation between sediment metals contamination and community structure affects the use of the benthos as indicators for evaluating the health of the entire study area. Analyzing benthic community in soft-bottom sediments may be useful for evaluating very localized conditions, but its use for long-term monitoring of river health is questionable based on the reconnaissance survey data. More extensive discussion of the usefulness of the benthic community as an indicator of river health is discussed in the final Task 4 reports, *Recommendations of Biological Indicators* and *Recommended Biological Indicators for the lower Columbia River* (Tetra Tech 1992d,e).

6.0 OVERVIEW AND CONCLUSIONS

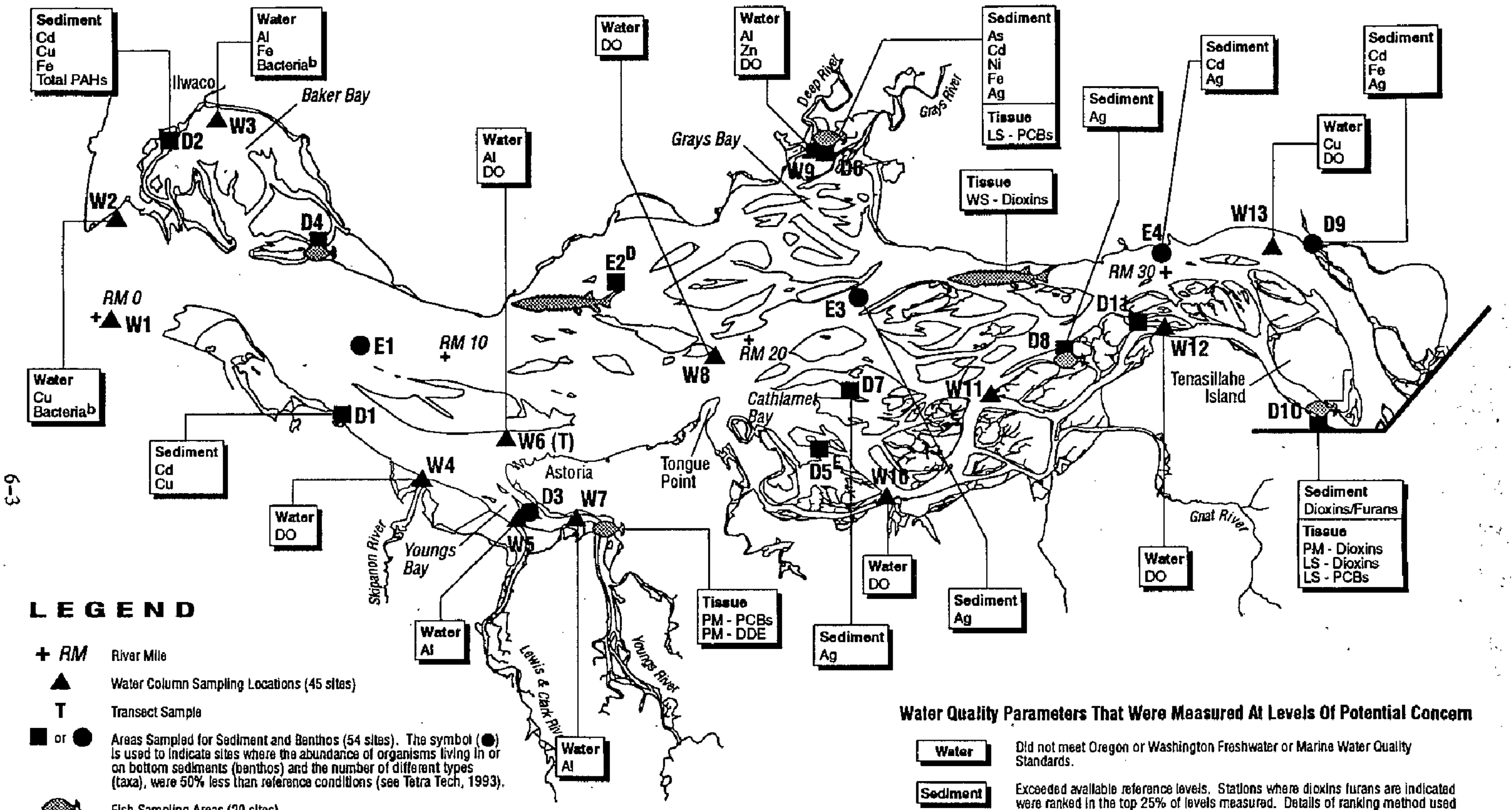
The reconnaissance survey of the lower Columbia river was designed to provide a preliminary assessment of water quality in the 146 mile stretch of river between Bonneville Dam and the Pacific Ocean. Water, sediment, and tissue samples were collected throughout the lower river and analyzed for an extensive list of chemicals. Benthic organisms were also enumerated at all sediment collection sites to permit examination of the relationships among benthic community indices, sediment contaminant levels, and habitat characteristics. This survey represents the most extensive sampling effort conducted on the lower Columbia river. Nevertheless, it is important to remember that it was designed to be a reconnaissance effort. The survey represents a snapshot of environmental conditions in the lower river during low flow conditions. Analyses were conducted on single samples to maximize the number of locations that could be evaluated with available resources. This approach is appropriate for a reconnaissance, but does not allow for rigorous statistical comparisons to be made among the results obtained.

In general, reconnaissance surveys are conducted to make a preliminary assessment of environmental conditions of a study area to identify current environmental conditions and contaminant levels, identify potential contaminants of concern and identify smaller areas for more specific studies. When coupled with knowledge of historical studies and information on potential pollutant sources, the results of a reconnaissance survey may provide a preliminary assessment of potential environmental problems or reveal additional data gaps that could be filled through more focused studies. Therefore, the reconnaissance survey is typically of broad scope and attempts to sample a large number of contaminants, potential problem areas, and environmental media (i.e., water, sediments, and organisms such as fish or crayfish) with the financial and technical resources available. A reconnaissance survey may then be followed by contaminant, site, and/or media specific studies that would allow refinement in the knowledge of problems identified based on the reconnaissance survey results. Therefore, reconnaissance survey results do not allow for the complete identification of contaminants of concern, problem areas, or a complete assessment of the environmental health of the study area. These concerns are more appropriately addressed through inter-state and inter-agency coordination of specific environmental investigations and routine monitoring programs.

One of the main objectives of the reconnaissance survey was to identify potential water quality problems in the lower Columbia River. Figures 6-1 through 6-4 show the sampling stations at which one or more of the measured parameters were either 1) high relative to other stations in the river (e.g., sediment dioxins and furans, tissue contaminants); 2) exceeded the federal or state water quality standards or effects-based reference values adopted for this study for some metals and organic contaminants in the water column and sediments; or 3) indicative environmentally stressed conditions (i.e., reduced abundance or richness of benthic aquatic organisms).

The potential problem areas identified based on the results of the reconnaissance survey (this report) and review of historical data (Tetra Tech 1992a) are ranked or prioritized for each medium in the final Task 7 report: *Reconnaissance Survey of the lower Columbia River. Task 7: Conclusions and Recommendations* (Tetra Tech 1993b). The Task 7 report also identifies the problem chemicals and parameters for each environmental medium sampled and provides an overview of the major findings of each task (Tasks 1 through 6) performed as part of the design and implementation of the reconnaissance survey and includes summary information on historical data (Tetra Tech 1992a), identification and characterization of pollutant sources (Tetra Tech 1992c), review of physical characteristics of the river (Tetra Tech 1992b), review and recommendation of biological indicators (Tetra Tech 1992d,e), identification and location of beneficial uses (Tetra Tech 1992f), and this report.

It should be noted that with the exception of dioxin and furan levels, sediment and water column contaminants without established reference criteria and contaminants for which laboratory detection limits exceeded the reference values used in this study are not shown, despite their possible occurrence at levels that could potentially affect aquatic organisms. However, without reference values it is not possible to determine the potential environmental significance of the measured levels of these contaminants at this time. These contaminants (both metals and organic compounds) include barium and mercury for chronic freshwater quality criteria, mercury and nickel for marine criteria for the protection of aquatic organisms, arsenic and mercury for the protection of humans due to the consumption of contaminated fish, and all of the water quality criteria for pesticides and polychlorinated biphenyls (PCBs). In addition, 1) no reference values were available for sediment concentrations of aluminum, barium, beryllium, selenium, and thallium, 2) the detection limits for sediment antimony concentrations were greater than the available reference level, 3) reference values were not available for a number of the pesticides, and none of the



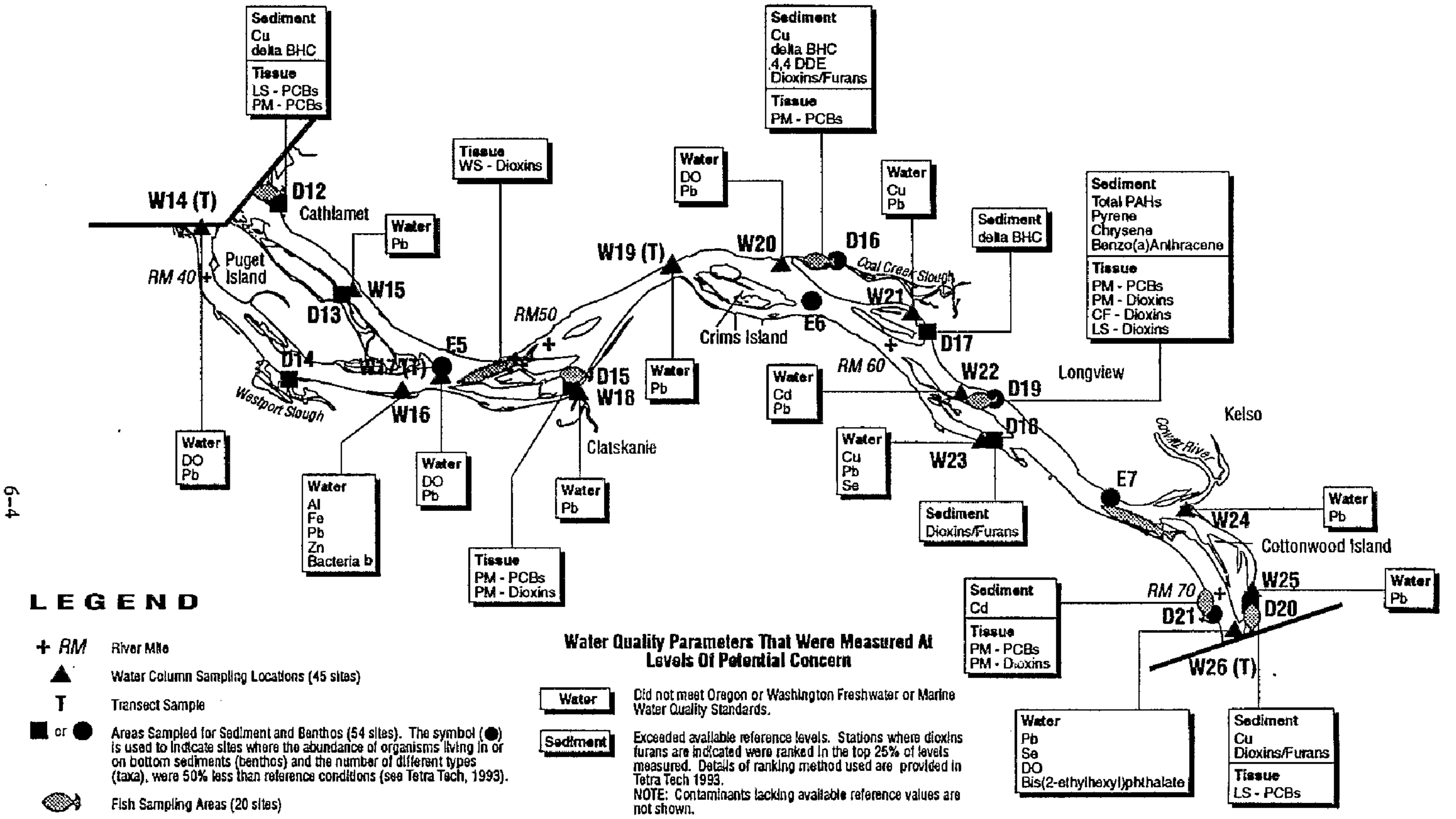
L E G E N D

+ *RM*	River Mile
▲	Water Column Sampling Locations (45 sites)
T	Transect Sample
■ or ●	Areas Sampled for Sediment and Benthos (54 sites). The symbol (●) is used to indicate sites where the abundance of organisms living in or on bottom sediments (benthos) and the number of different types (taxa), were 50% less than reference conditions (see Tetra Tech, 1993).
🐟	Fish Sampling Areas (20 sites)
🐟	Approximate White Sturgeon Sampling Locations (8 sites)
b	Bacteria Sampling Locations Exceeding Federal *Enterococcus* Criteria
D	Used to indicate fine-grained sediment stations where greater than 20 percent of the sediment had an effective grain size diameter less than 100 microns. Stations with a "D" superscript were reclassified as fine-grained based on the survey results.
E	Used to indicate coarse-grained sediment stations where less than 20 percent of the sediment had an effective diameter less than 100 microns. Stations with an "E" superscript were reclassified as coarse-grained based on the survey results.
W	Used to indicate water stations.

Water Quality Parameters That Were Measured At Levels Of Potential Concern

Water	Did not meet Oregon or Washington Freshwater or Marine Water Quality Standards.
Sediment	Exceeded available reference levels. Stations where dioxins furans are indicated were ranked in the top 25% of levels measured. Details of ranking method used are provided in Tetra Tech 1993. NOTE: Contaminants lacking available reference values are not shown.
Tissue	Indicates tissue sampling station where tissue contaminant concentrations exceeded New York State guidelines for the protection of fish eating wildlife. Fish species are identified by: LS=largescale sucker, CP=carp, PM=peamouth, WS=white sturgeon, CF=crayfish. NOTE: contaminants lacking reference values not shown.

Figure 6-1. Sampling Locations Where Water Quality Parameters Were Measured at Levels of Potential Concern, River Segment 1.



LEGEND

+ *RM*	River Mile
▲	Water Column Sampling Locations (45 sites)
T	Transect Sample
■ or ●	Areas Sampled for Sediment and Benthos (54 sites). The symbol (●) is used to indicate sites where the abundance of organisms living in or on bottom sediments (benthos) and the number of different types (taxa), were 50% less than reference conditions (see Tetra Tech, 1993).
	Fish Sampling Areas (20 sites)
	Approximate White Sturgeon Sampling Locations (8 sites)
b	Bacteria Sampling Locations Exceeding Federal *Enterococcus* Criteria
D	Used to indicate fine-grained sediment stations where greater than 20 percent of the sediment had an effective grain size diameter less than 100 microns. Stations with a "D" superscript were reclassified as fine-grained based on the survey results.
E	Used to indicate coarse-grained sediment stations where less than 20 percent of the sediment had an effective diameter less than 100 microns. Stations with an "E" superscript were reclassified as coarse-grained based on the survey results
W	Used to indicate water stations

Water Quality Parameters That Were Measured At Levels Of Potential Concern

Water	Did not meet Oregon or Washington Freshwater or Marine Water Quality Standards.
Sediment	Exceeded available reference levels. Stations where dioxins furans are indicated were ranked in the top 25% of levels measured. Details of ranking method used are provided in Tetra Tech 1993. NOTE: Contaminants lacking available reference values are not shown.
Tissue	Indicates tissue sampling station where tissue contaminant concentrations exceeded New York State guidelines for the protection of fish eating wildlife. Fish species are identified by: LS=largescale sucker, CP=carp, PM=peamouth, WS=white sturgeon, CF=crayfish. NOTE: contaminants lacking reference values not shown.

Figure 6-2. Sampling Locations Where Water Quality Parameters Were Measured at Levels of Potential Concern, River Segment 2.

LEGEND

+ *RM*	River Mile
▲	Water Column Sampling Locations (45 sites)
T	Transect Sample
■ or ●	Areas Sampled for Sediment and Benthos (54 sites). The symbol (●) is used to indicate sites where the abundance of organisms living in or on bottom sediments (benthos) and the number of different types (taxa), were 50% less than reference conditions (see Tetra Tech, 1993).
🐟	Fish Sampling Areas (20 sites)
🐟	Approximate White Sturgeon Sampling Locations (8 sites)
b	Bacteria Sampling Locations Exceeding Federal *Enterococcus* Criteria
D	Used to indicate fine-grained sediment stations where greater than 20 percent of the sediment had an effective grain size diameter less than 100 microns. Stations with a "D" superscript were reclassified as fine-grained based on the survey results.
E	Used to indicate coarse-grained sediment stations where less than 20 percent of the sediment had an effective diameter less than 100 microns. Stations with an "E" superscript were reclassified as coarse-grained based on the survey results.
W	Used to indicate water stations.

Water Quality Parameters That Were Measured At Levels Of Potential Concern

Water	Did not meet Oregon or Washington Freshwater or Marine Water Quality Standards.
Sediment	Exceeded available reference levels. Stations where dioxins furans are indicated were ranked in the top 25% of levels measured. Details of ranking method used are provided in Tetra Tech 1993. NOTE: Contaminants lacking available reference values are not shown.
Tissue	Indicates tissue sampling station where tissue contaminant concentrations exceeded New York State guidelines for the protection of fish eating wildlife. Fish species are identified by: LS=largescale sucker, CP=carp, PM=peamouth, WS=white sturgeon, CF=crayfish. NOTE: contaminants lacking reference values not shown.

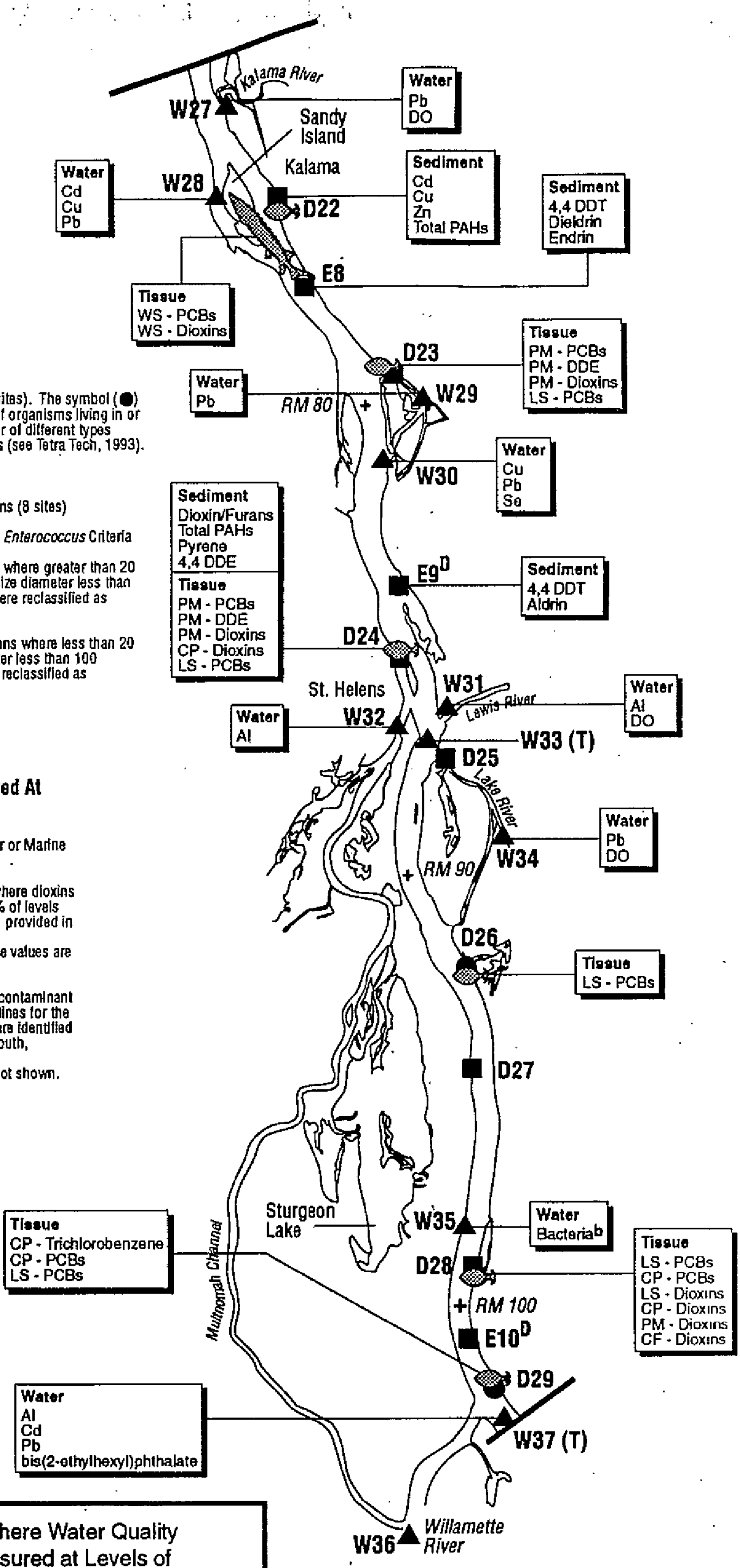
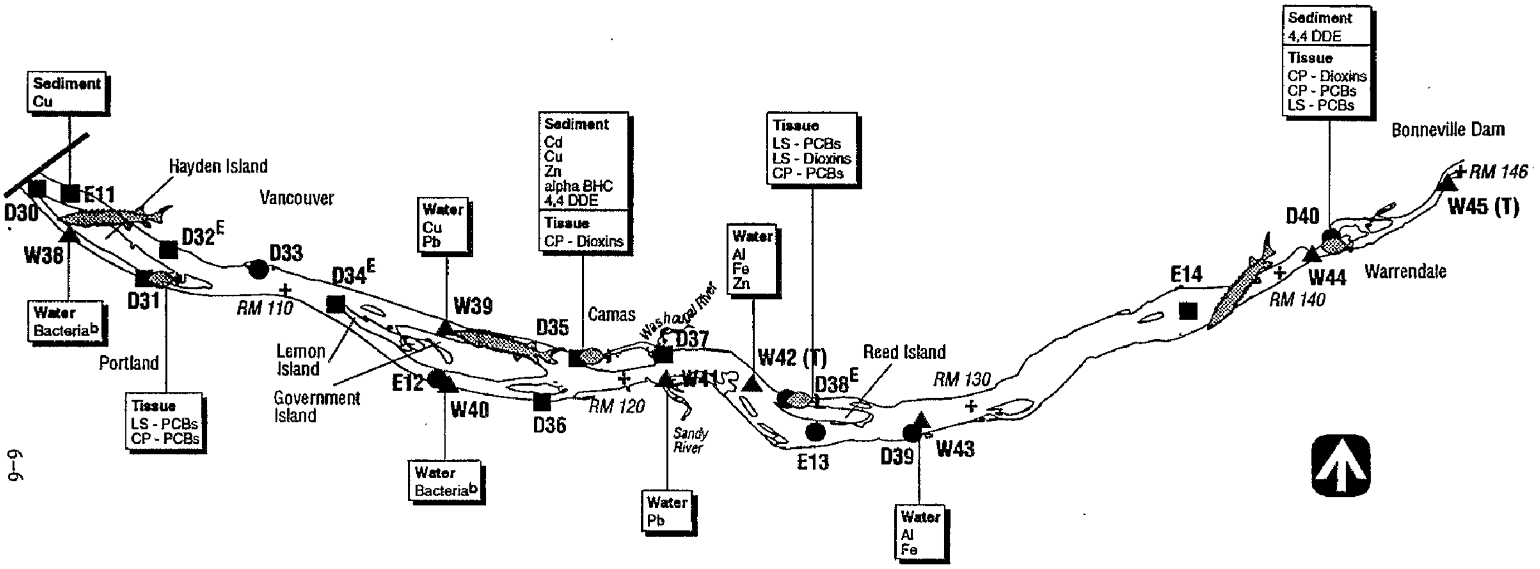


Figure 6-3. Sampling Locations Where Water Quality Parameters Were Measured at Levels of Potential Concern, River Segment 3.



LEGEND

+ *RM*	River Mile
▲	Water Column Sampling Locations (45 sites)
T	Transect Sample
■ or ●	Areas Sampled for Sediment and Benthos (54 sites). The symbol (●) is used to indicate sites where the abundance of organisms living in or on bottom sediments (benthos) and the number of different types (taxa), were 50% less than reference conditions (see Tetra Tech, 1993).
🐟	Fish Sampling Areas (20 sites)
🐟	Approximate White Sturgeon Sampling Locations (8 sites)
b	Bacteria Sampling Locations Exceeding Federal *Enterococcus* Criteria
D	Used to indicate fine-grained sediment stations where greater than 20 percent of the sediment had an effective grain size diameter less than 100 microns. Stations with a "D" superscript were reclassified as fine-grained based on the survey results.
E	Used to indicate coarse-grained sediment stations where less than 20 percent of the sediment had an effective diameter less than 100 microns. Stations with an "E" superscript were reclassified as coarse-grained based on the survey results.
W	Used to indicate water stations.

Water Quality Parameters That Were Measured At Levels Of Potential Concern

Water	Did not meet Oregon or Washington Freshwater or Marine Water Quality Standards.
Sediment	Exceeded available reference levels. Stations where dioxins furans are indicated were ranked in the top 25% of levels measured. Details of ranking method used are provided in Tetra Tech 1993. NOTE: Contaminants lacking available reference values are not shown.
Tissue	Indicates tissue sampling station where tissue contaminant concentrations exceeded New York State guidelines for the protection of fish eating wildlife. Fish species are identified by: LS=largescale sucker, CP=carp, PM=peamouth, WS=white sturgeon, CF=crayfish. NOTE: contaminants lacking reference values not shown.

Figure 6-4. Sampling Locations Where Water Quality Parameters Were Measured at Levels of Potential Concern, River Segment 4.

dioxin, furan, or organotin compounds detected in sediments, and 4) detection limits for the pesticides dieldrin and endrin exceeded the lowest available reference value.

The reconnaissance survey results are briefly summarized by medium below.

6.1 WATER COLUMN

The water column data collected for the reconnaissance survey characterized conventional water quality (especially temperature and dissolved oxygen), phytoplankton levels, bacterial indicators of pathogens, and levels of metals and organic contaminants in the lower Columbia River. Levels of halogenated organic compounds (primarily chlorinated and brominated organic compounds, also known as AOX) were also studied to evaluate the influence of the effluent discharge of halogenated organic compounds from bleached kraft pulp and paper mills to the river.

A total of 45 water column stations were sampled for conventional constituents such as salinity, conductivity, temperature, dissolved oxygen; 4 nutrients; 16 metals; and cyanide. Halogenated organic compounds (AOX) were sampled at 19 stations and phytoplankton (water column algae) were analyzed at 22 stations. A total of 83 semi-volatile or volatile organic compounds, 29 pesticide compounds, 7 polychlorinated biphenyl compounds (PCBs), and total organic carbon were measured at 5 stations. Indicator bacteria were also measured at 6 shore-based stations on 5 separate days over a 30-day period.

In general, the water column study of the lower Columbia River indicated a number of potential water quality problems. Levels of indicator enterococcus bacteria exceeded federal criteria at all the stations surveyed for bacteria, low levels of dissolved oxygen were noted at several stations (Figure 6-1 and 6-3), and there were indications that the water temperature criterion of 20° C is exceeded regularly in the study area below Bonneville Dam.

Dissolved oxygen (DO) concentrations and/or DO percent saturation were below state standards for fresh water at eleven freshwater stations and at three estuarine stations. However, many of these exceedances were due to DO percent saturation falling not more than a few percent below the 90 percent standard. Significant DO standards exceedances occurred in the estuary in the Skipanon River, in Lake River, and at the mid-channel Columbia River station below Skamokawa Creek at river mile 33. Water temperature conditions during the survey were below the Washington established criterion (20° C). At several stations below Bonneville Dam, temperatures were above 19° C. These temperatures indicate near exceedances. However, historical data indicate that the 20° C standard is frequently exceeded, especially during the period of July, August, and September. Elevated temperatures (above the established criterion of 20° C) have implications primarily for the river's anadromous fish species as well as for other resident biota. Historically (since 1938), the temperature of the lower Columbia River appears to have exceeded 20° C in August. The construction of various impoundments on the river, has served to stabilize water temperature in spring and summer and increase water temperature in fall and winter.

The phytoplankton data and historical (1990) nutrient data (the nutrient data collected for the reconnaissance study were considered to be unusable) indicate that although nutrients are available for phytoplankton growth during the low-flow period, phytoplankton abundance and biomass were relatively low. Nuisance levels of phytoplankton, especially blue-green algae (cyanobacteria), were not observed during the survey.

Indicator bacteria concentrations (fecal coliform and enterococcus bacteria) were measured to assess the sanitary quality of river water at a few swimming and potential shellfish harvesting areas. Fecal coliform counts at three of the six stations sampled (Ilwaco, Sauvie Island, and North Portland Harbor) exceeded state standards. The fecal coliform geometric mean concentration at station W3 in Ilwaco exceeded the state standard for marine and shellfish harvesting waters. Enterococcus counts were generally higher than those for fecal coliforms, and exceeded federal standards at all stations sampled.

Metals were detected in a number of the samples collected during the survey. However, these data have been qualified as estimates due the lack of quality assurance data provided by the contract laboratory. Cyanide was not detected. Based on comparison with available state and federal chronic marine and freshwater criteria, many of the concentrations of metals detected in the survey exceeded established criteria. Exceedances of the freshwater chronic criteria were noted for aluminum, cadmium, copper, iron, lead, and zinc (Figure 6-1 through 6-4). However, the laboratory detection limits for some metals were higher than the available criteria. The freshwater criteria for lead, mercury, selenium, and silver and the marine chronic criteria for lead, mercury, nickel, and selenium were lower than the detection limits achieved in this study. Due to possible laboratory contamination of the water aluminum samples, many of the reported concentrations that exceeded the freshwater quality criterion for aluminum were also qualified as undetected. The available freshwater chronic criteria were not exceeded in any sample from a freshwater station for the metals antimony, beryllium, chromium, nickel, or thallium.

The reconnaissance survey results, however, did not compare favorably with recent (1990) measurements reported by the Washington Department of Ecology (WDOE) of lower Columbia River water column concentrations of the metals cadmium, copper, lead, mercury, and zinc. The WDOE data indicate that the reconnaissance survey metals results, at least for these metals, may have been positively biased due to contamination in the field or laboratory. Therefore, conclusions regarding water quality problems based on the reconnaissance survey metals data should be made cautiously. It is recommended that future sample collection and analyses for water column metals use rigorously clean field sampling and laboratory analysis techniques to minimize the potential for significant metal sample contamination.

Although potential point sources were identified for the metals detected in the reconnaissance survey samples, nonpoint and in-place sources of these metals are also likely sources of these metals in the lower Columbia River. The data on the relative contribution of point, nonpoint, and in-place pollutant sources is extremely limited. Furthermore, the limited nature of a reconnaissance survey does not allow for the identification of specific pollution sources.

All of the organic chemicals of concern were undetected in the samples collected during the survey, except for the organic compound bis(2-ethylhexyl)phthalate (see Table 2-10). This compound was reported from two stations: the Portland/Vancouver area and below the confluence of the Kalama and Columbia rivers. Although this chemical is a common laboratory blank contaminant, neither field nor laboratory method blanks showed evidence of contamination from this compound. The reported concentrations of bis(2-ethylhexyl)phthalate at both stations exceeded the freshwater chronic criterion of 3 μg/L.

In several instances, the laboratory detection limits for the organic compounds not detected in the water column during this survey were greater than the established marine and freshwater chronic criteria. These compounds include pentachlorophenol, hexachlorocyclopentadiene, the pesticides DDT, heptachlor, alpha-chlordane, aldrin, dieldrin, mirex, parathion, toxaphene, endrin, methoxychlor, and PCBs. It is possible that many of these compounds were present in the water column, but at concentrations below the detection limits of the conventional laboratory methods used in this study. Although water column concentrations of dioxins and furans were not measured in this study (since the expected concentrations are below conventional laboratory detection limits), a modeling study of the Columbia River indicates that water column dioxin levels are likely above the regulatory limits for this compound for the protection of human health due to inputs of this chemical from chlorine bleach pulp and paper mills that discharge to the river.

Halogenated organic compound concentrations in the upper reach of the study area below Bonneville Dam, but above the influence of the bleached kraft pulp and paper mills ranged from 10 to 15 μg Cl^-/L. These concentrations increased to 40 to 60 μg Cl^-/L in samples collected below the bleached kraft pulp and paper mill outfalls near Longview. In the estuary, concentrations of 250 to 255 μg Cl^-/L were reported, although such levels are likely due to analytical interferences in the laboratory method used. The elevated concentrations of halogenated organic compounds below the bleached kraft pulp and paper mills in Longview suggests these potentially toxic compounds are transported in the water column into downstream wildlife refuge areas (see Figure 2-19) where their potential fate or effect are presently not known. The widespread distribution of pulp and paper mill effluents indicated by the survey results may also warrant some concern because of the known bioaccumulation and toxicity of halogenated organic compounds (Kallquist et al. 1989).

6.2 SEDIMENT CHEMISTRY

A total of 54 sediment stations were sampled for 16 metals, cyanide, acid volatile sulfides, 55 semivolatile organic compounds, 29 pesticide compounds, and 7 polychlorinated biphenyl compounds (PCBs). Of the 54 stations, 20 stations were sampled for 17 dioxin and furan compounds, 10 stations were sampled for 3 organotin compounds, and 6 stations were sampled for 7 radionuclides. Following sampling, sediment grain size data was used to classify the sediments as fine- or coarse-grained. Based on sediment grain size data, a total of 41 stations were classified as fine-grained and 13 stations were classified as coarse-grained.

Sediment contaminants (both metals and organic compounds) were frequently detected in the sediments collected. Sediments represent a major repository for contaminants entering aquatic environments, resulting in the potential for adverse impacts to ecosystem health (Giesy and Hoke 1990, Landrum and Robbins 1990). Based on survey results, sediment organic contaminants that exceeded reference values occurred over a large stretch of the lower river, primarily in finer-grained sediments (Figures 6-1 through 6-4). This section of the lower river supports significant population centers, a concentrated industrial base, and is the point of entry for several major tributaries, including the Willamette, Cowlitz and Lewis rivers. Some of the tributary basins support extensive agricultural and industrial activity. It is likely, therefore, that significant contaminant loading from these tributaries into the lower Columbia River is occurring (Tetra Tech 1992c). The relative contribution of these tributaries needs to be assessed on the basis of more extensive sampling in tributary mouths throughout the year. Point and nonpoint sources of municipal and industrial pollutants along the river are also likely sources of many of these contaminants as well.

As in the case of water column contaminants, several metals were detected in sediments at levels exceeding reference values (arsenic, cadmium, copper, iron, silver, nickel, and zinc) (Figures 6-1 through 6-4). Because many of these metals also occur naturally as constituents of rocks and sediments, identifying sources of these metals in the sediments based on survey data is difficult. It is noteworthy, however, that some of the metals (e.g., cadmium, copper, iron, and zinc) occurring at concentrations exceeding criteria in the water column were also detected at concentrations exceeding effects-based reference levels in sediments from some stations. Identifying relationships between water column and sediment metals levels at individual stations is not possible because water and sediment samples were collected at different places in the study area and the single water column samples collected during the low-flow period when suspended sediment levels in the river are at their lowest are not representative of the sediments deposited at the sediment sampling stations.

Dioxin and furan compounds were detected at each of the 20 stations analyzed for these compounds. The highest sediment dioxin and furan levels measured in the survey were from areas downstream of Longview, Wauna, St. Helens, and Kalama. Potential sources for the dioxins and furans in these areas include bleached kraft pulp and paper mill operations, municipal treatment plants, and tributary rivers and streams. The detection of dioxins and furans at all 20 stations analyzed for these chemicals may be indicative of a distribution more widespread than determined in this survey.

As in the case of dioxins and furans, the high frequency of detection of organotin compounds in sediments (all 10 stations contained detectable quantities) also suggests potentially widespread contamination in the lower river. The extensive vessel traffic and large numbers of marinas and dry docking facilities along the river are likely contributors of organotins to the sediments.

Metals were detected at concentrations exceeding the effects-based sediment reference levels adopted for this study at a number of stations (see Table 3-3). Polycyclic aromatic hydrocarbons (PAHs), PCBs, and most pesticides were detected relatively infrequently, but the detected concentrations generally exceeded their effects-based reference values (see Table 3-5). Dioxins and furans, and organotin compounds were detected frequently at the more limited number of stations sampled for these compounds. However, assessment of the biological significance of the detected levels of dioxins, furans, and organotin compounds is difficult because of the lack of effects-based reference values for these contaminants.

The reconnaissance survey determined the concentration of contaminants in coarse and fine sand, silty sediments typical of the mainstem of the lower Columbia River, and in a number of backwater areas. However, areas of finer sediments (i.e. silts and clays) with potentially higher levels of contaminants likely exist in shallow isolated backwater areas of the river, including sloughs, marsh channels, mudflats, and the channel bottom in the region of the turbidity maximum in the estuary. These areas may be significant locations for the uptake of sediment associated contaminants by aquatic organisms and wildlife that live along the river. These fine sediments also have the potential to harbor the highest levels of contaminants in the river. However, due to the nature of the sampling vessel and the low water levels encountered during the reconnaissance survey, many of these areas were not accessible, but should be considered a high priority for future sampling efforts.

6.3 TISSUE BIOACCUMULATION

This section reports on the results of fish and crayfish tissue analysis of 11 trace metals and 108 organic compounds in 5 different aquatic species. Crayfish, carp, peamouth, largescale sucker and white sturgeon were collected during the reconnaissance survey for analysis of tissue chemical burdens. Crayfish were collected at 18 locations, carp and peamouth at 12 locations, and largescale sucker at 18 locations along the lower Columbia River. Commercially caught white sturgeon from each of the four major river segments were obtained from fish buyers located along the lower Columbia River. Crayfish, carp, largescale sucker, and peamouth were collected near sediment chemistry sampling locations in order to evaluate possible relationships between sediment and tissue contaminant concentrations.

The accumulation of contaminants in selected lower Columbia River biota was evaluated as part of an integrated approach to the reconnaissance survey. Bioaccumulation is often a valuable component of aquatic ecosystem monitoring programs. The reason for including bioaccumulation studies is that biota can serve as integrators of chemicals that may be widespread in the environment, but are present in less than detectable amounts. In addition, bioaccumulation studies make it possible to estimate of contaminant loads in biota (body burdens). These estimates are an important step in evaluating potential adverse effects on the organisms themselves, and to any animals that prey on these organisms, including humans.

These tissue results indicate the widespread occurrence of several metals, pesticides, PCBs, and dioxin and furan compounds in fish that inhabit the lower Columbia River. At 21 stations, contaminant concentrations exceeded at least one of the New York State guidelines (usually for PCBs or dioxins) for the protection of fish-eating wildlife (Newell et al. 1987)(Figures 6-1 to 6-4). These results suggest potential adverse effects to wildlife. The reconnaissance survey results were generally similar to historical measurements of tissue concentrations of metals and organic compounds measured in national surveys conducted by the U.S. Fish and Wildlife Service and the U.S. Environmental Protection Agency (U.S. FWS 1991, U.S. EPA 1991a). It was difficult to assess the potential effect of the measured tissue concentrations of many of the metals and organic compounds due to the lack of established effects-based regulatory levels for these substances in fish tissues.

The maximum levels of mercury in samples of white sturgeon and peamouth (0.35 and 0.23 mg/kg wet weight, respectively) were close to the Food and Drug Administration (FDA) action level for mercury in fish of 1 mg/kg. The designation of the Columbia River as water quality limited, due to an assessment by the U.S. Environmental Protection Agency of the human health risk due to the levels of dioxin in water and fish tissues, also indicates concern for the human health effects of the consumption of fish from the lower Columbia River. However, a more definitive assessment of the significance of the tissue contaminant levels observed in lower Columbia River biota will require, in part, development of more effects-based reference criteria for the chemicals detected in the survey.

Although potential point sources were identified for the metals and organic compounds detected in the reconnaissance survey tissue samples, nonpoint and in-place sources of these metals are also likely sources of these constituents in the lower Columbia River. As noted above, the data on the relative contribution of point, nonpoint, and in-place pollutant sources is extremely limited. Furthermore, the limited nature of a reconnaissance survey does not allow for the definitive identification of specific pollution sources.

6.4 BENTHIC COMMUNITY

One commonly used approach in studies of aquatic pollution is assessment of the *in situ* benthic community to determine if community structure has been affected by exposure to sediment contaminants. Benthic analysis of sediment samples collected at 54 stations in the lower Columbia River suggests that the primary influences structuring benthic communities are the physical factors of salinity, sediment grain-size, and percent total organic carbon.

Of the 54 stations sampled, 38 stations had depressed organism abundance or diversity in comparison to reference stations within the study area. Of these stations, 19 were rated as depauperate based on both low abundance and taxa richness (Figures 6-1 through 6-4). The lower diversity and/or abundance stations may indicate stressed communities. The occurrence, however, of both high abundance/diversity and depauperate communities in habitats with similar physical characteristics, coupled with the absence of correlation between community structure and sediment contaminant levels, suggests additional factors may be responsible for shaping benthic community structure. The nature of these factors is not clear from the reconnaissance survey data. However, the dynamic physical characteristics of this large river suggests that temporal and spatial instabilities in localized habitats should also be considered as potential factors influencing benthic community structure. Seasonal sampling and habitat sampling by stratified-random design is required to elucidate the physical, biological, and chemical factors influencing benthic community structure in the lower Columbia River.

Benthic community data collected for this study indicates that the lower Columbia River benthic communities largely reflect the dynamic nature of the river environment. Habitat characteristics (i.e., salinity, grain size, and habitat stability) appear to greatly influence the specific characteristics of the benthic communities at each area sampled. Two major ecological zones are evident from the benthic community data: an estuary zone where fresh and marine waters mix and a freshwater zone. The estuary zone appears to be further subdivided into a marine-related species assemblage and an euryhaline (transitional) assemblage. Sediment grain size or texture did not appear to explain differences in community abundance measured in this zone, but too few samples were collected to fully examine these possible relationships.

In contrast to the estuary zone, the communities in the freshwater zone tended to be influenced by sediment grain size and habitat stability. Community indices such as the number of taxa or types of organisms and the numbers of individuals differed significantly between fine- and coarse-grained sediment stations in the freshwater zone. Seven taxa were dominant at all stations within the freshwater zone. The dominant taxa are characterized by highly adaptive and opportunistic lifestyles.

Community indices (the numbers of taxa and the numbers of organisms) at stations in the estuary and freshwater zones were compared to derived, within-system reference conditions. Depressions in both taxa richness and abundance indicated that 19 stations had community indices that were substantially below reference conditions. Of these stations, three were located in the estuary, six in freshwater coarse-grained sediments, and 10 in freshwater fine-grained sediments. These depressions do not appear to be related to sediment metals concentrations because no significant correlations were found between sediment metals concentrations and the numbers of taxa, total abundance, or specific indicator taxa abundance at these stations. Although there was no apparent relationship between sediment contaminant levels and benthic organism abundance or taxa richness, the reconnaissance survey benthic sampling was relatively limited in scope and sampled across a number of habitat types which would tend to complicate relationships of contaminant concentrations to benthic community variables. More extensive sampling of benthos and contaminant levels within particular habitat types may reveal relationships between contaminants and benthic community variables.

Based on the limited reconnaissance survey of benthic communities, analysis of benthic community structure in the lower Columbia River does not appear to be of utility for assessing impacts of sediment contamination. However, certain benthic organisms, particularly the amphipod *Corophium salmonis* and the bivalve clam *Corbicula fluminea* as well as resident fish (e.g., peamouth, bass, and crappie) have been identified as useful organisms for use as biological indicator species in future studies of the lower

Columbia River (see Tetra Tech 1992d,e for additional information on recommended biological indicators).

6.5 CONCLUSIONS

The results of this survey indicate a number of potential water quality problems that warrant concern and possibly more specific investigations. Many of the organic chemicals tested for were either not detected or detected at low levels in water, sediment and tissue. However, measured levels of metals and bacteria in water samples frequently exceeded state and federal criteria. Although reconnaissance water temperature data did not exceed the 20° C Washington standard, historical data indicate chronic exceedance of the temperature standard in summer in the lower river. Levels of a number of metals and organic chemicals in sediments exceeded effects-based reference values and levels of several metals and organic chemicals in fish tissue exceeded either average levels from nationwide studies or levels observed to cause adverse biological effects. Of particular note is the widespread occurrence of dioxins and furans in both sediments and biota. The compounds have a number of both point and nonpoint sources which include effluents from bleach kraft pulp and paper mills, municipal wastewater treatment plants, and incomplete combustion of organic matter (e.g., forest fires, waste incineration, and burning of fossil fuels). These facts indicate a potential for adverse effects on aquatic biota, wildlife, beneficial uses, and human health that warrants concern and further study.

The fact that dioxin levels in the Columbia River are a water quality problem for aquatic organisms and humans has been recognized by the states of Washington and Oregon and the U.S. EPA. The U.S. EPA has established a limit of the total maximum daily load (TMDL) or discharge of dioxins to the Columbia River (U.S. EPA 1991c,d) and both state environmental agencies (Oregon Department of Environmental Quality and Washington Department of Ecology) have issued effluent discharge permits that establish limits for, and require monitoring of, effluent dioxin concentrations from bleached kraft pulp and paper mills along the river (Tetra Tech 1992c). Further investigations are being conducted by U.S. EPA Region X and the states of Oregon and Washington to provide additional information for the refinement of the TMDL and to monitor the effect of the regulatory actions that have been implemented.

In addition to dioxins and furans, the measured fish and crayfish tissue concentrations of the pesticide DDT and its metabolites, as well as PCBs, indicate potential adverse effects to fish-eating wildlife that reside in and along the river. These results indicate that further study on tissue contamination in the lower Columbia River is warranted.

7.0 REFERENCES

Amendola, G., D. Barna, R. Blossen, L. LaFluer, A. McBride, F. Thomas, T. Tiernan, and R. Whittemore. 1989. The occurrence and fate of PCDDs and PCDFs in five bleached kraft pulp and paper mills. Chemosphere 18:1181-1188.

American Association of Public Health (APHA). 1985. Standard methods for the examination of water and wastewater. 16th edition.

American Public Health Association (APHA). 1989. Standard methods for the examination of water and wastewater. 17th edition. Washingon, D.C.

Amspoker, M.C. and C.D. McIntire. 1986. Effects of sedimentary processes and salinity on the diatom flora of the Columbia River Estuary. Botanica Marina 29:391-399.

Ankley, G.T., V.R. Mattson, E.N. Leonard, C.W. West, and J.L. Bennett. 1993. Predicting the acute toxicity of copper in freshwater sediments: Evaluation of the role of acid-volatile sulfide. Environ. Toxicol. Chem. 12:315-320.

Bagley, S.T. and R.J. Seidler. 1977. Significance of fecal coliform-positive *Klebsiella*. Appl. Environ. Microbiol. 33:1141-1148.

Balls, P.W. and R.E. Laslett. 1991. A simple estuarine water sampler suitable for trace metals and other constituents. Estuarine, Coastal and Shelf Science 33:623-629.

Barnes, R.D. 1987. Invertebrate Zoology. Saunders College Publishing. Philadelphia, PA. 893 pp.

Barron, M.G. 1990. Bioconcentration. Env. Sci. Technol. 24:1612-1618.

Beasley, T.M., L.A. Ball, and B.A. Blakesley. 1981. Plutonium and americium export to the Northeast Pacific Ocean by Columbia River runoff. Estuarine, Coastal and Shelf Science 13:659-669.

Beasley, T.M. and C.D. Jennings. 1984. Inventories of ^{239,240}Pu, ^{241}Am, ^{137}Cs, and ^{60}Co in Columbia River sediments from Hanford to the Columbia River estuary. Env. Sci. Technol. 18:207-212.

Becker, C.D. and R.H. Gray. 1992. Past and present water-quality conditions in the Hanford Reach, Columbia River. Environmental Monitoring and Assessment 22:137-152.

Beeton, A.M. and W.T. Edmondson. 1972. The eutrophication problem. Journal Fisheries Research Board Canada 29:673-682.

Bero, A.S. and R.J. Gibbs. 1990. Mechanisms of pollutant transport in the Hudson estuary. The Science of the Total Environment 97/98:9-22.

Bloom, N.S. and E.A. Crecelius. 1983. Determination of mercury in seawater at sub-nanogram per liter levels. Marine Chemistry 14:49-59.

Bloom, N.S. and E.A. Crecelius. 1984. Determination of silver in sea water by coprecipitation with cobalt pyrrolidinedithiocarbamate and Zeeman graphite-furnace atomic absorption sectrometry. Analytical Chimica Acta 156:139-145.

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. EPA-600/3-77-033. U.S. Environmental Protection Agency Environmental Research Laboratory, Corvallis, Oregon. 114 pp.

Bolstridge, J.C. 1982. Green Lake: Physical, chemical and biological analysis in preparation for lake restoration. M.S. thesis. University of Washington, Seattle, WA. 92 pp.

Bortleson, G. 3 June 1992. Personal Communication (phone by Curtis DeGasperi). United States Geological Survey, Tacoma, WA.

Bosquet, T.M. 1992. Results of the NCASI round robin study. pp. E21-E46. In: Abstracts to presentations at the 1992 West Coast regional meeting of the National Council of the Paper Industry for Air and Stream Improvement, Inc. September 30 to October 1, 1992, Portland, Oregon.

Bryan, G.W., P.E. Gibbs, R.J. Huggett, L.A. Curtis, D.S. Bailey, and D.M. Dauer. 1989. Effects of tributyltin pollution on the mud snail, *Ilyanassa obsoleta*, from the York River and Sarah Creek, Chesapeake Bay. Mar. Pollut. Bull. 20:458-462.

Burton, G. Allen. 1991. Annual Review: Assessing the Toxicity of Freshwater Sediments. Environmental Toxicology and Chemistry. 10:1585-1627.

Butkus, S. 22 July 1992. Personal Communication (phone by Mr. Curtis DeGasperi, Tetra Tech, Redmond, Washington). Washington Department of Ecology, Olympia, WA.

Cabelli, V.J. 1983a. Public health and water quality significance of viral diseases transmitted by drinking water and recreational water. Wat. Sci. Tech. 15:1-15.

Cabelli, V.J. 1983b. Health effects criteria for marine recreational waters. EPA-600/1-80-031. Health Effects Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH. 98 pp.

Cabelli, V.J., A.P. Dufour, L.J. McCabe, and M.A. Levin. 1982. Swimming-associated gastroenteritis and water quality. American Journal of Epidemiology 115:606-616.

Cabelli, V.J., A.P. Dufour, L.J. McCabe, and M.A. Levin. 1983. A marine recreational water quality criterion consistent with indicator concepts and risk analysis. Journal of the Water Pollution Control Federation 55:1306-1314.

Bero, A.S. and R.J. Gibbs. 1990. Mechanisms of pollutant transport in the Hudson estuary. The Science of the Total Environment 97/98:9-22.

Bloom, N.S. and E.A. Crecelius. 1983. Determination of mercury in seawater at sub-nanogram per liter levels. Marine Chemistry 14:49-59.

Bloom, N.S. and E.A. Crecelius. 1984. Determination of silver in sea water by coprecipitation with cobalt pyrrolidinedithiocarbamate and Zeeman graphite-furnace atomic absorption sectrometry. Analytical Chimica Acta 156:139-145.

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. EPA-600/3-77-033. U.S. Environmental Protection Agency Environmental Research Laboratory, Corvallis, Oregon. 114 pp.

Bolstridge, J.C. 1982. Green Lake: Physical, chemical and biological analysis in preparation for lake restoration. M.S. thesis. University of Washington, Seattle, WA. 92 pp.

Bortleson, G. 3 June 1992. Personal Communication (phone by Curtis DeGasperi). United States Geological Survey, Tacoma, WA.

Bosquet, T.M. 1992. Results of the NCASI round robin study. pp. E21-E46. In: Abstracts to presentations at the 1992 West Coast regional meeting of the National Council of the Paper Industry for Air and Stream Improvement, Inc. September 30 to October 1, 1992, Portland, Oregon.

Bryan, G.W., P.E. Gibbs, R.J. Huggett, L.A. Curtis, D.S. Bailey, and D.M. Dauer. 1989. Effects of tributyltin pollution on the mud snail, *Ilyanassa obsoleta*, from the York River and Sarah Creek, Chesapeake Bay. Mar. Pollut. Bull. 20:458-462.

Burton, G. Allen. 1991. Annual Review: Assessing the Toxicity of Freshwater Sediments. Environmental Toxicology and Chemistry. 10:1585-1627.

Butkus, S. 22 July 1992. Personal Communication (phone by Mr. Curtis DeGasperi, Tetra Tech, Redmond, Washington). Washington Department of Ecology, Olympia, WA.

Cabelli, V.J. 1983a. Public health and water quality significance of viral diseases transmitted by drinking water and recreational water. Wat. Sci. Tech. 15:1-15.

Cabelli, V.J. 1983b. Health effects criteria for marine recreational waters. EPA-600/1-80-031. Health Effects Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH. 98 pp.

Cabelli, V.J., A.P. Dufour, L.J. McCabe, and M.A. Levin. 1982. Swimming-associated gastroenteritis and water quality. American Journal of Epidemiology 115:606-616.

Cabelli, V.J., A.P. Dufour, L.J. McCabe, and M.A. Levin. 1983. A marine recreational water quality criterion consistent with indicator concepts and risk analysis. Journal of the Water Pollution Control Federation 55:1306-1314.

DiToro, D.M., J.D. Mahoney, D.J. Hansen, K.J. Scott, M.B. Hicks, S.M. Mays, and M.S. Redmond. 1990. Toxicity of cadmium in sediments: The role of acid volatile sulfide. Environ. Toxicol. Chem. 9:1489-1504.

Dowson, P.H., J.M. Bubb, and J.N. Lester. 1992. Organotin distribution in sediments and waters of selected east coast estuaries in the UK. Mar. Pollut. Bull. 24:492-498.

Dufour, A.P. 1984. Health effects criteria for fresh recreational waters. EPA-600/1-84-004. Health Effects Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC. 33 pp.

Edmondson, W.T. 1991. The uses of ecology: Lake Washington and beyond. University of Washington Press, Seattle. 329 pp.

Edmondson, W.T. and A.H. Litt. 1982. *Daphnia* in Lake Washington. Limnol. Oceanogr. 27:272-293.

Ennel, M., L. Kaj, and L. Wennberg. 1989. Long-distance distribution of halogenated organic compounds (AOX). pp. 29-36. In: River basin management -- V. Proceedings of an IAWPRC conference, Rovaniemi, Finland, 31 July - 4 August 1989. H. Laikari, ed. Pergamon Press, New York.

Ennel, M. and Wennberg. 1991. Distribution of halogenated organic compounds (AOX) -- Swedish transport to surrounding sea areas and mass balance studies of five drainage systems. Water Sci. Technol. 24:385-395.

Environmental Canada. 1990. Control of TCDD/TCDF in the Canadian pulp and paper industry.

Espourteille, F.A., J. Greaves, and R.J. Huggett. 1993. Measurement of tributyltin contamination of sediments and *Crassostrea virginica* in the southern Chesapeake Bay. Environ. Toxicol. Chem. 12:305-314.

Farrington, J.W. 1991. Biogeochemical processes governing exposure and uptake of organic pollutant compounds in aquatic organisms. Environmental Health Perspective 90:75-84.

Ferley, J.P., D. Zmirov, and F. Balducci. 1989. Epidemiological significance of microbiological pollution criteria for river recreational waters. Internat. J. Epidem. 18:198-205.

Ferraro, S.P., R.C. Swartz, F.A. Cole, and D.W. Shultz. 1991. Temporal changes in the benthos along a pollution gradient: Discriminating the effects of natural phenomena from sewage-industrial wastewater effects. Estuarine, Coastal and Shelf Science 33:383-407.

Forster, W.O. 1972. Radionuclide distribution in Columbia River and adjacent Pacific shelf sediments. pp. 701-754. In: The Columbia River Estuary and Adjacent Ocean Waters. A.A. Pruter and D.L. Alverson, eds. University of Washington Press, Seattle, WA.

Forstner, U. and G.T.W. Wittmann. 1981. Metal Pollution in the Aquatic Environment. Springer-Verlag, Berlin. 486 pp.

Fox, D.S. 1981. A review of recent scientific literature on the Columbia River estuary, emphasizing aspects important to resource managers. Draft report. Columbia River Estuary Study Task Force, Astoria, Oregon. 146 pp.

Fox, D.S., S. Bell, W. Nehlsen, and J. Damron. 1984. The Columbia River estuary: Atlas of physical and biological characteristics. Columbia River Estuary Data Development Program, Astoria, Oregon.

Fuhrer, G.J. 1984. Chemical analyses of elutriates, native water, and bottom material from the Chetco, Rogue, and Columbia Rivers in western Oregon. Open File Report 84-133, U.S. Geological Survey, Reston, Virginia. 57 pp.

Fuhrer, G.J. 1986. Extractable cadmium, mercury, copper, lead, and zinc in the lower Columbia River estuary, Oregon and Washington. Water-Resources Investigations Report 86-4088. U.S. Geological Survey, Reston, Virginia. 61 pp.

Fuhrer, G.J. and F.A. Rinella. 1983. Analysis of elutriates, native water, and bottom material in selected rivers and estuaries in western Oregon and Washington. Open File Report 82-922. U.S. Geological survey, Reston, Virginia. 147 pp.

Fuhrer, G.J. and A.J. Horowitz. 1989. The vertical distribution of selected trace metals and organic compounds in bottom materials of the proposed lower Columbia River export channel, Oregon. Water-Resources Investigations Report 88-4051. U.S. Geological Survey, Reston, Virginia. 40 pp.

Fujioka, R.S., K. Tenno, and S. Kansak. 1988. Naturally occurring fecal coliforms and fecal streptococci in Hawaii's freshwater streams. Tox. Assess. 3:613-630.

Galvin, D.V., et al. 1984. Toxicant pretreatment planning study summary report. Municipality of Metropolitan Seattle. 201 pp. + appendices.

Geldenhuys, J.C., and P.D. Pretorius. 1989. The occurrence of enteric viruses in polluted water, correlation to indicator organisms and factors influencing their numbers. Wat. Sci. Technol. 21:105-109.

Giesy, J.P. and R.A. Hoke. 1990. Freshwater sediment quality criteria: toxicity bioassessment. pp. 265-348, In: Sediments: Chemistry and Toxicity of In-Place Pollutants. R. Bando, J.P. Giesy, and H. Muntau (Eds.). Lewis Publishers, Inc., Boston, Massachusetts.

Glenn, J.L. 1973. Relations among radionuclide content and physical, chemical, and mineral characteristics of Columbia River sediments. U.S. Geological Survey Professional Paper 433-M. U.S. Government Printing Office, Washington, D.C.

Grimvall, A., H. Borén, S. Jonsson, S. Karlsson, and R. Sävenhed. 1991. Organohalogens of natural and industrial origin in large recipients of bleach-plant effluents. Water Sci. Technol. 24:373-383.

Guillard, R.R.L. and P. Kilham. 1977. The ecology of marine planktonic diatoms. pp. 372-469. In: The biology of diatoms. D. Werner, ed. Botanical Monographs, Volume 13. University of California Press, Berkeley, CA.

Haertel, L. and C. Osterberg. 1967. Ecology of zooplankton, benthos and fishes in the Columbia River estuary. Ecology. 48:459-472.

Haertel, L.S., C. Osterberg, H. Curl, Jr., and P.K. Park. 1969. Nutrient and plankton ecology of the Columbia River estuary. Ecology. 50:962-978.

Hallock, D. 1992. Draft Report. Lower Columbia River Bi-State Water Quality Program: Bacteria Study -- Fall 1992. Prepared for Lower Collumbia River Bi-State Committee. Environmental Investigations and Laboratory Services Program, Ambient Monitoring Section, Washington Department of Ecology, Olympia, WA.

Haushild, W.L., H.H. Stevens, Jr., J.L. Nelson, and G.R. Dempster, Jr. 1973. Radionuclides in transport in the Columbia River from Pasco to Vancouver, Washington. Geological Survey Professional Paper 433-N. U.S. Government Printing Office, Washington, D.C.

Haushild, W.L., G.R. Dempster, Jr., and H.H. Stevens, Jr. 1975. Distribution of radionuclides in the Columbia River streambed, Hanford Reservation to Longview, Washington. U.S. Geological Survey Professional Paper 433-O. U.S. Government Printing Office, Washington, D.C.

Haynes, J.M., R.H. Gray, and J.C. Montgomery. 1978. Seasonal movements of white sturgeon (*Acipenser transmontanus*) in the mid-Columbia River. Trans. Am. Fish. Soc. 107:275-280.

Hedges, J.I., H.J. Turin, and J.R. Ertel. 1984. Sources and distributions of sedimentary organic matter in the Columbia River drainage basin, Washington and Oregon. Limnol. Oceanogr. 29:35-46.

Hem, J.D. 1970. Study and interpretation of the chemical characteristics of natural water. 2nd ed. Geological Survey Water-Supply Paper 1473.

Henny, C.J., L.J. Blus, S.V. Gregory, and C.J. Stafford. 1981. PCBs and organochlorine pesticides in wild mink and river otters from Oregon. Worldwide Furbearer Conference Proceedings, August 3-11, 1980. Frostburg, MO, pp. 1763-1780.

Hess, S.S. 1984. Age and growth of White sturgeon in the lower Columbia River, 1980-83. Oregon Department of Fish and Wildlife unpublished report, 18 pp.

Higley, D.L., S.L. Wilson, K.K. Jones, and R.L. Holton. 1983. Distribution and community structure of benthic infauna in channel and protected flat habitats of the Columbia River Estuary. Report to the Army Corps of Engineers. School of Oceanography, Oregon State University, Corvallis, Oregon. 81 pp.

Hileman, J.R., R. Cunningham, and V. Kollias. 1975. Columbia River nutrient study in cooperation with the Washington State Department of Ecology and the Oregon State Department of Environmental Quality. EPA Working Paper No. EPA-910-9-75-011. Surveillance and Analysis Division, U.S. Environmental Protection Agency, Region X, Seattle, WA.

Hinton, S.A., G.T. McCabe, Jr., and R.L. Emmett. 1990. Fishes, benthic invertebrates, and sediment characteristics in intertidal and subtidal habitats at five areas in the Columbia River Estuary. Final Report. U.S. Army Corps of Engineers, Portland, Oregon. 92 pp. + appendices.

Hoffman, E.J., G.L Mills, J.S. Latimer, and J.G. Quinn. 1984. Urban runoff as a source of polycyclic aromatic hydrocarbons to coastal waters. Environ. Sci. Technol. 18: 580-587.

Holton, R.L., D.L. Higley, M.A. Brzezinski, K.K. Jones, and S.L. Wilson. 1984. Final report on the benthic infauna work unit of the Columbia River Data Development Program. Benthic infauna of the Columbia River Estuary. College of Oceanography, Oregon State University, Corvallis, Oregon. 179 pp. + appendices.

Horowitz, A.J. 1991. Sediment-trace element chemistry. Second edition. Lewis Publishers, MI. 136 pp.

Hubbard, L.E., T.A. Herrett, R.L. Kraus, and C.G. Krull. 1991. Water resources data, Oregon, water year 1990. Volume 2. Western Oregon. U.S. Geological Survey Water-Data Report OR-90-2. Portland, Oregon. 336 pp.

Hubbard, L.E., T.A. Herrett, R.L. Kraus, and G.P. Ruppert. 1992. Water resources data, Oregon, water year 1992. U.S. Geological Survey Water-Data Report OR-91-1. Portland, Oregon. 475 pp.

Hubbel, D.W. and J.L. Glenn. 1973. Distribution of radionuclides in bottom sediments of the Columbia River estuary. U.S. Geological Survey Professional Paper 433-L. U.S. Government Printing Office, Washington, D.C.

Huggett, R.J., M.A. Unger, P.F. Seligman, and A.O. Valkirs. 1992. The marine biocide tributyltin: Assessing and managing the environmental risks. Env. Sci. Technol. 26:232-237.

Imhoff, K.R. 1989. Balance and elimination strategies for heavy metals, phosphorus, ammonia and AOX in the Ruhr catchment. pp. 285-293. In: River basin management -- V. Proceedings of an IAWPRC conference, Rovaniemi, Finland, 31 July - 4 August 1989. H. Laikari, ed. Pergamon Press, New York.

Jaquish, R.E. and P.J. Mitchell. 1988. Environmental monitoring at Hanford for 1987. PNL-6464. Prepared for U.S. Department of Energy. Pacific Northwest Laboratory, Richland, Washington.

Jaquish, R.E. and R.W. Bryce. 1989. Hanford Site environmental report for calendar year 1988. PNL-6825. Prepared for U.S. Department of Energy. Pacific Northwest Laboratory, Richland, Washington. 239 pp.

Jaquish, R.E. and R.W. Bryce. 1990. Hanford Site environmental report for calendar year 1989. PNL-7346. Prepared for U.S. Department of Energy. Pacific Northwest Laboratory, Richland, Washington. 355 pp.

Johnson, A. and B. Hopkins. 30 April 1991. Personal Communication (letter to Steve Saunders, WDOE). Washington Department of Ecology, Olympia, Washington.

Johnson, A. and D. Norton. 1988. Screening survey for chemical contaminants and toxicity in sediments at five lower Columbia River ports September 22-24, 1987. Environmental Investigations and Laboratory Services Program, Washington Department of Ecology, Olympia, Washington.

Johnson, V., N. Cutshall, and C. Osterberg. 1967. Retention of ^{65}Zn by Columbia River sediment. Water Resources Research 3:99-102.

Källqvist, T., G.E. Carlberg, and A. Kringstad. 1989. Ecotoxicological characterization of industrial wastewater - sulfite pulp mill with bleaching. Ecotoxicol. Environ. Sat. 18:321-336.

Karlin, R. 1980. Sediment sources and clay mineral distributions off the Oregon coast. Journal of Sedimentary Petrology 50:543-560.

Knittel, M.D., R.J. Seidler, C. Eby, and L.M. Cabe. 1977. Colonization of the botanical environment by *Klebsiella* isolates of pathogenic origin. Appl. Environ. Microbiol. 34:557-563.

Krauskopf, K.B. 1979. Introduction to Geochemistry. McGraw-Hill, New York.

Landrum, P.F. and J.A. Robbins 1990. Bioavailability of sediment-associated contaminants to benthic invertebrates. pp. 237-263. In: Sediments: chemistry and toxicity of in-place pollutants. R. Bando, J.P. Geisy, and H. Montan, eds. Lewis Publishers, Inc., Wisconsin.

Lara-Lara, J.R., B.E. Frey, and L.F. Small. 1990a. Primary production in the Columbia River estuary. II. Grazing losses, transport, and a phytoplankton carbon budget. Pacific Science 44:38-50.

Lara-Lara, J.R., B.E. Frey, and L.F. Small. 1990b. Primary production in the Columbia River estuary. I. Spatial and temporal variability of properties. Pacific Science 44:17-37.

Limno-Tech (LTI) and Tetra Tech. 1991. Phase I screening model application for Columbia River dioxins. Prepared for U.S. Environmental Protection Agency, Region X, Seattle, Washington. Tetra Tech, Inc., Fairfax, Virginia. 35 pp.

Lincoln, J.H. and R.F. Foster. 1943. Report on investigation of pollution in the Lower Columbia River. Prepared for Washington State Pollution Commission and Oregon State Sanitary Authority. 143 pp.

Long, E.R. and L.G. Morgan. 1990. The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program. National Oceanic and Atmospheric Administration, Seattle, WA. NOAA Technical Memorandum NOS OMA 52.

Loring, D.H. 1990. Lithium -- a new approach for the granulometric normalization of trace metal data. Marine Chemistry 29:155-168.

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

Lukas, J. 11 May 1993. Personal Communication (fax to Mr. Tad Deshler, Tetra Tech, Inc., Redmond, Washington). Oregon Department of Fish and Wildlife, Portland, Oregon.

Luoma, S.N. 1989. Can we determine the biological availability of sediment-bound trace elements? Hydrobiologia 176/177:379-396.

Macdonald, R.W., W.J. Cretney, N. Crewe, and D. Paton. 1992. A history of octachlorodibenzo-*p*-dioxin, 2,3,7,8-tetrachlorodibenzofuran, and 3,3',4,4'-tetrachlorobiphenyl contamination in Howe Sound, British Columbia. Environ. Sci. Technol. 26:1544-1550.

May, T.W. and G.L. McKinney. 1981. Cadmium, mercury, arsenic, and selenium concentrations in freshwater fish, 1976-1977 - National Pesticide Monitoring Program. Pesticide Monitoring Journal 15:14-38.

McCabe, G.T. and S.A. Hinton. 1990a. Benthic infauna and sediment characteristics in the Columbia River near Westport, Oregon, August 1989. Final Report. U.S. Army Corps of Engineers, Portland, Oregon and National Marine Fisheries Service, Seattle, Washington. 17 pp. + appendices.

McCabe, G.T. and S.A. Hinton. 1990b. Definition of habitat requirements for spawning and rearing of white sturgeon and quantification of extent of habitat available in the Columbia River downstream from Bonneville Dam, Report D. In: Nigro, A.A. (ed). Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam. Annual Progress Report, April 1989-March 1990, Annual Report 1990. Oregon Department of Fish and Wildlife, Washington Department of Fisheries, U.S. Fish and Wildlife Service, and National Marine Fisheries Service. Report to Bonneville Power Administration, Portland, Oregon.

McCabe, G.T., S.A. Hinton, R.L. Emmett, and R.J. McConnell. 1990. Benthic invertebrates, sediment characteristics, and demersal fishes off Cottonwood Island, Columbia River, before and after rock groin construction, 1987-1988. Final Report. U.S. Army Corps of Engineers, Portland, Oregon and National Marine Fisheries Service, Seattle, Washington. 14 pp.

McGarigal, K., R.G. Anthony, and F.B. Isaacs. 1991. Interactions of humans and bald eagles on the Columbia River estuary. Wildlife Monographs, 115:1-47.

McGriff, D. 1983. Growth, maturity, and fecundity of the crayfish, *Pacifastacus leniusculus*, from the Sacramento-San Joaquin Delta. California Fish and Game 69:227-242.

Melcher, C.E. and S.D. King. 1992. The 1991 lower Columbia River and buoy 10 recreational fisheries. Oregon Department of Fish and Wildlife. 73 pp.

Menzie, C.A., B.B. Potocki, and J. Santodonato. 1992. Exposure to carcinogenic PAHs in the environment. Env. Sci. Technol. 26:1278-1284.

Mitchell, D.J. and L.A. Smock. 1991. Distribution, life history and production of crayfish in the James River, Virginia. American Midland Naturalist 126:353-363.

Moffatt, R.L., R.E. Wellman, and J.M. Gordon. 1990. Statistical summaries of streamflow data in Oregon: Volume 1 -- Monthly and annual streamflow, and flow-duration values. U.S. Geological Survey. Open-File Report 90-118.

Moore, A.M. 1968. Water temperatures in the lower Columbia River. Geological Survey Circular 551. U.S. Geological Survey, Washington, D.C.

Moore, D. S. and G.P. McCabe. 1989. Introduction to the Practice of Statistics. W.H. Freeman and Co. New York, NY. 790 pp.

Mullane, N. 22 July 1992. Personal communication (phone by Mr. Curtis DeGasperi, Tetra Tech, Redmond, Washington). Oregon Department of Environmental Quality, Portland, Oregon.

Myers, M.S., L.D. Rhodes, and B.B. McCain. 1987. Pathologic anatomy and patterns of occurrence of hepatic neoplasms, putative preneoplastic lesions, and other idiopathic hepatic conditions in English sole (*Parophrys vetulus*) from Puget Sound, Washington. J. Natl. Cancer Inst. 72:333-363.

Näf, C., D. Broman, H. Pettersen, C. Rolff, and Y. Zebuhr. 1992. Flux estimates and pattern recognition of particulate polycyclic aromatic hydrocarbons, polychlorinated dibenzo-p-dioxins, and dibenzofurans in the waters outside various emission sources on the Swedish Baltic Coast. Env. Sci. Technol. 26:1444-1457.

Nalepa, T.F. and P.F. Landrum. 1988. Benthic invertebrates and contaminant levels in the Great Lakes: Effects, fates and role in cycling. In: Toxic contaminants and ecosystem health: A Great Lakes focus. Evans, M.S. (ed). John Wiley and Sons, New York.

Napier, B.A. 1991. Selection of dominant radionuclides for Phase I of the Hanford Environmental Dose Reconstruction Project. PNL-7231 HEDR. Prepared for Technical Steering Panel. Pacific Northwest Laboratory, Richland, Washington.

National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI). 1972. *Klebsiella pneumoniae* infection: A review with reference to the water-borne epidemiologic significance of *K. pneunoniae* presence in the natural environment. Stream Improvement Technical Bulletin No. 254. NCASI, New York. 24 pp.

National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI). 1975. Further studies of the sanitary significance of *Klebsiella pneumoniae* occurrence in mill effluents and surface waters: Part 1. The distribution and densities of *Klebsiella* in receiving waters. Part 2. Biochemical, antimicrobial susceptibility, virulence and serological type characterization of *Klebsiella* isolates from natural receiving waters. Stream Improvement Technical Bulletin No. 279. NCASI, New York. 49 pp. + appendices.

National Oceanic and Atomospheric Administration (NOAA). 1990. Tide tables 1991. High and low water predictions. West Coast of North and South America, including the Hawaiian Islands.

National Oceanic and Atmospheric Administration (NOAA). 1991a. Climatological Data, Oregon. Volume 97.

National Oceanic and Atmospheric Administration (NOAA). 1991b. Climatological Data, Washington. Volume 95.

Neal, V.T. 1972. Physical aspects of the Columbia River and its estuary. pp. 19-40. In: The Columbia River Estuary and Adjacent Ocean Waters. A.A. Pruter and D.L. Alverson, eds. University of Washington Press, Seattle, WA.

Nemec, A.F.L. 1988. Documentation for SIGTREE. International Statistics and Research Corp.

Newell, A.J., D.W. Johnson, and L.K. Allen. 1987. Niagara river biota contamination project: Fish flesh criteria for piscivorous wildlife. New York State Department of Environmental Conservation, Division of Fish and Wildlife, Bureau of Environmental Protection.

Noshkin, V.E., K.M. Wong, T.A. Jokela, R.J. Eagle, and J.L. Brunk. 1978. Radionuclides in the marine environment near the Farallon Islands. (UCRL-52381). Prepared for U.S. Energy Research and Development Administration. Lawrence Livermore National Laboratory, Livermore, California. 17 pp.

Oregon Administrative Rules (OAR). 1990. Regulations relating to water quality control. Chapter 340-41.

O'Shea, M.L. and R. Field. 1991. Detection and disinfection of pathogens in storm-generated flows. Can. J. Microbiol. 38:267-276.

Paerl, H.W. 1988. Nuisance phytoplankton blooms in coastal, estuarine, and inland waters. Limnol. Oceanogr. 33:823-847.

Pardue, J.H., R.D. DeLaune, and W.H. Patrick, Jr. 1992. Metal to aluminum correlation in Louisiana coastal wetlands: Identification of elevated metal concentrations. Journal of Environmental Quality 21:539-545.

Park, P.K., G.R. Webster, and R. Yamamoto. 1969. Alkalinity budget of the Columbia River. Limnol. Oceangr. 14:559-567.

Park, P.K., M. Catalfomo, G.R. Webster, and B.H. Reid. 1970. Nutrients and carbon dioxide in the Columbia River. Limnol. Oceanogr. 15:70-79.

Park, P.K., C.L. Osterberg, and W.O. Forster. 1972. Chemical budget of the Columbia River. pp. 123-134. In: The Columbia River Estuary and Adjacent Ocean Waters. A.A. Pruter and D.L. Alverson, eds. University of Washington Press, Seattle, Washington.

Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Ann. Rev. 16:229-311.

Pennak, R.W. 1978. Fresh-water Invertebrates of the United States. Second edition. John Wiley & Sons, New York. 803 pp.

Perkin, R.G. and E.R. Walker. 1972. Salinity calculations from *in situ* measurements. Journal of Geophysical Research 77:6618-6621.

Perkins, R.W., J.L. Nelson, and W.L. Haushild. 1966. Behavior and transport of radionuclides in the Columbia River between Hanford and Vancouver, Washington. Limnol. Oceanogr. 11:235-248.

Persaud, D., R. Jaagumagi, and A. Hayton. 1991. Draft. The Provincial Sediment Quality Guidelines. Water Resources Branch, Ontario Ministry of the Environment, Toronto, Ontario, Canada. Draft.

Portland General Electric Company (PG&E). 1991. Trojan Nuclear Plant operational environmental radiological surveillance program. PG&E, Portland, Oregon.

Raj, C. 1992. Personal Communication (phone by Mr. Curtis DeGasperi, Tetra Tech, Redmond, Washington). Oregon Department of Environmental Quality, Portland, Oregon.

Reinert, R.E., B.A. Knuth, M.A. Kamrin, and Q.J. Stober. 1991. Risk assessment, risk management, and fish consumption advisories in the United States. Fisheries 16:5-12.

Renfro, W.C., W.O. Forster, C.L. Osterberg. 1972. Seasonal and areal distributions of radionuclides in the biota of the Columbia River estuary. pp. 777-798. In: The Columbia River Estuary and Adjacent Ocean Waters. A.A. Pruter and D.L. Alverson, eds. University of Washington Press, Seattle, Washington.

Rickert, D.A., R.R. Petersen, S.W. McKenzie, W.G. Hines, and Stephen A. Wille. 1977a. Algal conditions and the potential for future algal problems in the Willamette River, Oregon. U.S. Geological Survey Circular 715-G.

Rickert, D.A., V.C. Kennedy, S.W. McKenzie, and W.G. Hines. 1977b. A synoptic survey of trace metals in bottom sediments of the Willamette River, Oregon. Circular 715-F. U.S. Geological Survey, Portland, Oregon. 27 pp.

Rigler, F. 1968. Further observations inconsistent with the hypothesis that the molybdenum method measures orthophosphate in lake water. Limnol. Oceanogr. 13:7-13.

Rigler, F. 1973. A dynamic view of the phosphorus cycle in lakes. pp. 539-572. In: Environmental Phosphorus Handbook. E.J. Griffiths et al., eds. John Wiley & Sons, New York.

Ripple, S.R. 1992. Looking back at nuclear weapons facilities: The use of retrospective health risk assessments. Environ. Sci. Technol. 26:1270-1277.

Robeck, G.G., C. Henderson, and R.C. Palange. 1954. Water quality studies on the Columbia River. U.S. Department of Health, Education, and Welfare, Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

Robertson, D.E. and J.J. Fix. 1977. Association of Hanford origin radionuclides with Columbia River sediment. BNWL-2305. Battelle-Pacific Northwest Laboratory, Richland, Washington. 36 pp. + appendices.

Schmitt, C.J. and W.G. Brumbaugh. 1990. National contaminant biomonitoring program: Concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc in U.S. freshwater fish, 1976-1984. Arch. Environ. Contam. Toxicol. 19:731-747.

Schmitt, C.J., J.L. Zajicek, and P.H. Peterman. 1990. National Contaminant Biomonitoring Program: Residues of organochlorine chemicals in U.S. freshwater fish, 1976-1984. Arch. Environ. Contam. Toxicol. 19:748-781.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Bulletin 184. Fisheries Research Board of Canada, Ottawa.

Sherwood, C.R., J.S. Creager, E.H. Roy, G. Gelfenbaun, and T. Dempsey. 1984. Sedimentary processes and evironments in the Columbia River estuary. Final report on the Sedimentation and Shoaling Work Unit of the Columbia River Estuary Data Development Program. Columbia River Estuary Study Taskforce, Astoria, Oregon. 318 pp.

Shiller, A.M. and E.A. Boyle. 1985. Dissolved zinc in rivers. Nature 317:49-52.

Shiller, A.M. and E.A. Boyle. 1987. Variablility of dissolved trace metals in the Mississippi River. Geochim. Cosmochim. Acta 51:3273-3277.

Silverstone, M. 1993. Personal communication (letter to Dr. Steve Ellis, Tetra Tech, Redmond, Washington). State of Washington Department of Health, Seattle, Washington.

Simenstad, C.A. 1984. Final report on the Epibenthic Organisms Work Unit of the Columbia River Estuary Data Development Program. Epibenthic organisms of the Columbia River Estuary. Report PB85-102127. Prepared for National Oceanic and Atmospheric Administration, Rockville, Maryland. Fisheries Research Institute, College of Ocean and Fishery Sciences, University of Washington, Seattle, Washington. 55 pp. + appendices.

Simenstad, C.A., D. Jay, C.D. McIntire, W. Nehlsen, C. Sherwood, and L. Small. 1984. The dynamics of the Columbia River estuarine ecosystem, Volumes I and II. Columbia River Estuary Study Taskforce, Astoria, Oregon.

Simenstad, C.A., L.F. Small, C. McIntire, D.A. Jay, and C. Sherwood. 1990. Columbia River Estuary studies: An introduction to the estuary, a brief history, and prior studies. Prog. Oceanog. 25:1-13.

Sittig, M. 1985. Handbook of toxic and hazardous chemicals and carcinogens. Second Edition. Noyes Publications, Park Ridge, New Jersey. 950 pp.

Sylvester, R.O. and D.A. Carlson. 1961. A report on Lower Columbia River basic water quality data analysis for the year 1960. Prepared for the Cooperative Water Quality Basic Data Program. Oregon State Sanitary Authority, Northwest Pulp and Paper Association, and Washington State Pollution Control Commission. University of Washington, Seattle, Washington.

Tanizaki, Y. T. Shimokawa, and M. Nakamura. 1992. Physiochemical speciation of trace elements in river waters by size fractionation. Environ. Sci. Technol. 26:1433-1444.

Taylor, H.E., J.R. Garbarino, and T.I. Brinton. 1990. The occurrence and distribution of trace metals in the Mississippi River and its tributaries. The Science of the Total Environment 97/98:369-384.

Tetra Tech. 1976. Water quality analysis--Columbia River. Prepared for National Commission on Water Quality. Tetra Tech, Inc., Pasadena, CA. 123 pp.

Tetra Tech. 1986. Recommended protocols for measuring selected environmental variables in Puget Sound. Prepared for U.S. Environmental Protection Agency, Puget Sound Estuary Program. Tetra Tech, Inc. Bellevue, Washington.

Tetra Tech. 1991a. Reconnaissance Survey of the Lower Columbia River: Cruise Report. Prepared for Columbia River Bi-State Committee. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1991b. Reconnaissance Survey of the Lower Columbia River: QA/QC Plan. Prepared for Columbia River Bi-State Committee. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1991c. Reconnaissance Survey of the Lower Columbia River: Sampling Plan. Prepared for Columbia River Bi-State Committee. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1992a. Reconnaissance Survey of the Lower Columbia River: Task 1: Summary of Existing Data and Preliminary Identification of Problem Areas and Data Gaps. Prepared for Columbia River Bi-State Committee. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1992b. Reconnaissance survey of the lower Columbia River. Task 3: Review of hydraulic, hydrologic, sediment transport, and geomorphic characteristics of the lower Columbia River. Prepared for Columbia River Bi-State Committee. Tetra Tech, Inc., Bellevue, Washington. 46 pp. + appendices.

Tetra Tech. 1992c. Reconnaissance Survey of the Lower Columbia River: Task 2: Data Analysis Report - Inventory and Characterization of Pollutants. Prepared for Columbia River Bi-State Committee. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1992d. Reconnaissance Survey of the lower Columbia River. Task 4: Review of biological indicators to support recommendations on a biological monitoring approach. Prepared for Columbia River Bi-State Committee. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1992e. Reconnaissance Survey of the lower Columbia River. Task 4: Recommended biological indicators for the lower Columbia River. Prepared for Columbia River Bi-State Committee. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1992f. Reconnaissance Survey of the lower Columbia River. Task 5: Beneficial use descriptions and locations. Prepared for Columbia River Bi-State Committee. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1993a. Phase 4 draft report: Baseline ecological assessment of disposal activities in the Gulf of the Farallones: Ecological risk assessment. Prepared for Hazardous Materials Response Branch, National Oceanic and Atmospheric Administration, Seattle, Washington. Tetra Tech, Inc., Lafayette, California. 110 pp. + appendices.

Tetra Tech. 1993b. Reconnaissance Survey of the lower Columbia River. Task 7: Conclusions and Recommendations. Prepared for Columbia River Bi-State Committee. Tetra Tech, Inc., Redmond, Washington.

Thorp, J. H. and A. P. Covich (eds). 1991. Ecology and classification of North American Freshwater Invertebrates. Academic Press, San Diego. 911 pp.

Thurman, E.M., D.A. Goolsby, M.T. Meyer, and D.W. Kolpin. 1991. Herbicides in surface waters of the Midwestern United States: The effect of spring flush. Environ. Sci. Technol. 25:1794-1796.

Toombs, G.L., S.L. Martin, P.B. Culter, and M.G. Dibble. 1984. Environmental radiological surveillance report on Oregon surface waters. 1961-1983. Environmental Radiation Surveillance Program, Oregon State Health Division.

Toranzos, G.A. 1991. Current and possible alternate indicators of fecal contamination in tropical waters: A short review. Environmental Toxicology and Water Quality 6:121-130.

Uhler, A.D., G.S. Durell, W.G. Steinhauer, and A.M. Spellacy. 1993. Tributyltin levels in bivalve mollusks from the East and West Coasts of the United States: Results from the 1988-1990 National Status and Trends Mussel Watch Project. Environ. Toxicol. Chem. 12:139-153.

U.S. Army Corps of Engineers. 1990. Riverine sediment quality report. Portland District, Corps of Engineers, Portland, Oregon.

U.S. Army Corps of Engineers. 1991. Columbia River sediment database: estuarine and riverine. Portland District Corps of Engineers, Portland, Oregon.

U.S. Environmental Protection Agency. 1986a. Quality criteria for water. Office of Water Regulations and Standards, Washington, DC 20460. EPA 440/5-86-001.

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

U.S. Environmental Protection Agency. 1988a. Laboratory data validation functional guidelines for evaluating inorganics analyses. U.S. Environmental Protection Agency/Hazardous Site Evaluation Division, Washington, D.C.

U.S. Environmental Protection Agency. 1988b. Laboratory data validation functional guidelines for evaluating organics analyses. U.S. Environmental Protection Agency/Hazardous Site Evaluation Division, Washington, D.C.

U.S. Environmental Protection Agency. 1989. Interim procedures for estimating risks associated with exposures to mixtures of chlorinated dibenzo-p-dioxins and -dibenzofurans (CDDs and CDFs) and 1989 update. EPA/625/3-89/016. Risk Assessment Forum, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1991a. Bioaccumulation of selected pollutants in fish - A National Study. Vols. I and II. EPA 506/6-90/001a. Assessment and Watershed Protection Division, Office of Water Regulations and Standards, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1991b. Assessment and control of bioconcentratable contaminants in surface waters. Office of Water, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1991c. Total maximum daily load (TMDL) for 2,3,7,8-TCDD in the Columbia River Basin Decision Document. U.S. Environmental Protection Agency, Region X, Seattle, Washington.

U.S. Environmental Protection Agency. 1991d. Dioxin loadings to waters in the Columbia River Basin. Region 10 Fact Sheet.

U.S. Environmental Protection Agency. 1991e. Proposed sediment quality criteria for the protection of benthic organisms: Dieldrin. Draft EPA document. Office of Science and Technology, Health and Ecological Criteria Division, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1991f. Proposed sediment quality criteria for the protection of benthic organisms: Acenaphthene. Draft EPA document. Office of Science and Technology, Health and Ecological Criteria Division, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1991g. Proposed sediment quality criteria for the protection of benthic organisms: Endrin. Draft EPA document. Office of Science and Technology, Health and Ecological Criteria Division, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1991h. Proposed sediment quality criteria for the protection of benthic organisms: Fluoranthene. Draft EPA document. Office of Science and Technology, Health and Ecological Criteria Division, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1991i. Proposed sediment quality criteria for the protection of benthic organisms: Phenanthrene. Draft EPA document. Office of Science and Technology, Health and Ecological Criteria Division, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1992. Interim guidance on interpretation and implementation of aquatic life criteria for metals. Office of Science and Technology, Health and Ecological Criteria Division, U.S. EPA, Washington, D.C. 24 pp.

U.S. Environmental Protection Agency. Unpublished STORET water quality data (retrieval performed in 1991). U.S. EPA Region X. Seattle, Washington.

U.S. Fish and Wildlife Service. 1991. Unpublished data.

U.S. Geological Survey. Unpublished data from Bradwood, Oregon (1973-1980) (No. 14247400), Warrendale, Oregon (1972-present) (No. 14128910), and Beaver Army Terminal (1990-present).

Van Winkle, W. 1914. Quality of surface waters of Washington. Geological Survey Water-Supply Paper 339. U.S. Geological Survey, Washington, D.C.

Vasconcelos, G.J., N.C. Anthony, and G.L. Burns. 1975. Bacteriological survey of the lower Columbia River. EPA-910/9-75-006. U.S. Environmental Protection Agency, Region X, Seattle, Washington.

Velz, C.J. 1984. Applied stream sanitation. Second edition. John-Wiley & Sons, NY.

Washington Administrative Code (WAC). 1988. Water quality standards for surface waters of the State of Washington. Chapter 173-201. pp. 1-13.

Washington Administrative Code (WAC). 1991. Sediment management standards. Chapter 173-204. pp. 1-28.

Washington Administrative Code (WAC). 1992. Water standards for surface waters of the State of Washington. Chapter 173-201A. pp. 1-14.

Washington Department of Ecology (WDOE). 1989. Non-point source pollution assessment and management program. Washington Department of Ecology, Water Quality Program. Olympia, Washington.

Washington Department of Fisheries and Oregon Department of Fish and Wildlife. 1992. Status report. Columbia River fish runs & fisheries, 1938-91. Washington Department of Fisheries and Oregon Department of Fish and Wildlife. 224 pp.

Washington State Department of Health (WSDH). 1991. Bathing beach program and issues associated with water quality indicator organisms. Prepared for Washington State Board of Health. Washington Department of Health, Olympia, Washington.

Watson, J.W., M.G. Garrett, and R.G. Anthony. 1991. Foraging ecology of bald eagles in the Columbia River estuary. J. Wildlife Management 55:492-499.

Welch, E.B. 1980. Ecological effects of waste water. Cambridge University Press, New York, NY.

Weston, D.P. 1990. Hydrocarbon bioaccumulation from contaminated sediment by deposit-feeding polychaete *Abarenicola pacifica*. Mar. Biol. 107:159-169.

Wetzel, R.G. 1975. Limnology. W.B. Saunders Company, Philadelphia, Pennsylvania. 743 pp.

Whetten, J.T., J.C. Kelley, and L.G. Hanson. 1969. Characteristics of Columbia River sediment and sediment transport. J. Sediment. Petrol. 39:1149-1166.

Wilkinson, L. 1989. SYSTAT: the system for statistics. SYSTAT, Inc., Evanston, IL.

Williams, L.G. 1964. Possible relationships between plankton-diatom species numbers and water-quality estimates. Ecology 45:809-823.

Williams, L.G. 1972. Plankton diatom species biomasses and the quality of American rivers and the Great Lakes. Ecology 53:1038-1050.

Williams, J.R. and H.E. Pearson. 1985a. Streamflow statistics and drainage-basin characteristics for the Southwestern and Eastern Regions, Washington. Volume 1. Southwestern Washington. U.S. Geological Survey Open-File Report 84-145-A. Tacoma, Washington. 424 pp.

Williams, J.R. and H.E. Pearson. 1985b. Streamflow statistics and drainage-basin characteristics for the southwestern and eastern regions, Washington. Volume 2. Eastern Washington. U.S. Geological Survey Open-File Report 84-145-B. Tacoma, Washington. 662 pp.

Williams, L.G. and C. Scott. 1962. Principal diatoms of major waterways of the United States. Limnol. Oceanogr. 7:365-375.

Windom, H.L., J.T. Byrd, R.G. Smith, Jr., and R. Huan. 1991. Inadequacy of NASQUAN data for assessing metal trends in the nation's rivers. Env. Sci. Technol. 25:1137-1142.

Woodruff, R.K. and R.W. Hanf. 1991. Hanford Site environmental report for calendar year 1990. PNL-7930. Prepared for U.S. Department of Energy. Pacific Northwest Laboratory, Richland, Washington.

Woodruff, R.K. and R.W. Hanf. 1992. Hanford Site environmental report for calendar year 1990. PNL-8148. Prepared for U.S. Department of Energy. Pacific Northwest Laboratory, Richland, Washington.

Wydoski, R.S. and R.R. Whitney. 1979. Inland Fishes of Washington. University of Washington Press, Seattle. 220 pp.

Yee, C. 28 July 1992. Personal Communication (phone by Curtis DeGasperi). Washington Department of Ecology, Olympia, Washington.

Young, S.R. 1988. Columbia River sediment - 1989. Unpublished. File II.F.5, Environmental Department, James River Corp., Vancouver, Washington. 11 pp.

Young, S.R. 1989. Columbia River survey. Unpublished. File II.F.5, Technical Dept., James River Corp., Vancouver, Washington.

Young, S.R., J.Q. Word, C.W. Apts, M.E. Barrows, V.I. Cullinan, and N.P. Kohn. 1988. Confirmatory chemical analyses and solid-phase bioassays on sediment from the Columbia River estuary at Tongue Point, Oregon. PNL-6792/UC-11. Prepared for U.S. Army Corps of Engineers, Portland District. Portland, OR.

GLOSSARY OF SELECTED ENVIRONMENTAL TERMS[a]

acaricide	A pesticide that kills mites and ticks that infest domestic animals, crops, or humans.
acid digestion	The process of strong or weak acid treatment of a water, sediment, or tissue sample to remove or make available contaminants for laboratory analysis.
acid soluble concentration	The portion or concentration of a contaminant that is solubilized or removed during acid digestion.
Acipenseridae	The family of fish that includes species of sturgeon.
acute aquatic criteria	A standard established to protect aquatic organisms from short-term (1-hour) exposure to a specified contaminant.
acute toxicity	Any toxic effect that is produced with a short period of exposure. Although the effect most frequently considered is mortality, the end result of an acute effect could be any harmful biological effect.
adsorbable organic halogens	A term used to describe the measurement of the amount of halogenated organic compounds (i.e., chlorine-, bromine-, iodine-, and fluorine-containing compounds), some of which may be highly toxic, in water or wastewater.
advection	The transport of a substance along with the movement of the water.
algae	Micro- and macroscopic marine and freshwater non-flowering plants, lacking roots, and containing the plant photosynthetic pigment chlorophyll. The term algae may include attached algae (periphyton) and planktonic algae (phytoplankton).
aliquot	A subsample or portion of a larger sample.
alpha radiation	The type or radiation due to the emission of a charged particle from the nucleus of an atom. The particle is similar to the composition of the helium nucleus (2 protons and 2 neutrons). This is the most potentially damaging, but least penetrating type of radiation. Alpha radiation can be stopped by a sheet of paper or the outer dead layer of skin, and therefore generally causes biological damage only if sufficient quantities are emitted inside the body of an organism.

alpha spectrometry	A laboratory method for the measurement of radionuclides that emit alpha radiation.
ambient waters	The water environment of lakes, rivers, and streams.
amphipod	A small crustacean, sometimes called freshwater shrimp or sand fleas, that is an important food item for some fishes. Many live on the river bottom and feed on algae and detritus.
anadromous fish	Types of fish such as salmon, which reproduce in fresh water, spend a large part of their lives in the ocean, and return to fresh water rivers and streams to reproduce.
andesite	A dark-colored, fine-grained igneous rock which is intermediate in composition between basalt and rhyolite. Major component of Cascade Range stratovolcanos such as Mt. Hood and Mt. Rainier.
anion chromatography	A laboratory method for the measurement of anionic or negatively charged substances dissolved in water.
annelid	A multi-segmented worm.
anomalous	A value or concentration that differs substantially from typical or average values.
ANOVA	A statistical testing procedure that is also known as analysis of variance.
antagonistic effect	The reduction in the toxicity of a mixture of contaminants due to interactive effects that result in less measurable toxicity than would be expected due to the sum of the toxic effects of each individual contaminant.
anthropogenic	The types of environmental alterations or effects resulting from the domestic, agricultural, silvicultural, or industrial activities of humans, as opposed to effects or processes that occur in the environment without human intervention.
arachnid	Commonly known as spiders, animals that are characterized by four pairs of legs (thoracic appendages).
aromatic	An organic compound characterized by the presence of at least one benzene ring and which typically has a very characteristic odor.
arthropod	An animal with a segmented body, a hardened external skeleton, and jointed limbs or appendages. Arthropods include the groups of insects, crustaceans (e.g., crabs, crayfish, and shrimp), and spiders.
Astacidae	The family of organisms that includes crayfish.

backwater	A relatively still or quiescent body of water located in sloughs, bays, floodplains, or inlets of a river.
basalt	A dark-colored igneous rock commonly formed by the cooling of extruded volcanic magma.
bedload transport	The transport of fine and coarse sediment, gravel and rocks, and/or other debris that is moved downstream along the bottom of a stream or river by strong water currents.
beneficial uses	Uses of state waters that are defined for regulatory purposes, but which generally include use for domestic, stock watering, industrial, commercial, agricultural, irrigation, mining, fish and wildlife maintenance and enhancement, recreation, generation of electrical power and preservation of environmental and aesthetic values.
benthic organism	An organism that lives on or in the bottom sediments.
benthos	The community of aquatic organisms that live in or on the surface of the bottom sediments in the river.
beta radiation	A form of radiation emitted from a nucleus during radioactive decay. The particle emitted has a mass and charge that is similar to that of an electron. Beta radiation can be stopped by an inch of wood or a thin sheet of aluminum, and may cause biological damage if a sufficient amount is emitted inside, or occasionally outside, the body of an organism.
bioaccumulation	The biological process by which a contaminant accumulates in the tissues of an organism.
bioassay	A test procedure that measures the response of organisms (including living plants, animals, or tissues) to substances to estimate the dose rates (or concentrations) that cause adverse biological effects or mortality of the test organism. This test estimates the toxicity of contaminants.
bioavailability	The degree or potential of a contaminant to be accumulated via biological pathways into the tissues of an organism. Biological pathways include uptake through gut walls, fish gills, or through the outer protective tissues of an organism.
biochemical oxygen demand (BOD)	The quantity of dissolved oxygen consumed by the biological degradation of organic matter present in the water sample. Domestic and some industrial sewage has a very high BOD before it is treated. One objective of wastewater treatment is to perform the biological degradation of the sewage (secondary treatment) before it is discharged, thus ensuring that the treated wastewater discharge will not cause a significant reduction of dissolved oxygen in the receiving water.

bioconcentration	The result of bioaccumulation of a contaminant from ingestion of water or contaminated food. The bioconcentration factor (BCF) is often expressed as the ratio of the concentration of a chemical in the organism to that in the medium (typically water).
biodegradation	The conversion of organic compounds into breakdown products through biological activity. Toxic compounds may be converted into less toxic compounds by biodegradation. In some cases (i.e., the degradation of DDT to DDE) complex toxic compounds are converted to intermediate substances that can be more toxic than the original substance.
biological respiration	The biological consumption of oxygen and release of carbon dioxide due to the metabolic activity of organisms.
biologically active	A substance or chemical that can have a positive or negative effect on an organism.
biomagnification	The process by which concentrations of contaminants increase (magnify) in organisms from algae and plants, to animals that feed on plants, to animals that feed on other animals (i.e., as the contaminants are passed up the food chain). The increase is such that each animal in the food chain has a higher contaminant concentration than the contaminated food it ate.
biomass	The weight of a sample of organisms (e.g., algae, plants, or animals). The weight may be expressed as the weight before drying the sample (i.e., wet weight) or the weight after the sample has been dried (i.e., dry weight).
biota	The animals, plants, fungus, and microbes that live in a particular location or region.
biovolume	The volume of space that a living organism occupies.
bivalve	An aquatic invertebrate animal of the class Bivalvia (such as clams and oysters) that has two shells (or valves). Most of these animals feed by filtering the water for food.
blue-green algae	Common term for a group of algae that have a blue-green color. Members of this group are often the cause of nuisance algae conditions in water bodies. These algae are actually a type of photosynthetic bacteria.
brackish water	The result of the mixing of fresh and salt water in an estuary.
brominated	The addition of bromine to an organic compound.
carcinogen	A substance capable of causing cancer.

carnivorous	Animals or plants that eat other organisms not including plants. Plant-eating organisms are herbivorous.
cation	A positively charged chemical compound or element.
Catostomidae	The family of fish that includes suckers.
cell	The fundamental biological unit of structure and function in organisms.
cell lysis	The destruction or rupture of a cell.
chemical weathering	The weathering of rock material by chemical reactions of rain and groundwater with rock minerals and soils.
chironomid	A type of insect that: (1) has a larval or adolescent worm stage, (2) lives in aquatic sediments. The presence of certain types of chironomids may indicate the effects of organic enrichment or pollution.
chronic aquatic criteria	A standard established to protect aquatic organisms from short-term (96-hour) exposure to a specified contaminant.
chronic toxicity	Any toxic effect on an organism that results after exposure of relatively long duration, often about one-tenth or more of the life span of the organism). The end result of a chronic effect may be death, although effects may also be sublethal (i.e., involve other non-fatal, yet harmful effects such as reproductive impairment).
Clean Water Act	The federal act that created the framework of many current water quality regulations. Also known as the federal Water Pollution Control Act (33 U.S.C. 1251 *et seq.*).
colloid	A substance that, although not dissolved in water, remains suspended indefinitely and does not readily settle to the bottom. Colloids do not diffuse or diffuse very slowly through a membrane and usually have little effect on freezing point, boiling point, or osmotic pressure of the solution.
complexation	A chemical and/or physical-electrical interaction between two substances that results in binding them together (weakly or strongly).
compound	A distinct substance formed by a union of two or more ingredients in definite proportions by weight.
confidence limit	The statistical description of the range of possible values about the mean. A 95 percent confidence limit indicates the ranges expected within which 95 percent of the observations would fall.

congener	An organic compound that is similar in structure and composition to another compound.
contaminant	A term used to broadly identify the metals, radiological substances, and organic compounds that are released from point and nonpoint pollutant sources and that have the potential to become enriched in the aquatic environment due to human activities. Contaminant may also refer to a substance that, although naturally occurring, may cause adverse environmental effects when present in sufficient quantity.
conventional pollutant	Conventional pollutants, as specified under the Clean Water Act, are total suspended solids, fecal coliform bacteria, biochemical oxygen demand, pH, and oil and grease. In this report conventional pollutants generally include all environmental measurements (e.g., temperature and total organic carbon) exclusive of those made for metals, radionuclides, and organic pollutants.
criteria	Numerical limits for environmental concentrations of constituents that have been established as appropriate for the protection of aquatic life or human use of the aquatic resource.
crustacean	Any of various predominantly aquatic arthropods of the class Crustacea, including lobsters, crabs, crayfish, shrimps, and barnacles. These organisms characteristically have a segmented body, an exoskeleton composed of chitin, and paired, jointed limbs.
Curie (Ci)	Special unit of radioactivity equivalent to 37 billion ($3.7x10_{10}$) nuclear disintegrations per minute.
Cyprinidae	The family of fish also known as the minnow family. This family includes species of carp and peamouth.
density stratification	The result of warmer and/or less saline (salty) water overlying cooler and/or more saline water. Cooler and saltier waters are more dense than warmer and fresh water. These density differences result in a resistance to mixing which maintains the segregation or stratification of the different water layers.
deposit-feeding	Animals that feed on the detritus that collects on and in the river bottom sediments.
detection limit	The lowest concentration of a substance that can be measured in a laboratory analysis.
detention time	The time it takes for the volume of (or a substance in) a lake or river to be completely exchanged with new water (or substance). The water detention time gives one an idea how long a particular contaminant might spend in the water body of interest.

detritus	Partially decomposed plant or animal matter suspended in the water column or deposited in or on the sediments.
diatom	A single-celled or colonial (multi-celled) brown alga having a siliceous shell. These algae typically grow attached to the bottom or are suspended in the water.
diel	A 24-hour period that usually includes a day and the adjoining night.
dielectric fluid	A fluid that does not conduct electricity.
dilution	In the case of a river it is the proportion of river water to contaminant after the contaminant has been released from point or nonpoint pollution sources. Wastewaters containing relatively high concentrations of particular contaminants are diluted by the relatively less polluted river water. The concentration and rate of contaminant input and the volume of river water discharge determine the degree of dilution that occurs.
dilution capacity	The idea that it is possible to reduce the concentration of a contaminant discharged from point and nonpoint sources by dilution of the pollutant with river water to a concentration below that deemed intolerable by state and federal regulators.
dioxin	A group of complex organic compounds that contain chlorine. One type of dioxin, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, is one of the most potent toxic compounds produced by humans.
dissolved oxygen	The portion of oxygen gas that becomes soluble in water and is therefore available for fish and other aquatic animals to use. Many organisms cannot tolerate low oxygen concentrations, although some are adapted to survive under these conditions. Wastewater containing oxygen-demanding substances and the respiration of living and dead organisms consume dissolved oxygen. However, the photosynthetic activity of algae produces algae.
dissolved phase	The form of a chemical or element that is soluble in water.
diurnal	Relating to daytime or something recurring every day, often used as a synonym for diel.
domestic wastewater	Wastewater that flows from homes and other locations where water is used for cooking, washing, and the removal of human wastes. This type of waste generally has a high content of biochemical oxygen demand and nutrients. The waste may also contain toxics derived from a variety of household or commercial maintenance and cleaning products (e.g., paints, solvent, and detergents).

dose	The amount of chemical or radiation received by an organism. A dose may have no observable effect, non-fatal effects, or it may cause death.
drainage basin	The geographic area that collects the rainwater and associated material contained in the runoff that is delivered to a defined portion of a lake or river. The perimeter of the drainage basin is called the watershed. The watershed is the line that indicates where rainfall will run off to one drainage basin or another.
ebb tide	A term referring to the tidal period between the time of high water and the succeeding low water. The water level and the extent of ocean water intrusion decreases during the ebb tide.
ecosystem	A community of organisms interacting with one another and with their physical environment, such as a river, lake, or estuary. A river system, such as the lower Columbia River, can also be thought of as the sum of many interconnected ecosystems, such as the sloughs, marshes, floodplains, swamps, and estuary.
effluent	The liquid wastewater that is discharged from agricultural, municipal, and industrial operations. Effluents may or may not receive treatment.
effluent mixing zone	A regulatory defined zone or area where the effluent enters and mixes with the river water.
enrichment	Addition or accumulation of a substance within a body of water or sediments in excess of natural background levels with potential adverse effects on the organisms that inhabit the environment. However, enrichment of nutrients or organic matter may also result in increases in the numbers of organisms that benefit directly from these inputs (e.g., algae and pollution-tolerant benthic insect larvae). As used in this report the term is synonymous with pollution.
enteric disease	An illness due to disease-causing bacteria, amoebas, or virus.
epibenthic organisms	Aquatic organisms that live upon the surface of the river sediments.
epidemiological study	A study of the causes of outbreaks of disease. The study might attempt to determine the sources of the disease-causing organisms and the factors that result in infection (e.g., age, habits, prior health history).
episodic	An event that occurs periodically. Pertaining to or resembling an episode; incidental. For example, rainfall may be an episodic event.
erosion	The wearing away of rock or soil by the gradual detachment of soil or rock fragments by water, ice, and other mechanical and chemical forces.
estuarine	Pertaining to, or found in an estuary.

estuary	A coastal water body where ocean water is diluted by out-flowing fresh water from a river.
euryhaline species	Species of organism that have the ability to tolerate a wide range of salt water concentrations, but generally less than that of sea water. These species typically live in estuaries.
eutrophic condition	The condition of a lake due to the input of nutrients, from natural and/or human sources, that would be sufficient to support abundant algal life.
eutrophication	An increase in the input of nutrients by natural or human-induced causes. The increased rate of delivery of nutrients may result in an increase in the production of algae. A natural forest fire may increase the input of nutrients to a river. Human-induced (sometimes called cultural) eutrophication may be caused by input of treated sewage, and/or deforestation or urbanization of the drainage basin.
fallout	Radioactive materials that are released into the air from a nuclear detonation or accident and that eventually fall to earth's surface.
fecal coliforms	Bacteria that may originate from the intestines of warm-blooded animals. Not all of the bacteria are harmful; however, their measure may indicate the relative potential for the presence of harmful bacteria. High numbers of fecal coliform bacteria may limit beneficial uses such as swimming and shellfish harvesting.
feces	Solid waste excreted from animals including humans.
flat	A marshy, sandy, or muddy nearly horizonal coastal flatland which is alternately covered and exposed as the tide rises and falls.
flood tide	A term referring to the tidal period between the time of low water and the succeeding high water. The water level and the extent of ocean water intrusion increases during the flood tide.
fork length	The length of a fish from the tip of the head to the middle of the fork in the tail.
freshet	The annual spring rise of streams and rivers in mountainous areas as a result of melting snow.
fungicide	A substance that destroys or inhibits the growth of fungus.
gamma radiation	Short wavelength, high-energy electromagnetic radiation emitted from the nucleus of radioactive elements. Gamma rays are essentially the same as x-rays. To be stopped, they require heavy shielding, such as concrete, lead, or steel. In sufficient amounts, gamma rays may cause biological damage.

gastroenteritis	The disease of the intestinal tract that includes inflammation of the mucous membrane of the stomach and intestine.
gastropod	Any animal of the class Gastropoda (mollusks), such as a snail, slug, cowry, or limpet, characteristically having a single, usually coiled, shell and a ventral muscle serving as an organ of locomotion.
genus	The taxonomic category below family. A genus may consist of several distinct individual species; the first part of the scientific name of organisms.
geometric mean	Data that have many low values and a few very high values are considered to be log-normally distributed (skewed). To reduce the bias introduced to an arithmetic mean by these very high numbers, the logarithms of the data are averaged. The anti-log of this average is the geometric (or logarithmic) mean.
green algae	Algae that are have a color similar to many green land plants.
habitat	The place or environment where an organism lives. An organism's habitat must provide all of the basic requirements for life.
half-life	Length of time in which the concentration of a substance will be reduced to one-half its original concentration. Radiologic half-life is the length of time it takes for a radioactive substance to decay to half its original concentration.
halogenated	Organic compounds containing one or more halogens. Halogens include chlorine, bromine, fluorine, and iodine.
hardness	A measure of the polyvalent metal ion (e.g., calcium and magnesium ions) content of water.
hazardous waste	Any solid, liquid, or gaseous substance that, because of its source or measurable characteristics, is classified under state or federal law as hazardous and is subject to special handling, shipping, storage, and disposal requirements.
herbicide	A substance used to destroy or inhibit the growth of vegetation.
homogenation	The act of making a substance uniform (i.e., homogenous) in composition or structure.
human health criteria	A water quality criteria specified as the water column concentration of a particular toxic contaminant that should not be exceeded in order to protect humans from the adverse effects of consuming contaminated fish and/or drinking water.

hydrophobicity	The degree to which a substance repels water.
impoundments	Water reservoirs, including water retained behind large dams, used for water supply, transportation, and power generation.
immuno-compromised	A person whose disease-fighting immune system is not functioning properly and is therefore more susceptible to disease-causing organisms.
inorganic	Chemical compounds that do not contain carbon.
insecticide	A substance used to kill insects.
invertebrates	Animals without internal skeletons. Invertebrates include animals such as snails, oysters, insects, and crayfish.
iodated	The addition of iodine to a substance.
ionic content	The amount of ionic or charged elements and compounds dissolved in water.
ionic strength	A measure of the average electrostatic interactions among ions in an electrolyte.
isomers	Organic compounds with the same chemical composition and general structural form, but with subtle differences in the placement of specific chemical groups.
isotopes	Different atomic forms of the same element. Isotopes of a particular element have the same number of protons in their nuclei, and hence the same atomic number, but differ in the number of neutrons, and therefore in the mass number. Almost identical chemical properties exist between isotopes of a particular element.
lattice	A regular configuration of elements or minerals in crystalline rocks, minerals, or sediments.
leachate	Water or other liquid that has interacted with and leached from solid material, such as a layer of soil or debris.
lipid	A type of fatty substance. One of a class of compounds which contain long-chain aliphatic hydrocarbons and their derivatives, such as fatty acids, alcohols, amines, amino alcohols, and aldehydes; includes waxes, fats, and derived compounds
loading	The amount (quantity per time) of contaminant entering a system from a pollutant source.

low-flow	The seasonal period of lowest river flow due to an extended period with little rainfall and snowmelt runoff. In the Pacific Northwest this period generally occurs during late summer.
lysin	A specific antibody that acts to destroy cells.
marsh	A wetland where the dominant vegetation is non-woody plants, such as grasses and sedges, as opposed to a swamp where the dominant vegetation is woody plants like trees.
matrix spike	The addition of a known quantity of a substance to an environmental sample to determine the possible presence of substances that interfere with the laboratory measurement.
mean	The average value of a series of measurements. This is determined by dividing the sum of all of the measurements by the number of measurements made.
median	The middle value in a set of results when the data are ranked in increasing or decreasing order.
medium	The carrier (e.g., water) in which a biological or chemical reaction takes place.
membrane filtration	Use of a thin, microporous material of specific pore size to filter bacteria, algae, and other very small particles from water.
metabolic rate	The rate of consumption of energy by an organism for maintenance, growth, and reproduction. The rate at which food is synthesized into complex elements, complex elements are transformed into simple ones, and energy is made available for use by an organism through physical and chemical processes.
metabolism	All chemical processes occurring within an organism, including both synthesis and breakdown of organic materials.
metal alloy	A manufactured material made up of two or more metals or a metal and a non-metal.
metamorphic rock	A sedimentary or igneous rock that has been altered by the action of heat and/or pressure at depth in the earth's crust.
method blank	A check sample of laboratory distilled water which is treated to all of the preparation and analytical steps of the actual samples to assess possible contamination of the samples during processing or analysis.
microcoulometric method	A laboratory method which involves the measurement of the conductivity of the sample.

mollusc	Animals that include snails and octopus. These animals are characterized by a shell-secreting organ, the mantle, and a radula, a food grasping organ located in the forward area of the mouth.
National Pollutant Discharge Elimination System (NPDES)	A part of the federal Clean Water Act, that requires point source dischargers to obtain discharge permits. These permits are referred to as NPDES permits and are administered in their respective states by the Washington Department of Ecology and Oregon Department of Environmental Quality.
neap tide	A tide with the smallest range between high and low tide.
nematode	Any worm of the phylum Nematoda, having unsegmented, threadlike bodies. Many nematodes, such as the hookworm, are parasitic.
neutron	An atomic particle having no electric charge; its mass nearly equals that of a proton.
nitroaromatic	A nitrated benzene or benzene derivative.
non-carcinogen	A substance that is not capable of causing cancer.
nonpoint source	A pollution source that although collected from dispersed and generally uncontrolled sources (such as urban or agricultural runoff) may still be discharged from discrete pipes to a receiving water.
non-polar	Organic compounds that do not have a permanent electrical charge.
nutrient	A chemical element or compound that is required by an organism for maintenance, growth, and reproduction. If other physical and chemical conditions are optimal, excessive amounts of nutrients can lead to degradation of water quality by promoting excessive algal growth and accumulation. The subsequent decay of these algae may also cause depletion of oxygen with adverse effects on other aquatic organisms.
oligochaete	Any of various worms of the class Oligochaeta, including the earthworms.
oligotrophic	A condition of water bodies characterized by relatively low concentrations of nutrients and algae and having good water transparency. An oligotrophic lake has fewer nutrients than a mesotrophic or eutrophic lake.
omnivorous	Animals that eat both animal and vegetable substances.
organic	Pertaining or relating to a compound containing carbon and hydrogen.

organotin	Chemical butyltin containing compounds used in anti-foulant paints to protect the hulls of boats and ships, buoys, and dock pilings from marine organisms such as barnacles
Oregon Administrative Rules (OAR)	Contains all Oregon state regulations adopted by state agencies through the rulemaking process. For example, Chapter 340-41 OAR contains water quality standards.
Oregon Department of Environmental Quality (ODEQ)	The state agency that is responsible for developing, implementing, and enforcing many environmental protection laws and policies in the state of Oregon.
oxygen-demanding substances	Materials, such as domestic and some industrial wastes, and dead plant or animal tissue that use up dissolved oxygen in the water when they are degraded through chemical or biological processes.
parameter	A quantifiable or measurable characteristic. Water quality parameters include temperature, pH, salinity, dissolved oxygen, and the concentration of metals and organic compounds in water, sediments, and fish tissues.
particulate phase	The solid insoluble phase of a substance.
partitioning coefficient	In the equilibrium distribution of a substance between two phases, the constant ratio of the substance's concentration in one phase (e.g., water) to its concentration in the other phase (e.g., sediment).
pathogen	A biologic agent such as a virus, bacterium, or fungus that can cause disease in humans.
pelagic	Associated with or living in the water column as opposed to living on the bottom or along or near the shore.
periphyton	The community of algae that lives attached to submerged surfaces such as rocks or logs.
persistent	Compounds that are not readily degraded by physical, chemical, or biological processes.
pesticide	A general term used to describe chemical substances that are used to kill or control pest organisms. Pesticides include herbicides (for plant control), insecticides (for insect control), and algicides (algae control). Many of these compounds are manufactured and are not naturally found in the environment. Others, such as pyrethrum, are natural toxins that are extracted from plants and animals.

pH	The degree of alkalinity or acidity of a solution. Values of pH greater than the neutral value of 7 indicate alkaline or basic conditions, and values below 7 indicate acidic conditions. The pH value is the logarithm of the hydrogen ion concentration. The pH is the result of and influences chemical reactions that may affect the toxicity of a substance. A low pH may cause some metals to be more toxic (e.g., aluminum) and a high pH may cause other substances to be more toxic (e.g., ammonia).
photosynthesis	The process by which plants (including algae) use light energy to make their own food from carbon dioxide, water, and nutrients.
photosynthetic organisms	Plants and algae that manufacture their own food using light energy, nutrients, and carbon dioxide. In the presence of light these organisms consume carbon dioxide and produce oxygen.
phytoplankton	Algae that are suspended in the water and are carried along by the water currents.
plankton	Planktonic algae (phytoplankton) and small animals (zooplankton) suspended in the water column that drift with the currents or swim weakly.
piscivorous	Animals that feed on fishes.
plutonic rock	Igneous rock that has solidified from magma deep beneath the earth's surface.
point source	A discrete source of pollutants (from municipal, agricultural, or industrial sources) that are discharged from a single point, such as a pipe.
pollution	The input of any substance that changes the natural quality of the water or associated aquatic ecosystem.
pollution indicator species	An organism or species whose presence, absence, or relative abundance indicates that pollutant inputs may be causing an adverse environmental effect. Pollution-tolerant indicator species will generally be relatively abundant, and pollution-intolerant species will be rare or absent. However, if the effects of pollution are severe, few or no organisms remain in the polluted area.
polychaete	A type of annelid worm which is typified by many small hair-like projections on its body.
polychlorinated biphenyls	A group of manufactured chemicals, including about 70 different but closely related compounds, made up of carbon, hydrogen, and chlorine. These compounds are generally very persistent and biomagnify in food chains. PCBs are also suspected of causing cancer in humans.

polycyclic aromatic hydrocarbons	A class of complex organic compounds, some of which are persistent and cancer-causing. These compounds are formed from the combustion of organic material and petroleum products and are ubiquitous in the environment.
polyvalent metal ion	A metal ion or radical with more than one ionic charge.
potable	Water of suitable sanitary and chemical quality for drinking.
pre-emergence	The larval stage of an aquatic insect prior to its transformation and emergence from the water into the adult form.
precipitation	The amount, usually expressed in inches of liquid water depth, of water that has fallen at a given point over a specific time period.
predacious	Organisms that prey upon other organisms.
priority pollutants	Substance listed by the U.S. Environmental Protection Agency under the federal Clean Water Act as toxic and having priority for regulatory controls. The current list includes a total of 126 toxics including 13 metals, 2 inorganic compounds, and 111 organic compounds. The list does not include all known potentially toxic or harmful substances.
protocol	A standardized procedure for field collection, laboratory analysis, and/or interpretation of samples. Good protocols improve the quality of data and make data from different sources comparable.
radioactive decay	Disintegration of the nucleus of an unstable radioactive atom by spontaneous emission of charged particles and/or photons.
radionuclide	Radioactive forms or isotopes of an element.
receiving water	A natural water body (e.g., lake, river, stream, estuary or ocean) that is the recipient of pollutant inputs.
reconnaissance	A type of sampling program designed to determine the current status of something; a preliminary survey.
resuspension	The suspension of previously deposited bottom sediments due to physical disturbance. Resuspension may be caused by the burrowing activity of an organism or by strong river currents.
riverine	Of or pertaining to the river.
salinity	A measure of the quantity of dissolved salts in water.

salmonid	A fish of the family Salmonidae, which include salmon and trout, (as distinct from a salmonoid which is merely a fish that resembles a salmon).
sanitary wastewater	Wastewater which includes domestic sewage and may contain pathogens. Sanitary wastewater is not sanitary (i.e., clean or safe for human use) but contains the water typically used for human sanitation, including shower, bath, sink, toilet, and laundry washing wastewater.
scatter plot	A graph of unordered data which is used to visually discern patterns or relationships.
secondary treatment	A wastewater treatment method that usually involves the addition of biological treatment to the settling, skimming, and disinfection provided during primary treatment. Secondary treatment may remove up to 90 percent of the biochemical oxygen demand and more metals and toxic organic compounds than primary treatment. However, secondary treatment makes more nutrients immediately available from the final discharge due to the enhanced degradation of nutrient-containing organic matter in the secondary treatment process. A third level of treatment (tertiary) may be required to further reduce the nutrient, metal, or toxic organic content of the final effluent.
sedimentary rock	A rock formed by an accumulation of sediments that are subsequently buried and lithified (cemented).
sedimentation	The deposition of suspended material by water, wind, or gravity transport.
semivolatile	An organic compound that can partially vaporize at ambient temperature.
shelf sediment	Sediments deposited on the continental shelf.
shellfish	An aquatic animal, such as a mollusc (clams and snails) or crustacean (crabs and shrimps), having a shell or shell-like exoskeleton.
slack water	Water in which current movement is slight, such as that occurring in backwater areas beyond a stream channel or in an estuary at high or low tide.
slough	A section of an abandoned river channel containing stagnant or slowly moving water.
smelter	An industrial facility where metals are extracted and refined from ores to create raw and/or finished metal products.
sorption	The action of soaking up or attracting substances.

spring tide	A tide with the largest range between high and low tide. The spring tide typically occurs near the time of the new and full moon.
stormwater	Water that is generated by rainfall runoff from impermeable areas, such as streets and parking lots, and is often routed into drain systems to prevent flooding.
sublethal effect	An effect that does not cause immediate death of an organism, but causes more subtle effects such as an increase in metabolic rate, impairment of reproductive capabilities, or the ability to capture prey. These sublethal effects may result in the premature death of the organism, reduce the number of offspring, or threaten the long-term survival of the organism.
surface detention pond	A structure designed to retain wastewater or stormwater to allow for the control of the quantity and the improvement in the quality of water before discharge to a receiving water.
surrogate recovery	The check of laboratory performance by adding a known quantity of a labeled substance to the samples to estimate the efficiency of the recovery of the contaminant measured from the environmental sample.
suspended particles	Solid particles of pollutants, including sediment, that are suspended in water, sewage, or other liquids.
synergistic effect	The increase in the toxicity of a mixture of contaminants, due to interactive effects that results in greater toxicity than would be expected to result from the toxic effects of each individual contaminant.
taxa	A member of a taxonomic group of organisms. In this report, taxa generally refer to organisms identified to genus or species.
taxon	A group of organisms constituting one of the categories or formal units in taxonomic classification and characterized by common characteristics in varying degrees of distinction.
titrant	A standard solution of known concentration and composition used for analytical titrations.
total Kjeldahl nitrogen	The sum of total organic and ammonia nitrogen as measured by the Kjeldahl method.
toxic substance	A substance that, when present in sufficient quantity, may be poisonous or carcinogenic to living organisms.
total suspended solids	The total particles, both mineral (clay and sand) and organic (algae and small pieces of decomposed plant and animal material), that are suspended in water.

trace metal	A metal present in minor amounts in the earth's crust; that is, less than about 0.01 percent.
transformer	An electrical device that can transform (reduce or increase) the voltage of electricity in a transmission line, piece of industrial equipment, or a household appliance.
treatment	Chemical, biological, or mechanical procedures applied to an industrial or municipal discharge, or to other sources of contamination, to remove, reduce, or neutralize contaminants.
tributyltin	An organotin compound that is a potent toxin used in the anti-fouling paints applied to the hulls of boats and ships, buoys, and dock pilings to protect from marine organisms such as barnacles.
tritium	The radioactive isotope of hydrogen with one proton and two neutrons in the nucleus.
turbidity	A measure of the material suspended in the water. Increasing the turbidity of the water decreases the amount of light that penetrates the water column. High levels of turbidity may be harmful to some forms of aquatic life that prefer waters of high transparency.
un-ionized ammonia	Un-ionized ammonia or ammonium is the uncharged form of ammonia. The proportion of un-ionized ammonia increases as the pH increases.
U.S. Environmental Protection Agency (U.S. EPA)	The federal agency that administers many federal environmental laws. U.S. EPA Region X, which includes the area of the lower Columbia River basin in Oregon and Washington, is headquartered in Seattle, Washington.
volatile	An organic compound that can be readily vaporized at ambient temperature.
Washington Administrative Code (WAC)	Contains all Washington state regulations adopted by state agencies through the rulemaking process. For example, Chapter 173-201 WAC contains water quality standards.
Washington Department of Ecology (WDOE)	The state agency that is responsible for developing, implementing, and enforcing many environmental protection laws and policies in the state of Washington.
water column	The water in a lake, estuary, or ocean that extends from the surface of the bottom sediment to the water surface.

water contact recreation	Water recreation activities where people have direct or indirect contact with the water. This may be subdivided into primary contact (activities involving complete submergence such as swimming, water skiing, and skin diving) which would expose the person to bacterial infections, and secondary contact (which includes activities such as wading or fishing) where bacterial infections of the eyes, ears, respiratory or digestive system or urogenital areas would normally be avoided.
watershed	A ridge of high land or the line dividing two areas that are drained by different river systems. In lowland wetland areas this line may be difficult to define precisely.
wet weight	The weight of a sample before it is dried.
zooplankton	Tiny aquatic animals that feed on algae and other zooplankton and which are, in turn, fed upon by many fish and bottom-dwelling organisms.

[a] LIST OF SOURCES OF GLOSSARY TERMS:

Metro. 1987. Quality of local lakes and streams: 1985-1986 status report. Water Resources Section, Water Pollution Control Department, Municipality of Metropolitan Seattle (Metro), Seattle, WA.

Morris, W. (ed). The American Heritage Dictionary of the English language. Houghton Mifflin Company, Boston, MA.

Parker, S.P. (ed). McGraw-Hill dictionary of scientific and technical terms. Third edition. McGraw-Hill Company, New York, NY.

Puget Sound Water Quality Authority. 1990. 1991 Puget Sound Water Quality Management Plan. Adopted November 21, 1990. Puget Sound Water Quality Authority, Seattle, WA.

Rickert, D.A., V.C. Kennedy, S.W. McKenzie, and W.G. Hines. 1977. A synoptic survey of trace metals in bottom sediments of the Willamette River, Oregon. Geological Survey Circular 715-F. Geological Survey, U.S. Department of the Interior, Washington, D.C.

Rickert, D.A., R.R. Petersen, S.W. McKenzie, W.G. Hines, and S.A. Wille. 1977. Algal conditions and the potential for future algal problems in the Willamette River, Oregon. Geological Survey Circular 715-G. Geological Survey, U.S. Department of the Interior, Washington, D.C.

U.S. Department of Health, Education, and Welfare. Radiological health handbook. 1970. Public Health Service, U.S. Department of Health, Education, and Welfare, Washington, D.C.

Washington Administrative Code (WAC). Chapter 173-200 WAC, Chapter 173-201 WAC.

Woodruff, R.K. and R.W. Hanf (eds). 1992. Hanford site environmental report for calendar year 1991. PNL-8148. Prepared for U.S. Department of Energy. Pacific Northwest Laboratory, Richland, WA.