Puget Sound Estuary Program

ELLIOTT BAY ACTION PROGRAM:

The Relationship Between Source Control and Recovery of Contaminated Sediments in Two Problem Areas

TC-3338-23
FINAL REPORT

June 1988

Prepared for
U.S. Environmental Protection Agency
Region X – Office of Puget Sound
Seattle, Washington

TC 3338-23
Final Report

ELLIOTT BAY ACTION PROGRAM:

THE RELATIONSHIP BETWEEN SOURCE CONTROL AND RECOVERY OF CONTAMINATED SEDIMENTS IN TWO PROBLEM AREAS

Prepared by

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for

U.S. Environmental Protection Agency
Region X - Office of Puget Sound
Seattle, WA

June 1988

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PREFACE

This document was prepared by Tetra Tech, Inc. for the U.S. Environmental Protection Agency (EPA) Region X, Office of Puget Sound under the Elliott Bay Action Program work assignment of U.S. EPA Contract No. 68-02-4341. The primary objective of the Elliott Bay Action Program is to identify toxic contamination and appropriate corrective actions in Elliott Bay and the lower Duwamish River. Corrective actions include source controls and sediment remedial actions. An Interagency Work Group (IAWG), comprising representatives from the U.S. EPA, Washington Department of Ecology (Ecology), and other resource management agencies, provides technical oversight for all work conducted under this work assignment.

In this report, the relationship between source control and mitigation of contaminated sediments is evaluated in two problem areas in Elliott Bay. In a subsequent report, preferred alternatives for remediation of contaminated sediments in two Elliott Bay problem areas will be identified.

The following reports are in or have been drafted under the Elliott Bay Action Program:

- Analysis of toxic problem areas (PTI and Tetra Tech 1988)
- Evaluation of potential contaminant sources (Tetra Tech 1988a)
- Development of a revised action plan (PTI and Tetra Tech in preparation)
- Evaluation of the relationship between source control and recovery of contaminated sediments (this report)

- Development of a storm drain monitoring approach (Tetra Tech 1988d)

- Evaluation of sediment remedial alternatives (Tetra Tech 1988b)

- Development of a monitoring approach (EVS and Tetra Tech in preparation).

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ACKNOWLEDGMENTS

This document was prepared by Tetra Tech, Inc., under the direction of Dr. Jean M. Jacoby, for the U.S. Environmental Protection Agency in partial fulfillment of Contract No. 68-02-4341.

This project was funded through the National Estuary Program under the authorities of the Clean Water Act as amended. Funding was approved by the U.S. EPA Office of Marine and Estuarine Protection. Dr. Jack Gakstatter and Ms. Clare Ryan served as U.S. EPA Project Officers, and Dr. Don Wilson served as the Tetra Tech Program Manager.

The primary authors of this report are Ms. Lynne Kilpatrick-Howard, Dr. Jean Jacoby, and Dr. William Brownlie of Tetra Tech. Dr. Don Wilson assisted in modification of the model formulation and provided critical technical review of this document. Ms. Marcy Brooks-McAuliffe of Tetra Tech performed technical editing and supervised report production. The approach presented in this document is based on work conducted for the Commencement Bay Nearshore/Tideflats Feasibility Study by Tetra Tech for Ecology and U.S. EPA. Mr. G. Patrick Romberg of Municipality of Metropolitan Seattle (Metro) and Dr. Lucinda Jacobs of PTI Environmental Services provided technical guidance on various aspects of this report. Evaluation of sources of contaminants in the study areas was performed by Ms. Beth Schmoyer of Tetra Tech. Ms. Stacey Vineberg of Tetra Tech provided data management support and assisted in the model execution.

The Elliott Bay Toxics Action Program has benefited from the participation of IAWG and a Citizen's Advisory Committee (CAC). Duties of the IAWG and CAC members included 1) reviewing program documents, agency policies, and proposed actions; 2) providing data reports and other technical information to U.S. EPA; and 3) disseminating action program information to respective interest groups or constituencies. We thank the IAWG and CAC members for their past and continuing efforts. We are especially grateful

to Ms. Joan Thomas, Mr. Gary Brugger, and Mr. Dan Cargill for chairing the IAWG, and to Mr. David Schneidler and Ms. Janet Anderson for co-chairing the CAC.

EXECUTIVE SUMMARY

The goal of the Elliott Bay Action Program is to identify toxic contamination and appropriate corrective actions to mitigate contamination in Elliott Bay and the lower Duwamish River. Under this program, federal, state, and local agencies cooperate to respond to toxic contamination problems. One component of this program involves predicting the natural recovery of contaminated sediments in areas undergoing source control actions.

This study was undertaken to evaluate the relationship between source control and mitigation of sediment contamination in two high-priority problem areas in Elliott Bay, Seattle, Washington. An Interagency Work Group, comprising representatives from the U.S. EPA, Ecology, and other resource management agencies, selected the Denny Way and Slip 4 problem areas based on chemical contamination in offshore sediments. The time necessary for sediment concentrations to be reduced to the target cleanup goal after complete source elimination is estimated for each problem area through the application of the Sediment Contamination Assessment Model (SEDCAM), which was developed during the Commencement Bay Nearshore/Tideflats Feasibility Study (Tetra Tech 1987a). In addition, the fraction of source control required to maintain sediment concentrations at the level of the target cleanup goal is predicted for each problem area. The target cleanup goals are based on the "apparent effects threshold" (AET) approach (Tetra Tech 1986). The focus of the AET approach is to identify concentrations of contaminants in sediments that are associated with statistically significant biological effects (relative to reference conditions). The results of this study are intended to provide guidance for Ecology and U.S. EPA in the use of sediment contamination data and sediment criteria in toxic source control activities.

The formulation of the relationship between source loading and sediment accumulation of problem chemicals is essential to the development of sediment recovery scenarios. Variables that are important in understanding the sediment accumulation process include:

- The concentration of problem chemicals in recently deposited material and surface sediments
- Sedimentation rate
- Mixed layer depth
- The rate at which problem chemicals are lost due to biodegradation and diffusion across the sediment water interface.

SEDCAM is a mass balance equation that utilizes these variables to predict contaminant concentrations in surficial sediments as a function of time. The mass balance allows the change in concentration of a contaminant to be expressed as a function of contaminant input by accumulation and contaminant losses by burial and decay.

The rate at which sediments accumulate and the extent of their mixing in surficial layers are processes that influence the ability of the environment to dilute and attenuate contaminant input. Therefore, information on sediment accumulation and mixing processes in a given problem area is essential to adequately predict how concentrations of chemicals found in the surface mixed layer vary over time.

Very few core samples have been collected in either the Denny Way or Slip 4 problem areas that allow accurate characterization of the sedimentation rate and mixed layer depth over the spatial area of contamination. The depositional parameters in the Denny Way problem area were estimated based on studies performed by Romberg et al. (1987) in the vicinity of the outfall and by Carpenter et al. (1985) in shallow central Puget Sound bays. Two sedimentation rates (0.7 and 0.2 cm/yr) were selected for the model based on

the above studies to provide a range in sediment recovery scenarios in this area.

Depositional patterns in riverine systems are not well characterized and sedimentation rates in these systems are expected to be highly variable. Therefore, sedimentation rates of 0.8 cm/yr and 2.0 cm/yr were estimated for the Duwamish River Slip 4 problem area. The rate, 0.8 cm/yr, is expected to be a minimum rate resulting in longer sediment recovery times than those estimated using a sedimentation rate of 2.0 cm/yr. In addition to sedimentation rates, mixing depth, chemical persistence (i.e., decay rate), concentration of contaminants in the surface mixed layer, and the concentration of the incoming contaminants are important processes controlling the concentration of contaminants in surface sediments.

A mixed layer depth of 10 cm was estimated for both problem areas and is based on work by Carpenter et al. (1985) as well as the Commencement Bay Feasibility Study (Tetra Tech 1987b). Decay rates for problem chemicals were estimated during the Commencement Bay Feasibility Study (Tetra Tech 1987b) and were negligible for most chemicals. The concentration of a contaminant in the surface mixed layer was estimated to be the maximum concentration of the chemical observed in the problem area. This estimation is expected to be the most environmentally protective and thus the predicted recovery times are a maximum. The concentration of an incoming contaminant was estimated as a function of the concentration in the mixed layer and the degree of source control applied.

The sediment recovery results predicted by SEDCAM are based on four assumptions. First, the relationship between source loading and sediment accumulation prior to source control is assumed to be constant over time. This is the steady-state assumption. If source loading has increased or decreased recently the steady-state assumption will either over estimate or under estimate the recovery time of sediments. Second, the recommended sediment cleanup goals, which are based on Apparent Effects Threshold (AET) values, are assumed to be appropriate. Third, the implementation of source

control measures is assumed to be feasible. And fourth, the model assumes that mixing in the surface mixed layer occurs instantaneously.

Mercury, fluoranthene, chrysene, butyl benzyl phthalate, bis(2-ethylhexyl)phthalate, 4,4'-DDT, and total PCBs were selected as indicator chemicals for the development of sediment recovery scenarios in the Denny Way CSO problem area. In addition, for the purpose of evaluating the sediment recovery time for a metal other than mercury, sediment recovery scenarios were also developed for zinc. The predicted effect of complete source elimination on the recovery time of the indicator chemicals is based on the maximum concentration observed in the surface sediments for each indicator chemical. At a sedimentation rate of 0.2 cm/yr, it was estimated that acceptable surface sediment concentrations (i.e., less than the sediment cleanup goals) of mercury will not be achieved in the problem area before 90 yr after loading has been eliminated. Zinc concentrations, on the other hand, could reach the cleanup goal in approximately 40 yr. Acceptable surface sediment concentrations of fluoranthene, chrysene, butyl benzyl phthalate, bis(2-ethylhexyl)phthalate, and 4,4'-DDT will be achieved between 135 and 180 yr. In contrast, at a sedimentation rate of 0.7 cm/yr, sediment concentrations of mercury are expected to be reduced to an acceptable level in approximately 27 yr. At this sedimentation rate, zinc is predicted to recover in 12 yr, while acceptable concentrations of the additional indicator chemicals are expected to be achieved between 37 and 52 yr.

The predicted effect of completely eliminating source input to Slip 4 on the recovery time of sediments contaminated with chromium, fluoranthene, PCBs, and 4,4'-DDD is based on the maximum concentration observed for these chemicals in the problem area. At a sedimentation rate of 0.8 cm/yr, the model predicts that concentrations of chromium and fluoranthene will reach acceptable levels between 11 and 15 yr. Acceptable concentrations of 4,4'-DDD are expected to be achieved in approximately 37 yr, while PCB concentrations are not predicted to recover for 48 yr. In contrast, at a sedimentation rate of 2.0 cm/yr, it is estimated that acceptable levels of PCBs in Slip 4 could be achieved 19 yr after loading has been eliminated. At this sedimentation rate, acceptable surface sediment concentrations of

chromium, fluoranthene, and 4,4'-DDD are predicted to be achieved between 5 and 15 yr after 100 percent source control has been implemented.

There are several factors that limit the ability of the model to precisely reproduce real-world conditions. Some of the limitations are inherent in the formulation of the model while others are based on the lack of available data. The most significant limitations of the model include the following:

- The availability of accurate sediment accumulation rates
- The accurate quantification of chemical-specific decay rates
- The assumption that mixing in the surface mixed layer occurs instantaneously
- The availability of source loading and ancillary data
- The appropriateness of the steady-state assumption.

However, SEDCAM can be a useful tool to assess the relationship between source control and the recovery of contaminated sediments despite its limitations. Several factors have been identified that would facilitate the refinement of the model:

- Improved contaminant loading data
- Well-characterized sediment accumulation rates and sediment depositional patterns
- Applicable chemical-specific decay rates due to biodegradation and diffusion
- Validation of sediment recovery predictions through monitoring.

Based on the application of SEDCAM to the two high-priority problem areas in Elliott Bay the following conclusions can be drawn:

- Source elimination alone is not expected to result in sediment recovery in either the Denny Way CSO problem area or Slip 4 within a reasonable timeframe because of the current level of contamination

- Following sediment remediation, source control levels of 94 percent or greater in the Denny Way CSO and 98 percent or greater in Slip 4 will be required to maintain acceptable sediment quality in each problem area.

1.0 INTRODUCTION

1.1 OBJECTIVES

This study was undertaken to evaluate the relationship between source control and mitigation of sediment contamination in two high-priority problem areas in Elliott Bay, Seattle, Washington. The degree of source control required to attain acceptable sediment concentrations in a reasonable timeframe and in the long term is estimated. The feasibility of attaining acceptable levels in a reasonable timeframe will help determine appropriate corrective actions, including sediment remedial measures.

This document provides guidance for Ecology and U.S. EPA in the use of sediment contamination data and sediment criteria in toxic source control activities. The approach presented in this document is based on work conducted for the Commencement Bay Nearshore/Tideflats Feasibility Study (Tetra Tech 1987a). In that study, sediment recovery was predicted through application of the SEDCAM. The appropriateness of SEDCAM for use in Elliott Bay and Duwamish River habitats is evaluated in this document. The model is then applied to estimate natural sediment recovery in two problem areas within Elliott Bay.

1.2 OVERVIEW OF STUDY

Evaluation of the relationship between source control and sediment recovery is based on data collected and compiled in support of the Elliott Bay Action Program to identify and rank problem areas, chemicals, and contaminant sources (PTI and Tetra Tech 1988; Tetra Tech 1988a). This evaluation consists of three major components: 1) technical approach, 2) model application, and 3) limitations and recommendations.

Section 2.0 provides a description of the technical approach. In this section, sources of contaminants, cleanup goals, and problem chemicals are

identified. In addition, the relationship between contaminant sources and sediment accumulation is formulated and model parameters are identified. In Section 3.0, results of the model as applied to the two selected problem areas are presented. Potential limitations and recommended modifications of the model are discussed in Section 4.0.

1.3 STUDY AREA

Elliott Bay is a small embayment (21 km^2) located on the eastern shore of Puget Sound approximately midway between Admiralty Inlet and the Tacoma Narrows (Figure 1). The bay lies adjacent to the City of Seattle (estimated population of 488,200). The inner bay receives fresh water from the Duwamish River, a salt-wedge estuary whose mean runoff varies from approximately 12 m^3/sec in August to approximately 82 m^3/sec in January (Baker et al. 1983). The nearshore areas of Elliott Bay, as well as the lower reaches of the Duwamish River, have been significantly altered from their natural states. The lower 6 mi of the once-meandering river is now a straightened navigational channel, and the formerly expansive Seattle mudflats are now the equally vast industrial areas of the city.

Two problem areas were selected by the IAWG to evaluate the relationship between source control and recovery of contaminated sediments. One of the two problem areas selected by the work group was the Denny Way combined sewer overflow (CSO) and its associated receiving environment. This site was selected because sediments are highly contaminated and because ancillary source and offshore data from previous studies are available (PTI and Tetra Tech 1988). The work group recommended that the Denny Way CSO site also be used to evaluate sediment remedial alternatives under a separate task of the Elliott Bay Action Program (Tetra Tech 1988b). The second site selected by the work group was Slip 4 in the Duwamish River. Polychlorinated biphenyl (PCB) contamination in storm drain and offshore sediments prompted selection of this site. It was also selected to allow evaluation of the SEDCAM approach in a riverine environment. The selected sites are described below.

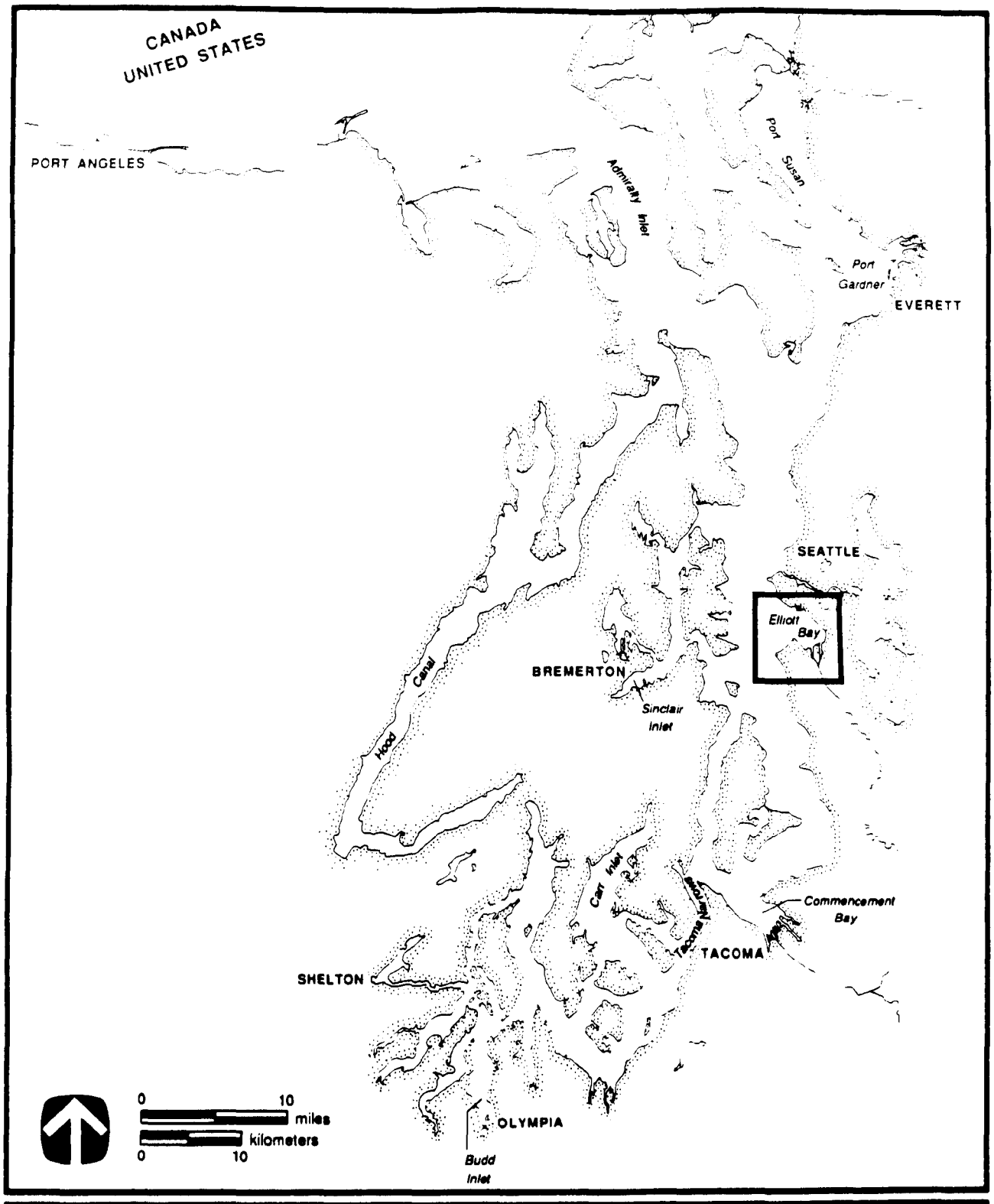


Figure 1. Project location: Elliott Bay and the lower Duwamish River.

1.3.1 Denny Way CSO Site

The Denny Way CSO, located along the northern shore of Elliott Bay (Figure 2), is the largest CSO discharging untreated wastewater into Elliott Bay. It discharged a total average volume of 500 Mgal/yr from approximately 30 to 60 events during wet years 1981-1983 when trunk lines leading to the municipal wastewater treatment plant overflowed (Romberg et al. 1987). These are referred to as overflow events. The service area consists of approximately 1,900 ac of mixed residential and commercial land. Although toxicant loading from this CSO has been decreasing in recent years, the Denny Way CSO has been identified as a major contributor of toxicants to bottom sediments near the site (Romberg et al. 1987; PTI and Tetra Tech 1988). Elevated concentrations of organic toxicants and heavy metals are present in bottom sediments near the outfall (Tomlinson et al. 1980; Malins et al. 1980; Romberg et al. 1984; Romberg et al. 1987; PTI and Tetra Tech 1988). In addition, altered benthic communities have been observed concomitant with elevated chemical concentrations in the vicinity of the outfall (Armstrong et al. 1978; Cominskey et al. 1984; Chapman et al. 1982). Recent source control efforts by Metro have reduced toxicant loading to the CSO (Romberg et al. 1987). However, sediment remedial actions may be required to improve environmental conditions in offshore sediments (Romberg and Sumeri 1988). Extensive spatial coverage of contaminant concentrations in the vicinity of the outfall facilitated identification of problem chemicals at this site.

1.3.2 Duwamish River Slip 4

Slip 4 is a riverine slip in the Duwamish River (Figure 2). The slip is an area of concern because highly elevated concentrations of PCBs have been measured in surficial sediments (summarized in Appendix B of Tetra Tech 1988d). High levels of PCBs have also been measured in sediments from three of the four storm drains that discharge to the slip. It is not known whether there is an ongoing source of PCBs in this drainage basin. A more detailed discussion of the source status of Slip 4 is presented in Section 3.3.

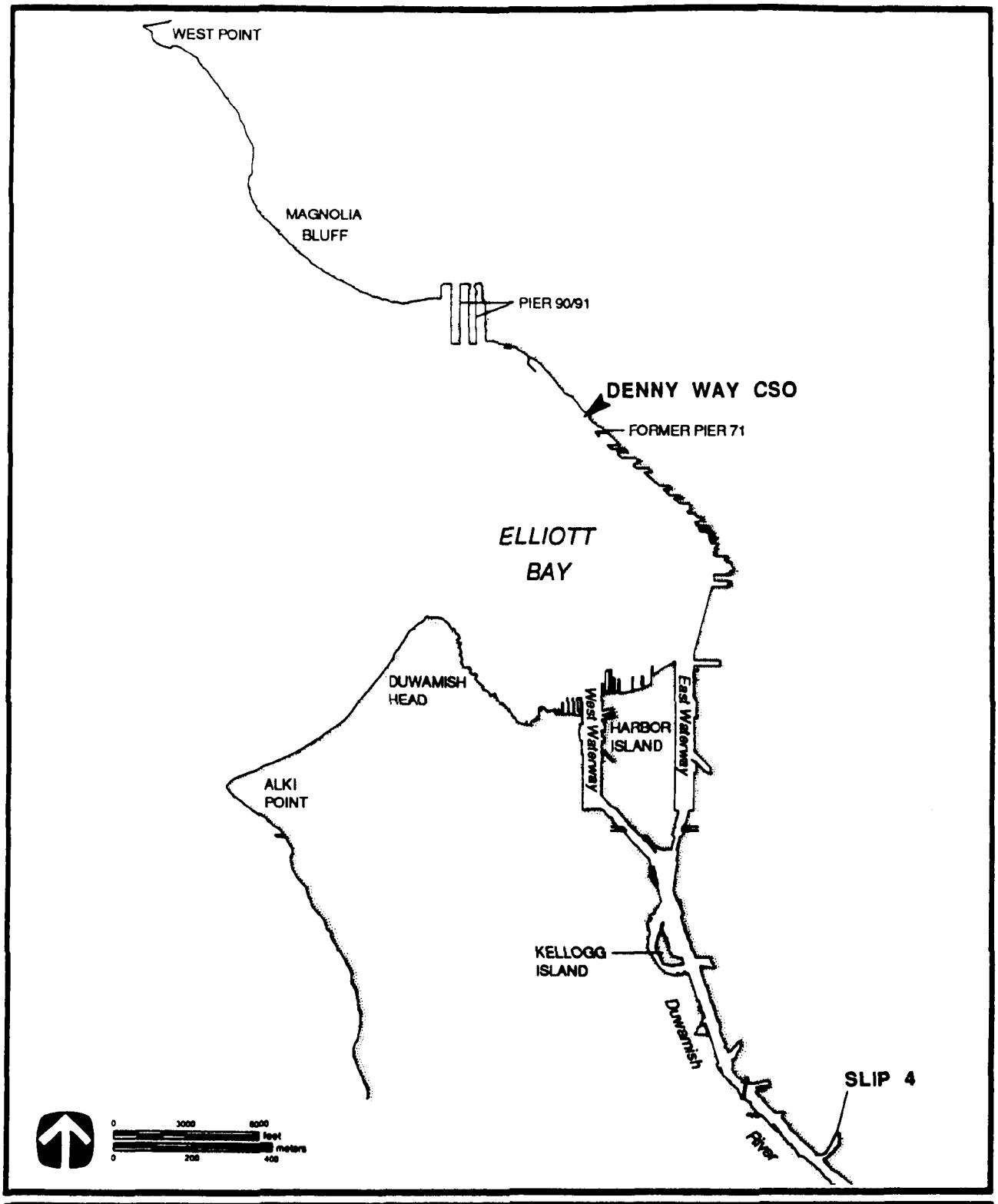


Figure 2. Problem area locations: Denny Way CSO and Slip 4.

The SEDCAM approach was not developed for use in a riverine habitat, and lack of available data on sedimentation rates and contaminant loading estimates may limit its application in the Duwamish River. The compounding effects of dredging, navigation, river currents and variable sedimentation rates in the Duwamish River may also limit its application.

2.0 TECHNICAL APPROACH

There are six components of the approach leading to the development of sediment recovery scenarios (Figure 3):

- Identification of cleanup goals
- Identification of problem areas and problem chemicals
- Identification of sources
- Formulation of an analytical approach to examine the relationship between source loading and sediment accumulation of problem chemicals
- Identification of key parameters
- Evaluation of the predicted response of sediments to source control.

Each component is detailed in the following sections.

2.1 IDENTIFICATION OF CLEANUP GOALS

A working definition of acceptable chemical concentration is required prior to assessing whether sediments will recovery in a reasonable timeframe. Because criteria for sediments are not yet available, target cleanup goals are based on the AET approach (Tetra Tech 1986). The focus of the AET approach is to identify concentrations of contaminants in sediments that are associated with statistically significant biological effects (relative to reference conditions). Biological indicators used to develop AET values include benthic infauna abundance and toxicity bioassays (i.e., amphipod mortality, oyster larvae abnormality, and Microtox bioluminescence). For a

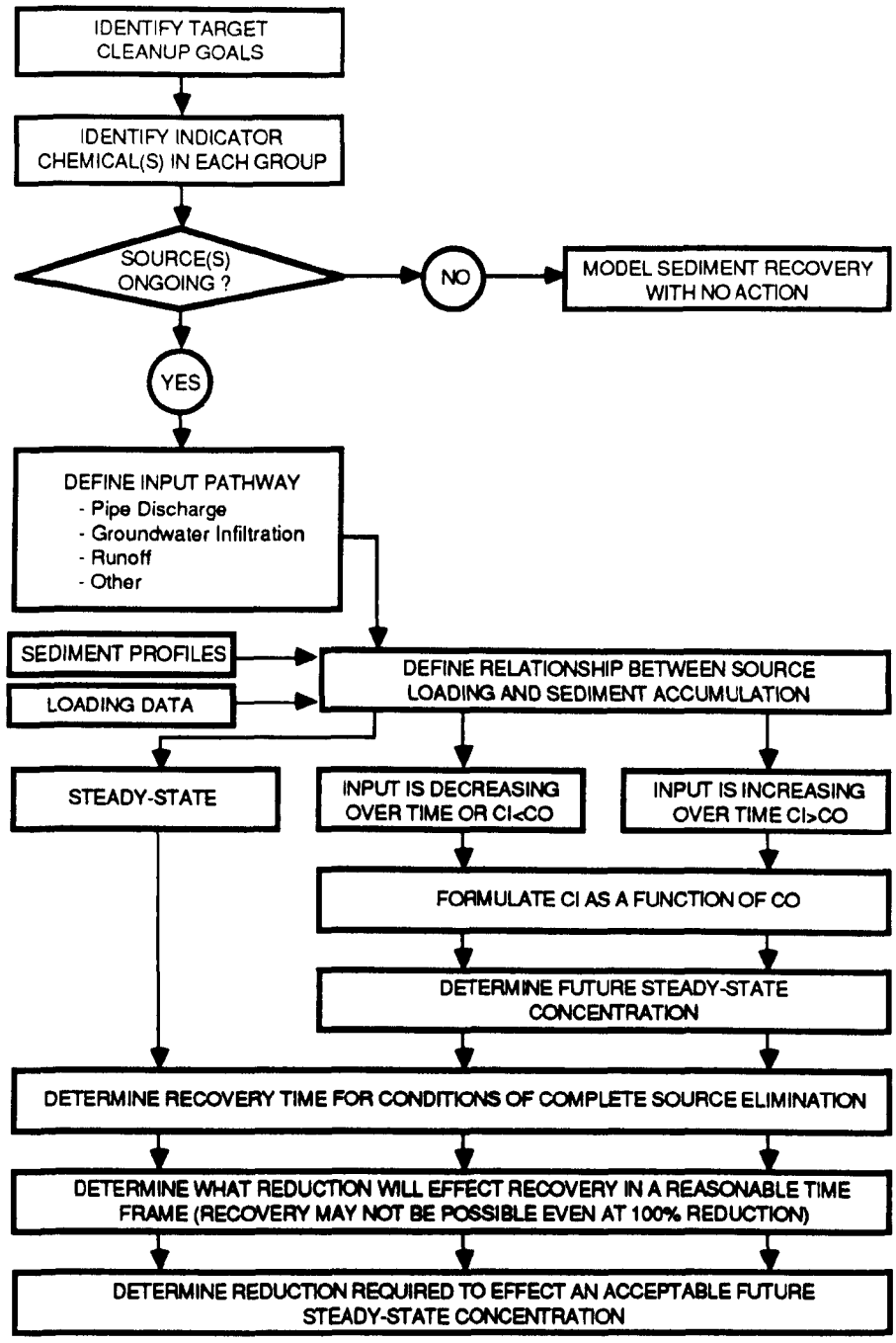


Figure 3. Flow chart for the development of sediment recovery scenarios.

given chemical and a specific biological indicator, the AET is the concentration above which statistically significant biological effects occurred in all samples of sediments analyzed. AET values have been proposed for 64 organic and inorganic toxic chemicals using synoptic chemical and biological data from 200 stations in Puget Sound (Tetra Tech 1987b). For each chemical, a separate AET was developed for each biological indicator, resulting in four sets of AET values. A list of the highest and lowest AET for each chemical is provided in Table 1. Target cleanup goals are based on the lowest AET value for problem chemicals.

AET values for iron, manganese, nickel, antimony, and chromium were not used as cleanup goals or to identify chemicals. Iron and manganese are not normally considered toxic chemicals. The AET values for antimony and chromium were not used because of the likelihood that analytical methods used to generate the AET for these chemicals are not directly comparable to the methods used in all historical studies. The AET value for nickel was not used because the range of nickel concentrations in the database used to generate Puget Sound AET values is relatively limited (PTI and Tetra Tech 1988).

The use of the lowest AET as the target cleanup goal is considered to yield criteria with a high degree of environmental protectiveness and thus leads to the development of "worst-case" sediment recovery scenarios. Because the model is sensitive to the value of the target cleanup goal, confidence in the estimated recovery times depends in part on the uncertainty inherent in the AET values. For some contaminants (e.g., total PCBs) the most sensitive biological indicator results in a target cleanup goal that is significantly lower than that produced by any of the other indicators.

2.2 IDENTIFICATION OF PROBLEM CHEMICALS

Problem chemicals were assigned priority based on the relative number of stations in each study area where concentrations exceeded the target cleanup goal. Chemistry data compiled from the following references were utilized to identify the problem chemicals in each of the study areas:

TABLE 1. PUGET SOUND AET VALUES
(ug/kg dry weight = ppb for organic compounds;
mg/kg dry weight = ppm for metals)

	Lowest AET[a]	Highest AET
LPAH[b]	5,200	6,100
Naphthalene	2,100	2,400
Acenaphthylene	560	640
Acenaphthene	500	980
Fluorene	540	1,800
Phenanthrene	1,500	5,400
Anthracene	960	1,900
HPAH[c]	12,000	38,000
Fluoranthene	1,700	9,800
Pyrene	2,600	11,000
Benzo(a)anthracene	1,300	4,500
Chrysene	1,400	6,700
Benzofluoranthenes	3,200	8,000
Benzo(a)pyrene	1,600	6,800
Indeno(1,2,3-c,d)pyrene	600	880
Dibenzo(a,h)anthracene	230	1,200
Benzo(g,h,i)perylene	670	5,400
Total PCBs	130	2,500
Total Chlorinated Benzenes	170	680
1,3-Dichlorobenzene	--	--
1,4-Dichlorobenzene	110	260
1,2-Dichlorobenzene	35	50
1,2,4-Trichlorobenzene	31	64
Hexachlorobenzene	70	230
Total Phthalates	3,300	3,400
Dimethyl phthalate	71	160
Diethyl phthalate	200	200
Di-n-butyl phthalate	1,400	1,400
Butyl benzyl phthalate	63	470
Bis(2-ethylhexyl) phthalate	1,900	1,900

TABLE 1. (Continued)

	Lowest AET[a]	Highest AET
Pesticides		
4,4'-DDE	9	15
4,4'-DDD	2	43
4,4'-DDT	3.9	11
Phenols		
Phenol	420	1,200
2-Methylphenol	63	63
4-Methylphenol	670	1,200
2,4-Dimethyl phenol	29	29
Pentachlorophenol	--	--
2-Methoxyphenol	930	930
Miscellaneous Extractables		
Hexachlorobutadiene	120	290
1-Methylphenanthrene	310	370
2-Methylnaphthalene	670	670
Biphenyl	260	270
Dibenzothiophene	240	250
Dibenzofuran	540	540
Benzyl alcohol	57	73
Benzoic acid	650	650
n-Nitrosodiphenylamine	40	220
Volatile Organic Compounds		
Tetrachloroethene	140	140
Ethyl benzene	33	37
Total xylenes	100	120
Metals		
Antimony	3.2	26
Arsenic	85	700
Cadmium	5.8	9.6
Copper	310	800
Lead	300	700
Mercury	0.41	2.1
Nickel	28	49
Silver	5.2	5.2
Zinc	260	1,600

TABLE 1. (Continued)

[a] By definition, the lowest AET is the sediment cleanup goal.

[b] LPAH = Low molecular weight polynuclear aromatic hydrocarbons.

[c] HPAH = High molecular weight polynuclear aromatic hydrocarbons.

Reference: Tetra Tech (1987b).

- Denny Way CSO
  - Malins et al. (1980)
  - Romberg et al. (1984)
  - Romberg et al. (1987)
  - PTI and Tetra Tech (1988)
- Duwamish River Slip 4
  - U.S. EPA (1982-1983)
  - Schlender, M. (16 April 1985, personal communication)
  - Sample, T. (23 October 1987, personal communication)
  - PTI and Tetra Tech (1988).

These data are presented in Appendices A and B.

For chemicals that were measured at multiple stations within a problem area, a high priority was assigned if the compound was detected at a concentration greater than the target cleanup level in at least 40 percent of the samples. A low priority was assigned to chemicals that were detected at a frequency of 40 percent or less. In addition, a low priority was assigned to contaminants which were analyzed for at only one station within a problem area.

In each problem area, indicator chemicals were identified. Indicator chemicals are those chemicals that are expected to drive sediment recovery scenarios and dictate sediment remedial action. In general, these indicator chemicals were selected from those classified as high priority. If no more than two compounds within each chemical compound class (e.g., metals, LPAH, HPAH) were assigned a high priority, each chemical was identified as an

indicator chemical. If more than two compounds within a chemical class were designated as high priority then the entire class of compounds was considered a potential problem. Indicator chemicals within the problem class were selected based on the following criteria:

- Frequency of target cleanup goal exceedances
- Spatial distribution of concentrations exceeding the cleanup goals
- Magnitude of cleanup goal exceedance
- Resistance to degradation.

A schematic of the process used to identify high priority, low priority, and indicator chemicals is presented in Figure 4. For each problem area, the SEDCAM approach was used to estimate the changes in concentrations over time of indicator chemicals in the surface sediments in each problem area.

2.3 IDENTIFICATION OF SOURCES

The status of contaminant sources is a critical element in the development of sediment recovery scenarios. Sources can be classified either as ongoing or historical. In addition to active industries, ongoing sources include industries that have ceased activities but whose property contains contaminants that can still be transported to the marine environment. Historical sources consist of industries that have ceased activities and whose property no longer contains contaminants that can be transported to the marine environment. Historical sources require no further characterization. Thus, sediment recovery scenarios can be developed with the assumption that input from historical sources is negligible.

Ongoing sources require further characterization before sediment recovery scenarios can be developed. Characterization of ongoing sources should include the following factors:

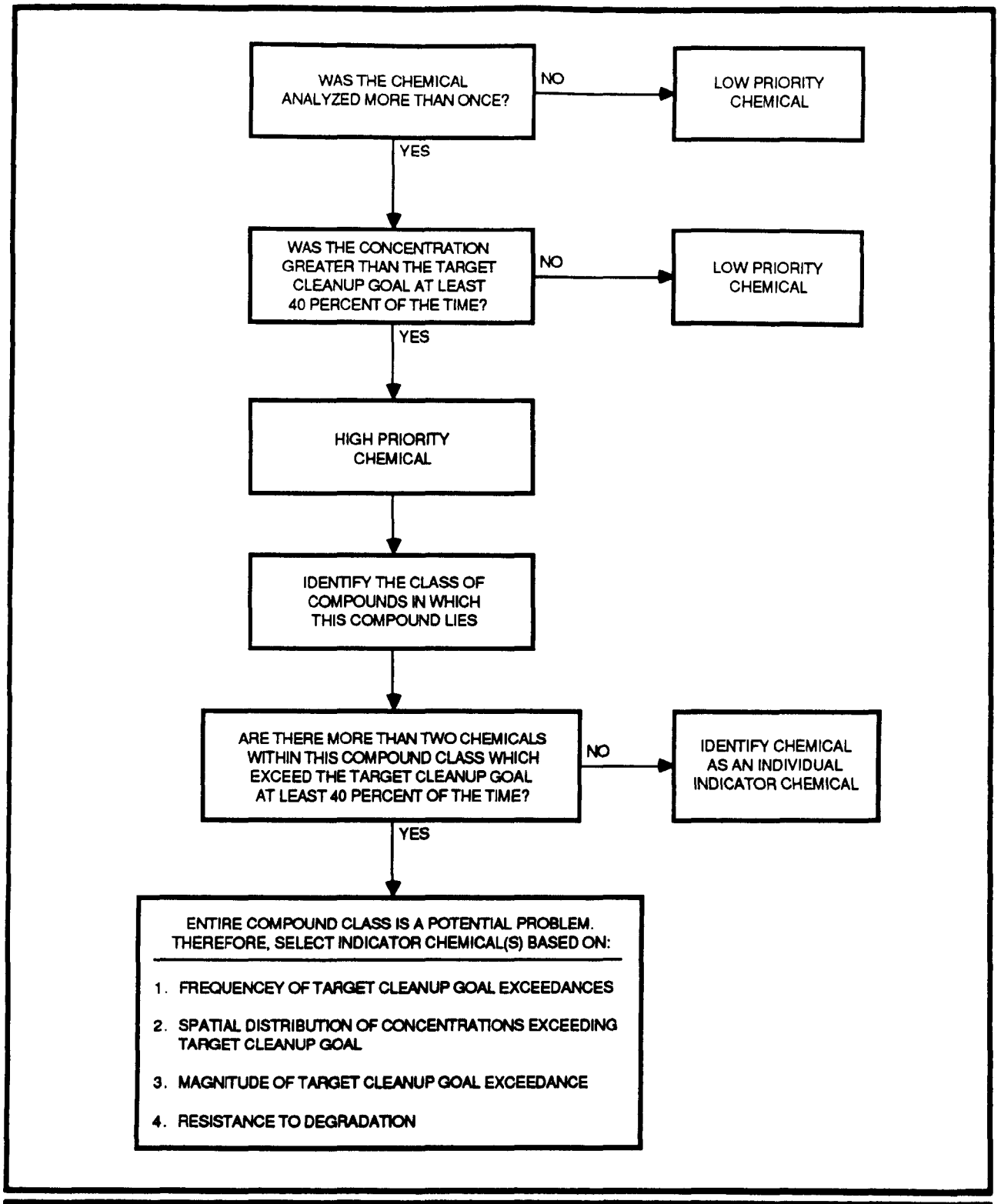


Figure 4. Flow chart for the identification of indicator chemicals.

- Transport pathway to the marine environment (e.g., groundwater infiltration, storm drain, ditch, process effluent pipe)

- Temporal trends in source loading

- Short-term variability in source loading.

The transport pathway will determine the type of source control technologies that can be applied, which in turn will determine the extent to which sources can be controlled. These facets of source control are not discussed in this document, but are relevant to the future assessment of remedial alternatives. Loading rates may vary significantly with time, especially in cases where loading is dependent on precipitation (e.g., storm drains) or sporadic disposal events (e.g., spills).

Source identifications for problem chemicals in the study areas was complicated by a lack of source loading data. Major sources of problem chemicals in the two study areas were identified under the Elliott Bay Action Program (Tetra Tech 1988a) on the basis of one or more of the following factors: proximity to areas of sediment contamination, known use or disposal of a characteristic problem chemical, and measured loading of problem chemicals. Major sources of problem chemicals detected in the surficial sediment offshore of the Denny Way CSO were identified by Romberg et al. (1987) and are summarized in Section 3.2.1. Information on sources of contaminants to Slip 4 was compiled from a variety of studies and is presented in Section 3.3.1.

2.4 FORMULATION OF THE SEDIMENT RECOVERY MODEL

The formulation of the relationship between source loading and sediment accumulation of problem chemicals is essential to the development of sediment recovery scenarios. Processes that influence the sediment concentration of contaminants include 1) temporal changes in source input, 2) sediment accumulation and mixing, 3) biodegradation, and 4) diffusive losses across the sediment-water interface. An exact mathematical representation of these processes would be extremely complex and would require an extensive

amount of data, much of which are unavailable. SEDCAM is a mass balance equation that attempts to predict the sediment concentration of contaminants in relation to source loading, sedimentation rates, mixing, biodegradation, and loss across the sediment-water interface. The model was developed for and applied to the waterways of Commencement Bay (Tetra Tech 1987a) and is evaluated here for application to two problem areas in Elliott Bay. SEDCAM estimates the time required for concentrations of contaminants in sediments to decrease to levels that are considered acceptable and is used to assess the potential success of source control.

The simplicity of the model limits its ability to precisely reproduce real-world conditions, but in the absence of more detailed knowledge of processes and parameters affecting sediment contamination and recovery, the model allows some predictions to be made.

The rate at which sediments accumulate and the extent of their mixing in surficial layers are processes that influence the ability of the environment to dilute and attenuate contaminant input. Therefore, information on sediment accumulation and mixing processes in a given problem area is essential to adequately predict how concentrations of chemicals found in the surface mixed layer vary over time.

Total sediment accumulation comprises both natural "background" particulates and particulates deriving from contaminated sources. In the absence of contaminant input, the accumulation of natural sediments buries contaminated surface sediments, effectively decreasing the toxicity of surface sediments. However, sediment mixing attenuates this effect by mixing the deeper contaminated sediments upward to the surface. The following variables are important in understanding the sediment accumulation process:

- Concentration of problem chemicals in recently deposited material

- Concentration of problem chemicals in surface sediments

- Sedimentation rate
- Depth of the surface mixed layer
- Rate at which problem chemicals are lost because of biodegradation and diffusion.

The sediment recovery model utilizes the above variables to predict contaminant concentrations in surficial sediments as a function of time.

The link between contaminant source and sink is illustrated schematically in Figure 5. The variation in chemical concentration (C) in the surface mixed layer with time (t) is derived from a mass balance and is described by the differential equation:

$$\frac{dC}{dt} = \frac{C_I * S}{D} - \frac{C * S}{D} - k_c * C \qquad (1)$$

change in concentration = accumulation - burial - decay over time

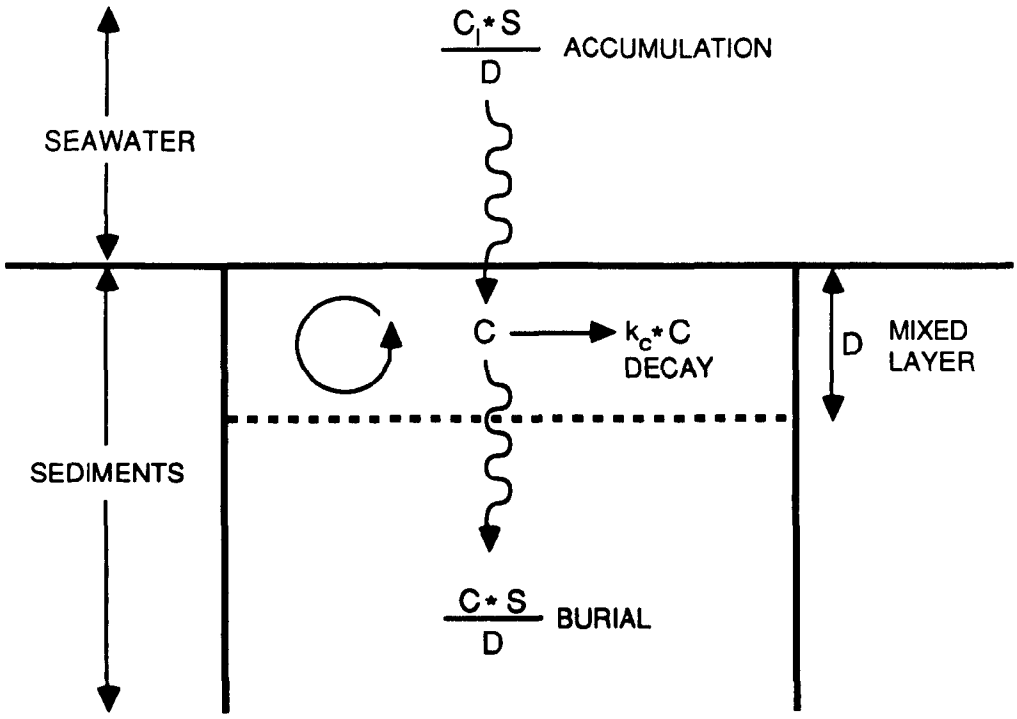
where:

C = Chemical concentration in the surface mixed layer (mg/g)
C_I = Concentration of contaminant in recently deposited material after source control (mg/g)
S = Rate of accumulation of solid material in the sediments (cm/yr)
D = Depth of sediments in the surface mixed layer (cm)
k_c = Combined first-order rate constant for contaminant loss by in situ degradation and diffusive loss (1/yr).

The solution to this equation is:

$$C = \frac{S}{(S+k_cD)} * C_I * \quad 1 - e^{\frac{-(k_cD+S)t}{D}} + C_o * e^{\frac{-(k_cD+S)t}{D}} \qquad (2)$$

where:



C_I = CHEMICAL CONCENTRATION IN RECENTLY DEPOSITED SEDIMENT (mg/g)
C = CHEMICAL CONCENTRATION IN SURFACE MIXED LAYER (mg/g)
S = SEDIMENT ACCUMULATION RATE (cm/yr)
D = DEPTH OF THE MIXED LAYER (cm)
k_c = FIRST ORDER DECAY CONSTANT (1/yr)

Figure 5. Schematic of processes controlling chemical concentrations in surface sediments.

t = time (yr)

C_0 = Concentration of contaminant in the surface mixed layer at $t = 0$ (mg/g).

The analytical solution assumes the following conditions:

- C_I, S, D, and k_c are constant after source control implementation
- The sediment that constitutes the mixed layer is well mixed
- C_I represents the concentration of contaminant in recently deposited material that settles (or is deposited) beyond the sediment-water interface.

The parameter C_0 is the initial concentration of a chemical contaminant in surface sediments. The distribution of problem chemical concentrations in Elliott Bay sediments were determined as part of the Elliott Bay Action Program (PTI and Tetra Tech 1988) and related studies. The maximum concentration of a problem chemical in surface sediments of a problem area was used in this report to calculate sediment recovery time. The maximum concentration of nearly all metals and organic compounds was observed at the stations located closest to the outfalls. If dredging is conducted, C_0 must be represented by the contaminant concentration in the sediment horizon exposed by dredging activity. The determination of other parameters (i.e., sedimentation rate, mixing depth, and decay constant) is more complex, and is described in the following section.

2.5 PARAMETER IDENTIFICATION

Sedimentation rate, mixing depth, chemical persistence (i.e., decay constant), and chemical loading are important processes controlling the concentration of contaminants in surface sediments. Sedimentation rate and mixing depth were not determined as part of the Elliott Bay Action Plan, and are estimated from other studies conducted in Puget Sound and in similar

environments (Carpenter et al. 1985; Lavelle et al. 1986; Tetra Tech 1987a). Chemical persistence was evaluated for selected chemicals during the Commencement Bay Feasibility Study (Tetra Tech 1987a). The approach and decay constants determined as part of that study are described here. In addition, any simplifying assumptions that eliminate the need to specify all parameters which compose C_I will be presented.

2.5.1 Sediment Accumulation

Sediment accumulation rates are necessary to determine the time that will elapse between controlling sources of contamination and reducing surficial sediment concentrations (i.e., the response time). The sedimentation rate (S) (cm/yr) is related to the mass accumulation rate (R) (mg/cm^2 yr) by the following expression:

$$R = S\ (1 - p)d \tag{3}$$

where:

p = porosity of sediments (unitless)
d = dry density of sediment (mg/cm^3).

Sediment rates determined for the waterways within Commencement Bay were derived from the analysis of excess Pb-210 and ranged from 0.14 cm/yr to 1.77 cm/yr (Tetra Tech 1987a). Recent Pb-210-derived mass accumulation rates estimated by Carpenter et al. (1985) for shallow bays in the central Puget Sound region range from 110 to 260 mg/cm^2 yr and result in sedimentation rates of 0.22-0.66 cm/yr for sediment porosity equal to zero.

The technique of measuring changes in excess Pb-210 activity with depth is often used in nearshore sediments because lead has a strong affinity for particles. In addition, the half-life of the isotope (22 yr) is appropriate to the time scale of sediment accumulation. However, the accuracy of the technique depends in part on constant sedimentation and Pb-210 accumulation rates. Factors unique to the environmental setting of the two selected problem areas complicate the application of this technique. These factors include dredging activities, shipping traffic, bluff erosion, and temporal

changes in deposition rates influenced by anthropogenic activities. Because of these complications, a successful application of the excess Pb-210 technique to the sediments offshore from the Denny Way CSO and in the Duwamish riverine slip would not be anticipated. Alternative methods that may be used to estimate the rate of sediment accumulation are described in Tetra Tech (1987a) and include the following:

- Evaluation of sediment core discontinuities
- Evaluation of dredging records
- Review of bathymetric records
- Assessment of particulate loading from point sources.

The method used to estimate the sediment accumulation rate in the absence of Pb-210 data in each problem area is described in more detail in Sections 3.2.2 and 3.3.2.

2.5.2 Surface Mixed Layer

Mixing of near-surface deposits occurs as a result of several factors including the activity of benthic organisms. The mixing layer depth can have a major influence on the response time of contaminant concentrations in sediments after sources have been controlled. The value of the depth of the surface mixed layer is important to the application of SEDCAM because it effectively defines the size of the reservoir that will attenuate concentration changes brought on by source control. This is illustrated by considering the hypothetical case where the mixed layer depth is measured to be zero. In terms of the model, this means that any change in the concentration of a contaminant in incoming sediments is instantly registered in the concentration of the surface sediments. Carpenter et al. (1985) observed surface mixed layer depths ranging from 7.3 to 11 cm in central Puget Sound shallow bays. The depths of the mixed layer determined for the Commencement Bay waterways during the Commencement Bay Nearshore/Tideflats Feasibility Study were derived from the analysis of excess Pb-210 and ranged from 0 to

20 cm (Tetra Tech 1987a). A mixed layer depth of 10 cm was assumed to best represent the average mixed layer depth in the Elliott Bay problem areas.

2.5.3 Chemical Persistence

SEDCAM incorporates a chemical-specific first-order rate constant, k_c, to represent the rate of total loss of contaminants from sediments that is not accounted for by burial. The formulation of loss as first-order decay assumes that loss is only a function of chemical concentration. The processes considered most likely to cause contaminant losses from sediments are microbial degradation and diffusion into the overlying water column. In situ degradation and diffusion can effectively reduce sediment contaminant concentrations over time, and thus are important considerations when estimating recovery times. Microbially mediated degradation may also be formulated as a zero- or second-order equation. The assumption of first-order decay represents a generalized simplification of the degradation process. Losses due to diffusion and biodegradation can be represented by the following differential equation:

$$\frac{dC}{dt} = k_c * C = k_{bio} * C + k_{dif} * C \qquad (4)$$

where:

C = Contaminant concentration in sediment at time t (mg/g)
k_c = Combined first-order decay constant (1/yr)
k_{bio} = Biodegradation component of decay constant (1/yr)
k_{dif} = Diffusive component of decay constant (1/yr).

The approach used in the Commencement Bay Nearshore/Tideflats Feasibility Study (Tetra Tech 1987a) and applied to the Elliott Bay problem areas was to select the lowest, most environmentally protective decay rate values. Such k values will result in upper estimates of recovery times for problem areas. Even relatively small decay rate constants have a marked effect on estimates of C (final sediment concentration at a given time). For example, if sedimentation rate and total sediment depth in the mixed layer are typically 1 cm/yr and 14 cm, respectively, and a value of k_c = 0.07/yr

(equivalent to a half-life of 9.9 yr, if half life = $0.693/k_c$) is assumed, the expression in the exponential term of the solution to the model (Equation 2) is as follows:

$$\frac{k_c D + S}{D} = \frac{(0.07*14) + 1}{14} = \frac{0.98 + 1}{14} \qquad (5)$$

Under the environmental conditions described above, a first-order decay constant of 0.07/yr has an effect on recovery times similar to doubling the sedimentation rate. As the decay rate constant decreases, its effect on the recovery time of sediments diminishes. At a very small k, the recovery time is dependent primarily on the sedimentation rate and the mixed layer depth.

Microbial degradation incorporates most chemical processes that could be expected to degrade compounds (e.g., oxidation, reduction, hydrolysis) and is typically more efficient than abiotic chemical degradation processes because of enzymatic catalysis (see Vogel et al. 1985). Also, the eventual mineralization of organic compounds (i.e., degradation to inorganic constituents, such as CO_2 and H_2O) has been attributed almost entirely to biodegradation (Lyman et al. 1982).

Losses associated with diffusion across the sediment-water interface were incorporated into k values only for compounds for which mobility was expected to be significant (based on octanol-water partition coefficients, or k_{ow}, which are indices of mobility of nonpolar organic compounds in sediment/water systems). Diffusion was considered negligible for organic compounds with log k_{ow} values >4 for reasons described in Commencement Bay Nearshore/Tideflats Feasibility Study (Tetra Tech 1987a). Diffusive losses would be expected to be minor for the nonpolar organic contaminants (e.g., PCBs) with high k_{ow} values and correspondingly low aqueous solubilities.

The relative contributions of biodegradation and diffusion to the combined first-order decay constant determined in the Commencement Bay Nearshore/Tideflats Feasibility Study (Tetra Tech 1987a) for metals, PCBs, polyaromatic hydrocarbons, chlorinated benzenes, trichloroethene (TCE),

tetrachloroethene (TECE), and 4-methylphenol were applied to the model for both Elliott Bay problem areas. The lowest values were chosen to estimate first-order decay constants when possible. For all chemicals except TCE, TECE, and 4-methylphenol, a value of 0/yr was assigned. A value of 0.69/yr (i.e., half-life of 1 yr) was selected to represent potential diffusive loss for TCE, TECE, and 4-methylphenol. These values should be refined if and when empirical data become available.

2.5.4 Incoming Contaminant Concentration

The parameter C_I is the concentration of a problem chemical in recently deposited sediments after source control. SEDCAM is used to evaluate sediment recovery through the reduction of C_I. Because the value of C_I is difficult to determine, the formulation of the parameter depends on the amount of information available and the applicability of the simplifying assumptions. C_I can be formulated as a function of the following variables:

- Source loading prior to source control
- Fraction reduction in loading due to source control measures
- Fraction of contaminant lost in transit between the point of discharge and the point of deposition
- Depositional area
- Sedimentation rate.

However, simplifying assumptions that eliminate the need to specify all of the parameters noted are desirable.

In many cases, a steady-state assumption can be applied (i.e., that the system was in steady-state prior to implementation of source control measures). This simply means that the input rate equals the removal rate, so that the concentration of the contaminant in the well-mixed box (see Figure 5) does not vary over time. The steady-state assumption is a useful

simplification because the incoming contaminant concentration (C_I) does not have to be quantified and can be represented by the equation:

$$C_I = C_o * f_L * \frac{S + k_c D}{S} \tag{6}$$

For the cases where $k_c = 0$, C_I can be directly determined from C_o and the degree of source control, f_L. Thus, Equation 6 becomes:

$$C_I = C_o * f_L \tag{7}$$

Estimating C_I from source loading data was not practical in the application of SEDCAM to either the area offshore from the Denny Way CSO or the Duwamish River Slip 4. Source loading data are only available for selected chemicals in the Denny Way CSO. Source loading of contaminants to Slip 4 has not been determined to date. Therefore, the steady-state assumptions were applied and C_I was formulated as a function of C_o, as in Equation 6.

In general, there are three cases that represent the relationship between source loading and sediment accumulation prior to source control:

- Source loading is increasing over time, or surficial sediment concentrations have not yet increased to levels supported by accumulating contaminated particles

- Source loading is decreasing over time, or surficial sediment concentrations have not yet adjusted to recent decreases in contaminant loading

- Source loading is in steady-state with sediment accumulation.

Temporal trends in loading may be derived from source loading data, disposal chronologies, and sediment profiles of problem chemicals. If source loading has either increased or decreased recently, the steady-state approximation

(i.e., $C_I = C_o$) will underestimate or overestimate the concentration in recently deposited sediments.

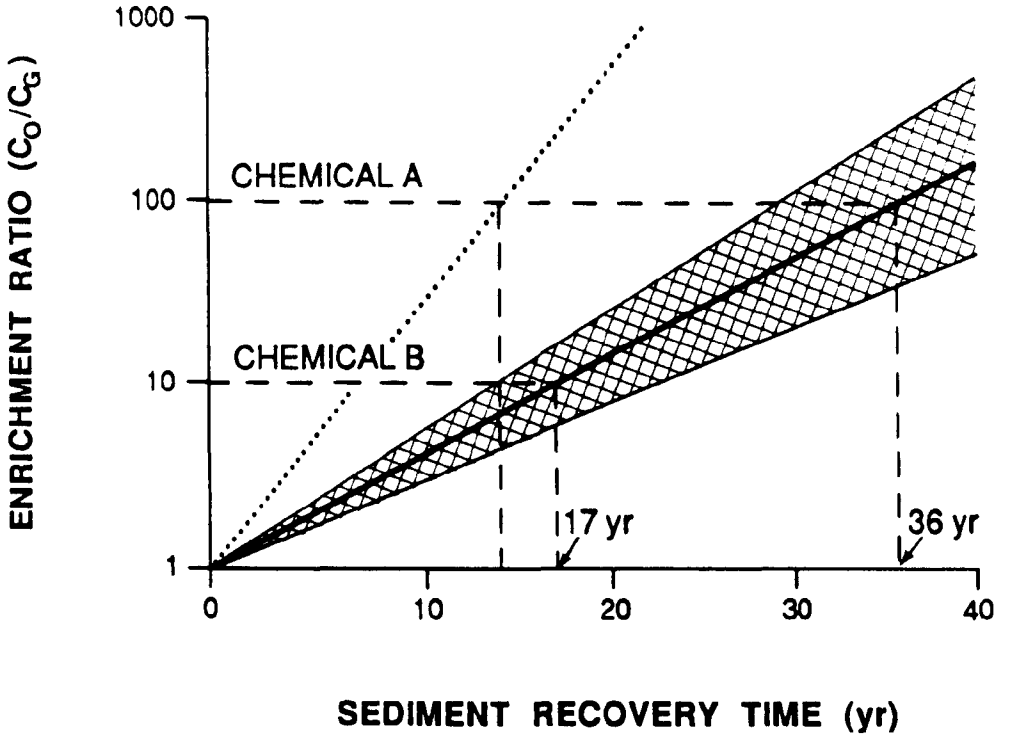
3.0 APPLICATION

In this section, sediment recovery scenarios are developed using SEDCAM for two selected problem areas in Elliott Bay. Several important pieces of information are derived from the sediment recovery scenarios:

- Recovery times if sources of contamination are completely eliminated
- Degree of source control required to effect sediment recovery in the long term
- Long-term effect of not controlling sources.

Recovery times predicted for complete source elimination provide a framework for evaluating the effectiveness of source control and the relative severity of contamination by different problem chemicals. The degree of source control required to effect sediment recovery in a reasonable timeframe will be greater than that required for long-term recovery; mixing of the surface sediments delays recovery, and the added time constraint must be compensated for by more extreme source control measures. In many cases, recovery in a reasonable timeframe may not be possible even with complete source elimination because chemical concentrations in sediments are too high or the sediment accumulation rate of clean material is too low. The long-term effects of not controlling sources is only of interest for chemicals associated with sources that are not in steady-state with sediment accumulation (i.e., sources that are relatively new, or have displayed pronounced increases or decreases in loading rates).

Results from the application of SEDCAM are presented in the format shown in Figure 6. For complete source elimination, estimated recovery time varies logarithmically with the ratio of contaminant concentration in surface sediments to its respective cleanup goal (C_O/C_G) (the enrichment



LEGEND

ESTIMATED UNCERTAINTY OF 20 PERCENT

SLOPE DETERMINED BY SEDIMENTATION RATE AND MIXED LAYER DEPTH (ASSUMES FIRST ORDER DECAY RATE CONSTANT EQUALS ZERO)

SLOPE DETERMINED BY SEDIENTATION RATE, MIXED LAYER DEPTH, AND FIRST ORDER DECAY

Figure 6. Schematic of hypothetical sediment recovery modeling results.

ratio). The slope of the line is determined by the sedimentation rate and mixing depth specific to each problem area. For chemicals that are degradable, the first-order decay constant may significantly influence the slope of the line. The influence some of hypothetical first-order decay on the recovery time of chemical A is shown in Figure 6 (dotted line) as a decrease in recovery time from 36 to 14 yr. Uncertainty in values assigned to depth of the mixed layer, sedimentation rate, and decay constant influences the uncertainty in the estimated recovery time. The hatched area around the solid line in Figure 6 represents an estimated uncertainty of 20 percent.

For certain problem chemicals, the enrichment ratio on the y-axis is corrected for background concentrations. For example, all metals have naturally occurring sediment concentrations. These concentrations become important if they approach the value designated as cleanup goal. In Puget Sound, for enrichment ratios exceeding 1, corrections greater than 10 percent are only required for the metals zinc, mercury, and copper. The corrected enrichment ratio is defined by:

$$\frac{C_O'}{C_G'} = \frac{C_O - C_B}{C_G - C_B} \tag{8}$$

where C_B is the background concentration and C_G is the target cleanup goal.

3.1 MODEL APPLICATION ASSUMPTIONS

The results from the application of the SEDCAM model to the two problem areas in Elliott Bay are based on the following assumptions:

- The relationship between source loading and sediment accumulation is constant over time (steady-state assumption)

- The recommended target cleanup goals are appropriate

- The implementation of source control measures is feasible

- Mixing in the surface mixed layer occurs instantaneously.

Given the dynamic nature of the environmental setting of both problem areas, the steady-state assumption is not expected to represent the true relationship between source loading and sediment accumulation. However, the assumption simplifies the application of the model when little or no source loading data are available.

The recommended cleanup goals are based on the most sensitive of a range of biological indicators. However, alternative goals may be based on a narrower range of biological indicators and less conservative sediment recovery scenarios may result.

The feasibility of source control depends on the ability to positively identify source inputs and pathways and therefore varies with each problem area.

The assumption that mixing in the surface mixed layer occurs instantaneously simply allows an analytical solution to the differential equation (Equation 1) that describes the variation in contaminant concentration in the mixed layer with time.

3.2 DENNY WAY CSO

3.2.1 Source Summary

The Denny Way CSO is the largest discharger to Elliott Bay and most frequent overflow point in Metro's combined sewer system. The Denny Way CSO discharges into Elliott Bay north of the Seattle downtown area at Denny Way. It produced a total average overflow volume of 500 Mgal/yr from approximately 30-60 overflow events during wet years 1981-1983 when trunk lines leading to the municipal wastewater treatment plant overflowed (Romberg et al. 1987). The service area consists of almost 1,900 ac of mixed residential and

commercial land. In previous studies, contaminated sediments and altered benthic communities have been found offshore from the Denny Way CSO.

In 1986, Metro conducted a trial study in the Denny Way CSO drainage basin to determine if toxicant sources could be identified and reduced, pending a structural solution to eliminate CSO discharges (Romberg et al. 1987). As part of the investigation, Metro developed an inventory of 530 potential sources in the drainage basin based on Standard Industrial Codes (SIC) and addresses from tax records. A questionnaire on wastewater discharges and chemical use was sent to each company identified as a potential source. Fifty-four percent of the businesses contacted responded to the questionnaire. Those businesses that failed to respond were visited or contacted by phone. Ninety-six potential sources were visited by Metro inspectors to confirm the questionnaire survey information and collect information to help develop practical source control strategies. In addition, sediment and wastewater samples were collected at key points within the CSO system (Figure 7) and analyzed for metals and organic toxicants. Wastewater samples were collected for two different events at most stations and sediment samples were collected once at each station (Romberg et al. 1987).

The highest metals concentrations in both wastewater and sediment samples were measured in stations downstream of two industrial laundries that discharge wastewater to the Denny Way CSO. In addition, a large volume of accumulated sediments in one part of the CSO system (Lake Union Tunnel), located downstream of both laundries, was found to have high metals concentrations. Both laundries installed new pretreatment equipment in 1986 to reduce the toxicant loadings in their discharges. Based on preliminary data, metals loadings in sediments and wastewater were estimated to have been reduced by 50 percent for copper, 77 percent for lead, and 24 percent for zinc after the pretreatment systems were installed (Romberg et al. 1987).

High concentrations of chromium and mercury in in-line discharge samples were traced to a movie film developing facility. The facility has been directed to use proper disposal practices, and as a result, the

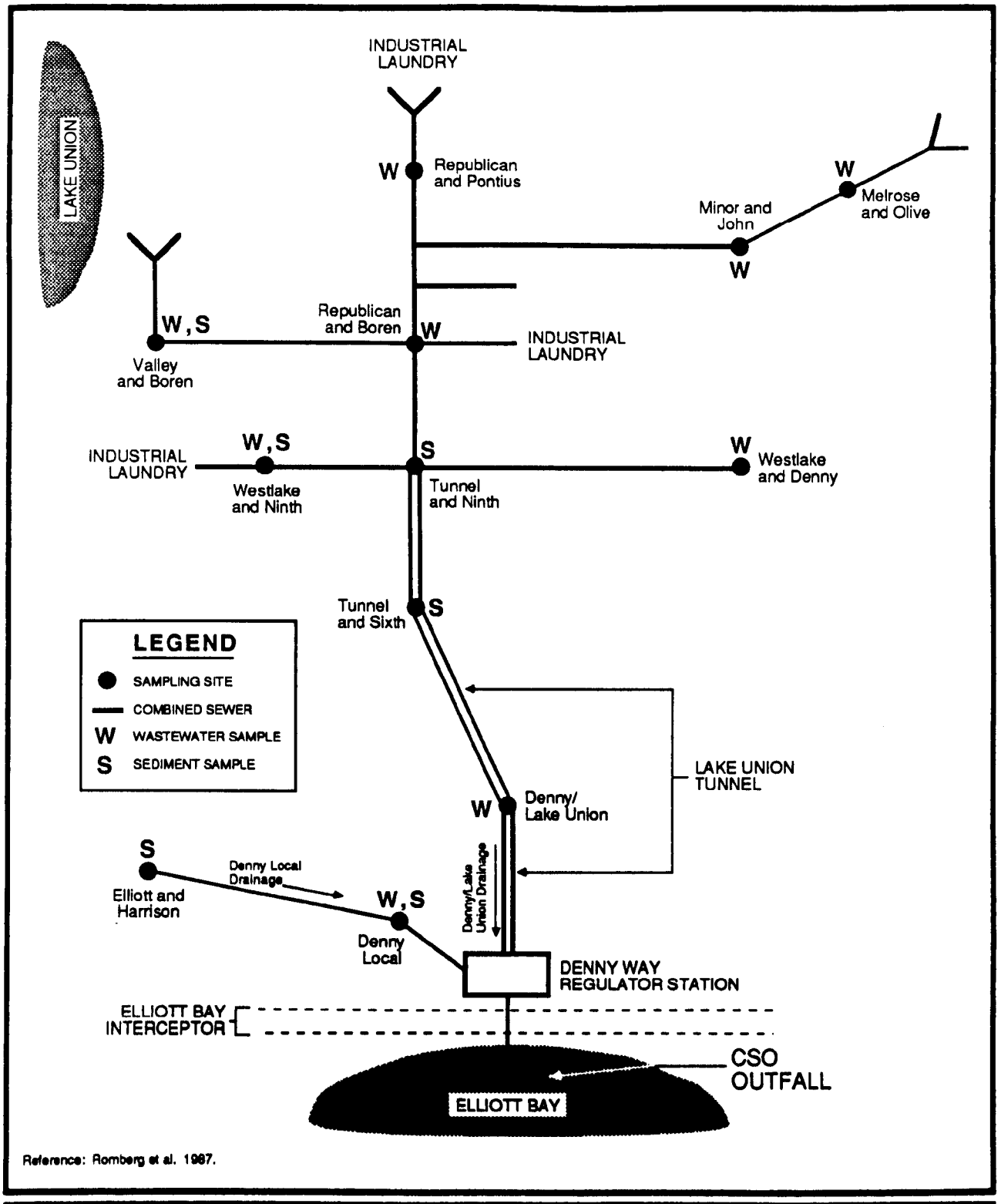


Figure 7. Sampling station locations in Metro's Denny Way CSO source toxicant investigation.

toxicant input from this source is expected to be eliminated or greatly reduced (Romberg et al. 1987).

Analyses of organic compounds were generally not as effective in tracing contaminant sources as analyses of metals because of large variations in organic compound concentrations among different sampling events at one station. However, concentrations of toluene, tetrachloroethane, and ethyl benzene were typically highest (range of 50-200 ug/L) in the wastewater samples collected downstream of the two industrial laundries (Romberg et al. 1987). These three volatile organic compounds were also present at relatively high concentrations (300-800 ug/kg wet weight) in sediment samples collected immediately downstream of the laundries. In addition, naphthalene appeared to be associated with the industrial laundries because it was present (8.5-170 ug/L) only in wastewater samples collected downstream of these two industrial laundries.

Metro is currently evaluating removal of the contaminated sediments to prevent them from being flushed into Elliott Bay. In addition, improvements in the stormwater routing program to enhance in-line storage, and a notification and control system to reduce source toxicant discharges when overflows occur are under consideration (Romberg et al. 1987). Projected source control measures are anticipated to reduce the number of CSO events from 50 events/yr to approximately 10 events/yr (Romberg and Sumeri 1988). Projected stormwater separation measures are anticipated to reduce the number of CSO events to approximately 10 events/yr by the mid-1990s (Romberg and Sumeri 1988).

3.2.2 Identification of Indicator Chemicals

Mercury, fluoranthene, chrysene, butyl benzyl phthalate, bis(2-ethylhexyl)phthalate, 4,4'-DDT, and total PCBs were selected as indicator chemicals for the development of sediment recovery scenarios in the Denny Way CSO problem area. In addition, for the purpose of examining sediment recovery times for a metal other than mercury, sediment recovery scenarios were also developed for zinc. Table 2 identifies all of the compounds determined to have an enrichment ratio greater than 1 for at least

TABLE 2. IDENTIFICATION OF INDICATOR CHEMICALS IN DENNY WAY CSO OFFSHORE SEDIMENTS

Compound	Largest Enrichment Ratio	Number of Historical Analyses with Ratio >1	Number of PTI and Tetra Tech (1988) Analyses with Ratio >1	Total No. of Analyses with Ratio >1	Number of Samples Analyzed	Percent of Samples with Ratio >1
Metals						
Cadmium	1.1	2	0	2	35	6
Lead	1.8	6	0	6	42	14
Silver	1.6	1	1	2	7	29
Zinc	2.1	14	0	14	42	33
Mercury	6.4	32	1	33	36	92
LPAH						
Phenanthrene	66	8	0	8	24	33
Anthracene	42	6	0	6	25	24
Fluorene	58	4	0	4	21	19
Acenaphthene	26	1	0	1	21	5
Total LPAH	36	3	0	3	21	14
HPAH						
Fluoranthene	36	10	0	10	25	40
Pyrene	14	6	0	6	25	24
Benzo(a)anthracene	8.2	8	0	8	23	35
Chrysene	19	10	0	10	23	43
Benzo(a)pyrene	4.7	6	0	6	23	26
Indeno(1,2,3-cd)pyrene	2.2	8	0	8	23	35
Benzo(g,h,i)perylene	2.1	7	0	7	22	32
Benzo(b+k)floranthene	5.1	4	0	4	21	19
Total HPAH	13	7	0	7	21	33
Chlorinated Benzenes						
1,4-dichlorobenzene	--	--	DL > AET[a]	--	1	--
1,2-dichlorobenzene	--	0	DL > AET	--	1	--
1,2,4-trichlorobenzene	--	0	DL > AET	--	1	--
hexachlorobenzene	--	0	DL > AET	--	1	--
Phthalates						
Butylbenzylphthalate	29	17	0	17	21	81
di-n-butyl phthalate	1.2	2	0	2	22	9
Dimethylphthalate	2.5	1	0	1	22	5
Bis (2-ethylhexyl) phthalate	28	13	0	13	20	65
Total phthalates	17	13	0	13	21	62

TABLE 2. (Continued)

Pesticides/PCBs						
4,4'-DDE	2	1	0	1	2	50
4,4'-DDD	6	1	DL > AET	1	2	50
4,4'-DDT	24	1	DL > AET	1	2	50
Total PCBs	20	27	DL > AET	27	33	82
Phenols						
Phenol	4.5	4	0	4	21	19
Pentachlorophenol	5.6	2	0	2	21	10

[a] Method detection limit exceeded cleanup goal.

one of the 42 stations. In addition, several chlorinated benzene compounds are listed. A determination of whether concentrations of the chlorinated benzenes exceeded the cleanup level could not be made. The only analysis for these compounds resulted in a detection limit that exceed the cleanup goal. Locations of the 42 sampling stations are presented in Figure 8. Areal distributions of the indicator chemicals (except 4,4'-DDT) are presented in Figures 9-15. The contaminant 4,4'-DDT was measured at only 2 stations [NS-01 (PTI and Tetra Tech 1988) and S0032 (Romberg et al. 1984)]. An enrichment ratio of 24 was determined at Station S0032 but a ratio at Station NS-01 could not be calculated because the method detection limit exceeded the target cleanup level. Appendix A summarizes the data evaluated to identify the indicator chemicals in the Denny Way CSO problem area.

3.2.3 Identification of a Sediment Accumulation Rate

Application of the Pb-210 age-dating method to samples collected in the area offshore from the Denny Way CSO provided inconclusive results (Romberg et al. 1987). However, Romberg et al. (1987) estimated a sediment accumulation rate of 0.7 cm/yr by observation of a distinctive feature in a core sample collected at Station 7 (see Figure 8). At Station 19, the closest Metro station to the outfall, a sedimentation rate of 1.4 cm/yr was determined by the same method. These estimated rates may have been influenced by recent excavation and building activities in the area. Therefore, the measured rates are assumed to be greater than those that might have been obtained if the setting had been undisturbed (Romberg, P., 7 March 1988, personal communication).

After implementation of source control, the sediment deposition rate around the CSO would be expected to decrease and would depend on the degree of source control applied. In the absence of CSO discharges, the Duwamish River, whose thin lens surface plume clings to the eastern shore of Elliott Bay, may become the primary source of particulates to the area. However, a recent study indicated that directly beyond the sources, most (i.e., 90 percent) of the suspended particulate matter from the Duwamish River remains in suspension and is transported to the main basin of Puget Sound within 5 days (Curl et al. 1987).

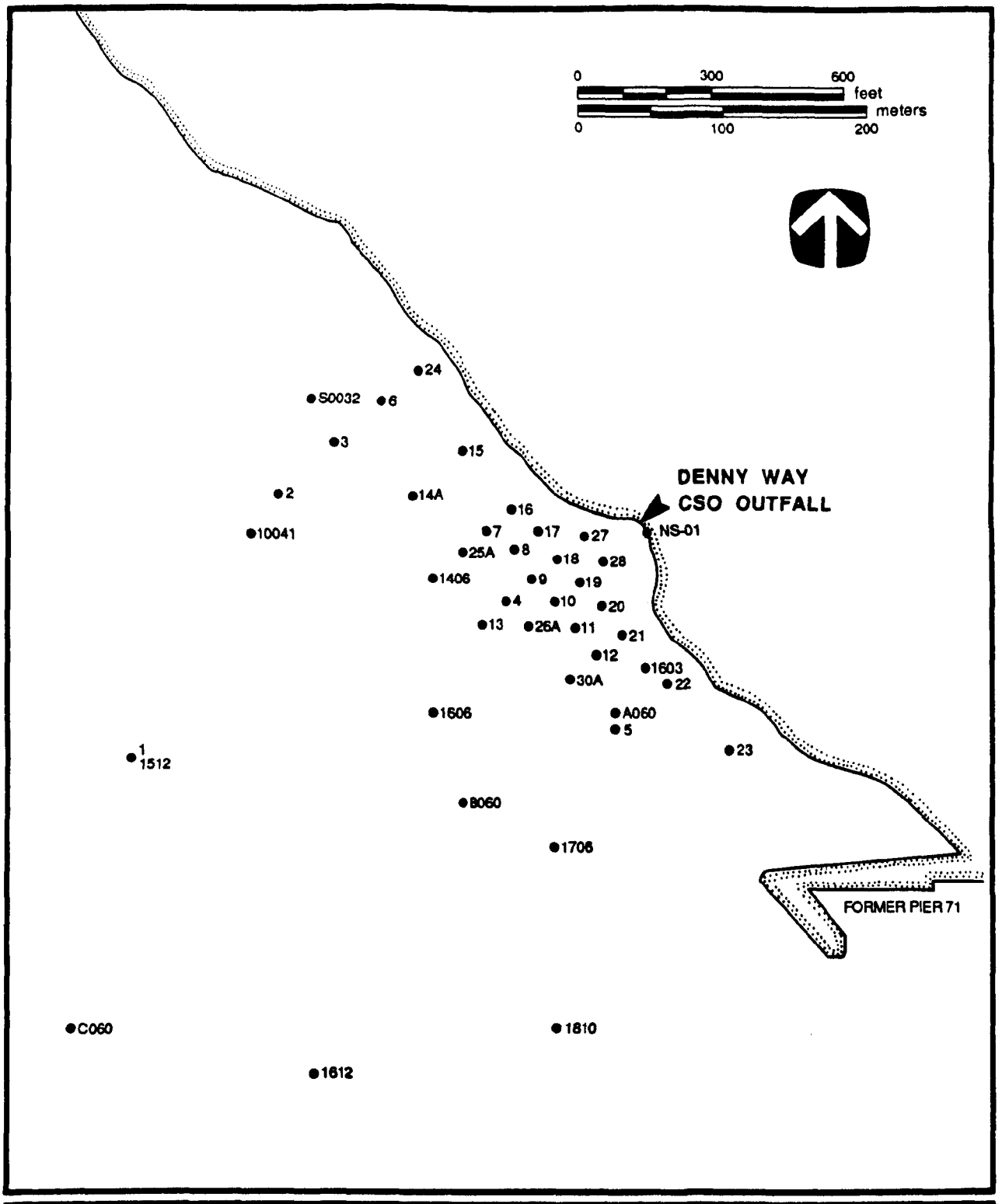


Figure 8. Sampling station locations in the Denny Way CSO problem area.

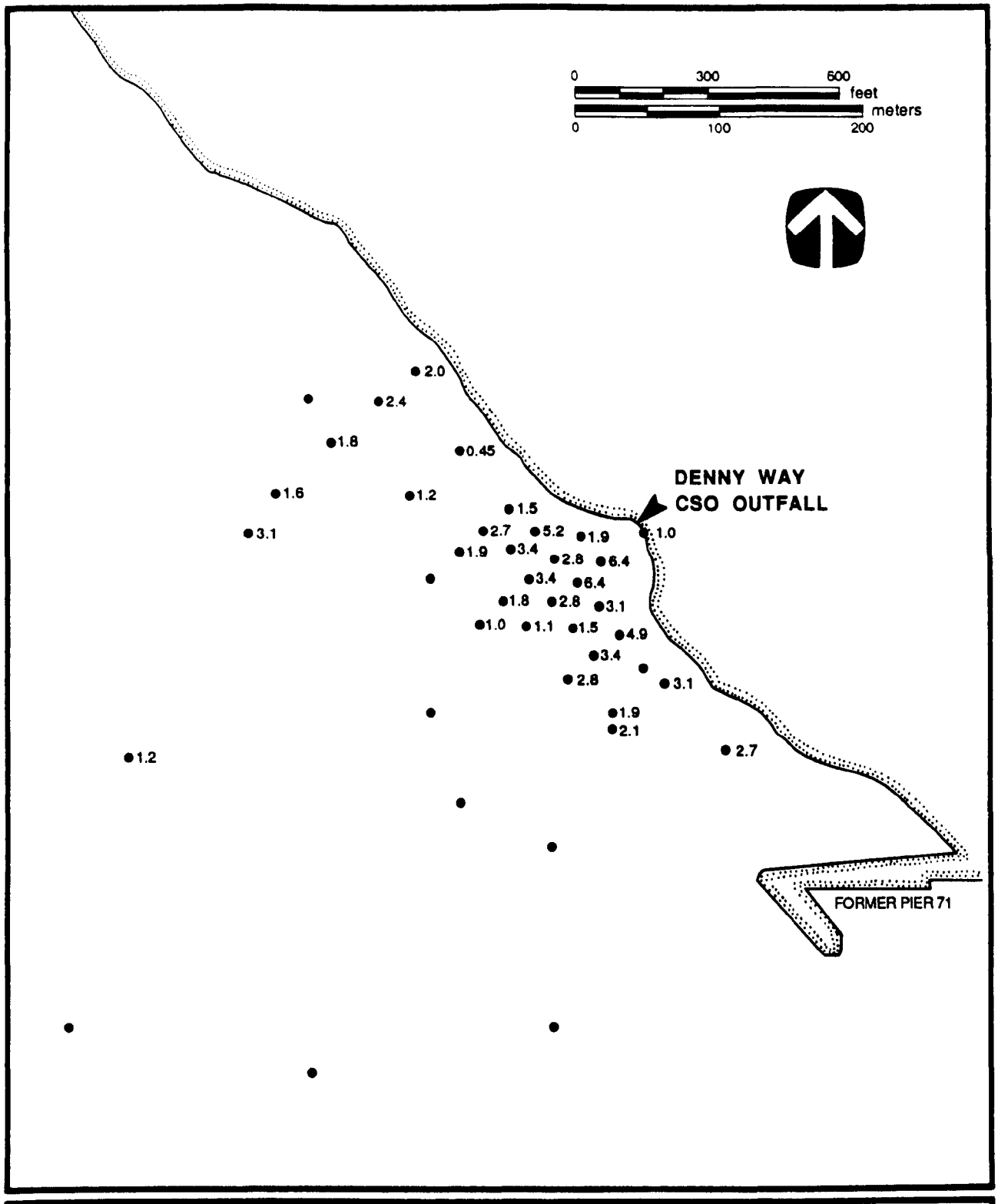


Figure 9. Areal distribution of mercury concentrations in Denny Way surficial sediments, corrected for background concentration and normalized to the target cleanup goal (C_O'/C_G').

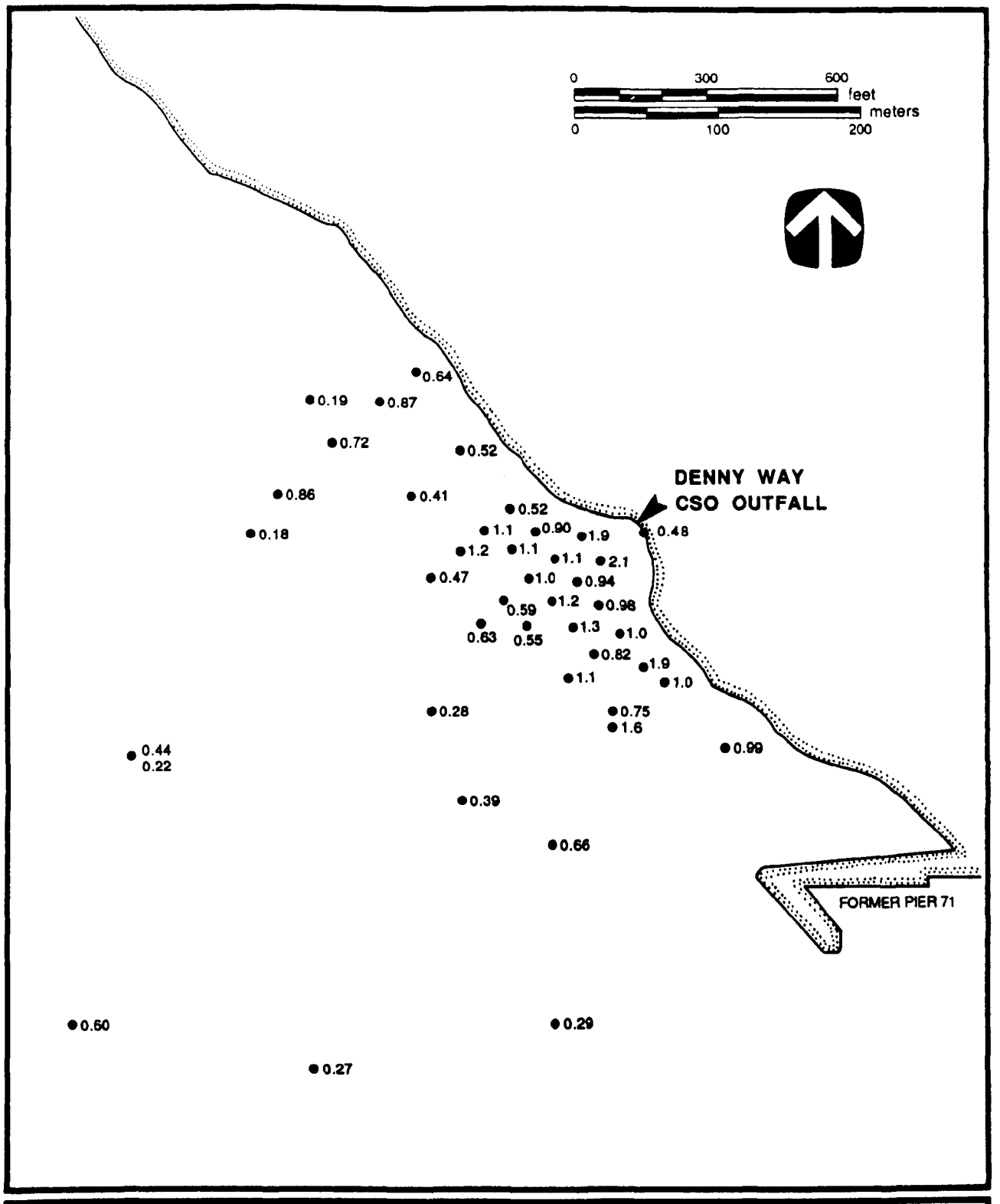


Figure 10. Areal distribution of zinc concentrations in Denny Way surficial sediments, corrected for background concentration and normalized to the target cleanup goal (C_O'/C_G').

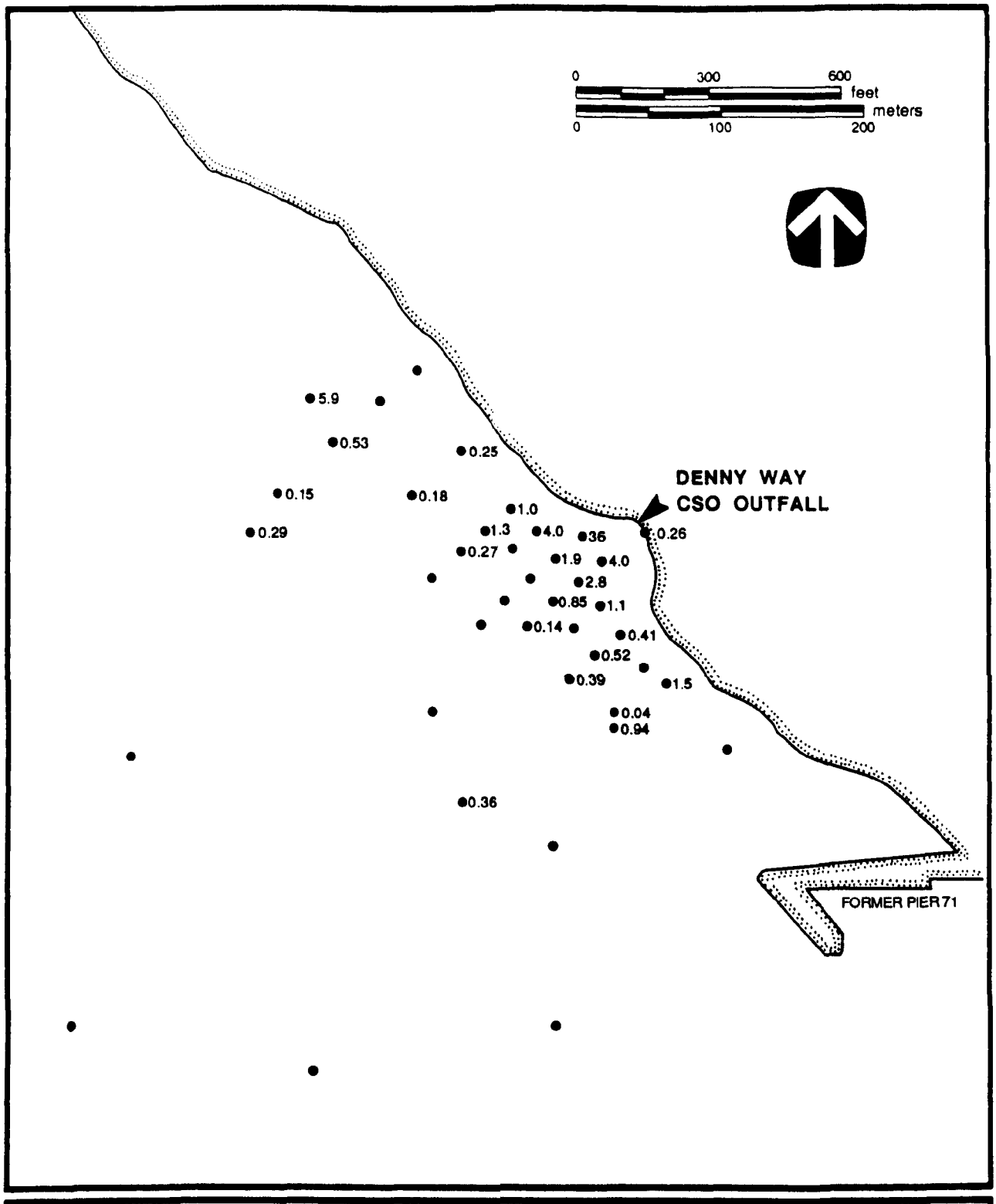


Figure 11. Areal distribution of fluoranthene concentrations in Denny Way surficial sediments, normalized to the target cleanup goal (C_O/C_G).

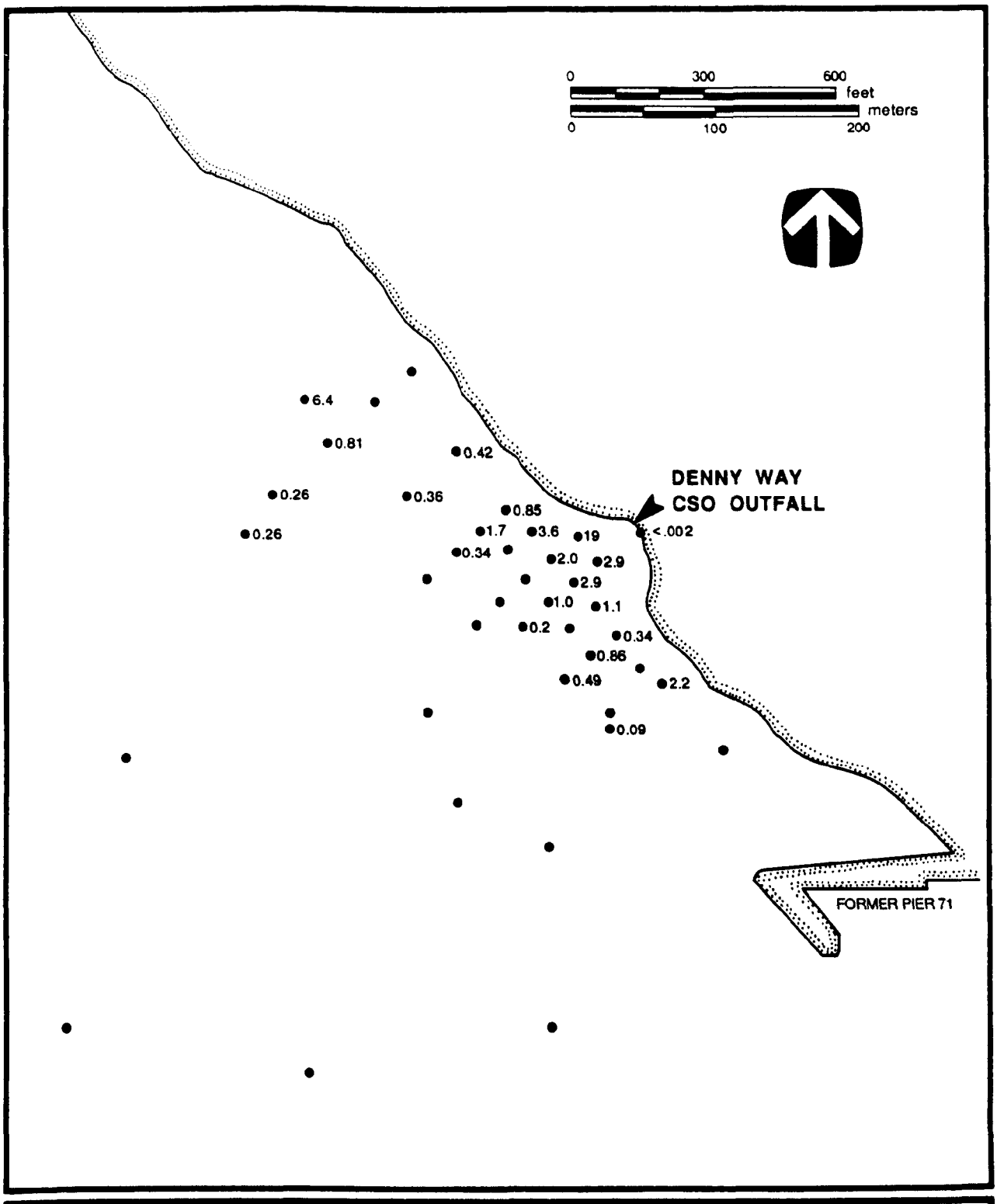


Figure 12. Areal distribution of chrysene concentrations in Denny Way surficial sediments, normalized to the target cleanup goal (C_O/C_G).

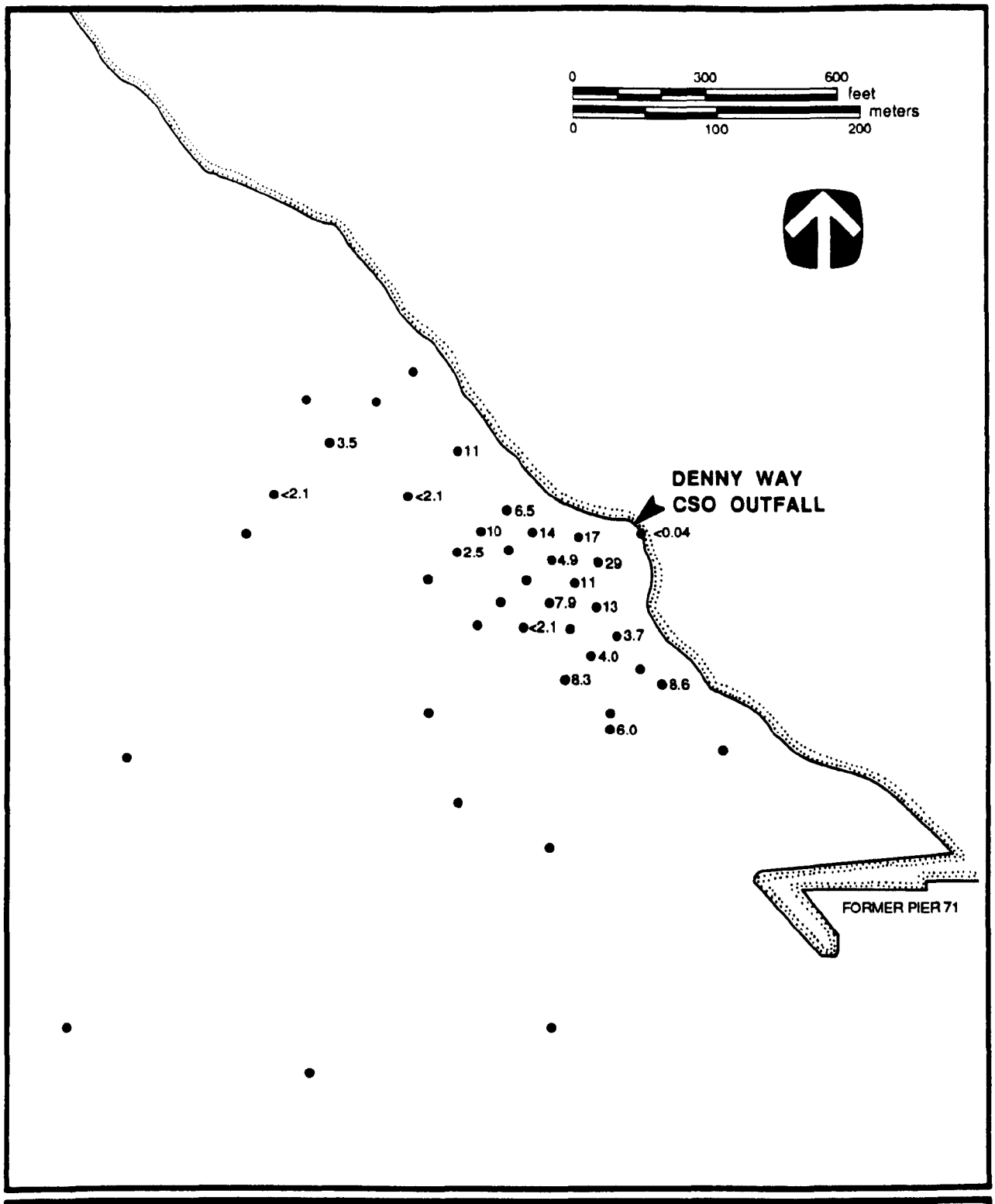


Figure 13. Areal distribution of butyl benzyl phthalate concentrations in Denny Way surficial sediments, normalized to the target cleanup goal (C_O/C_G).

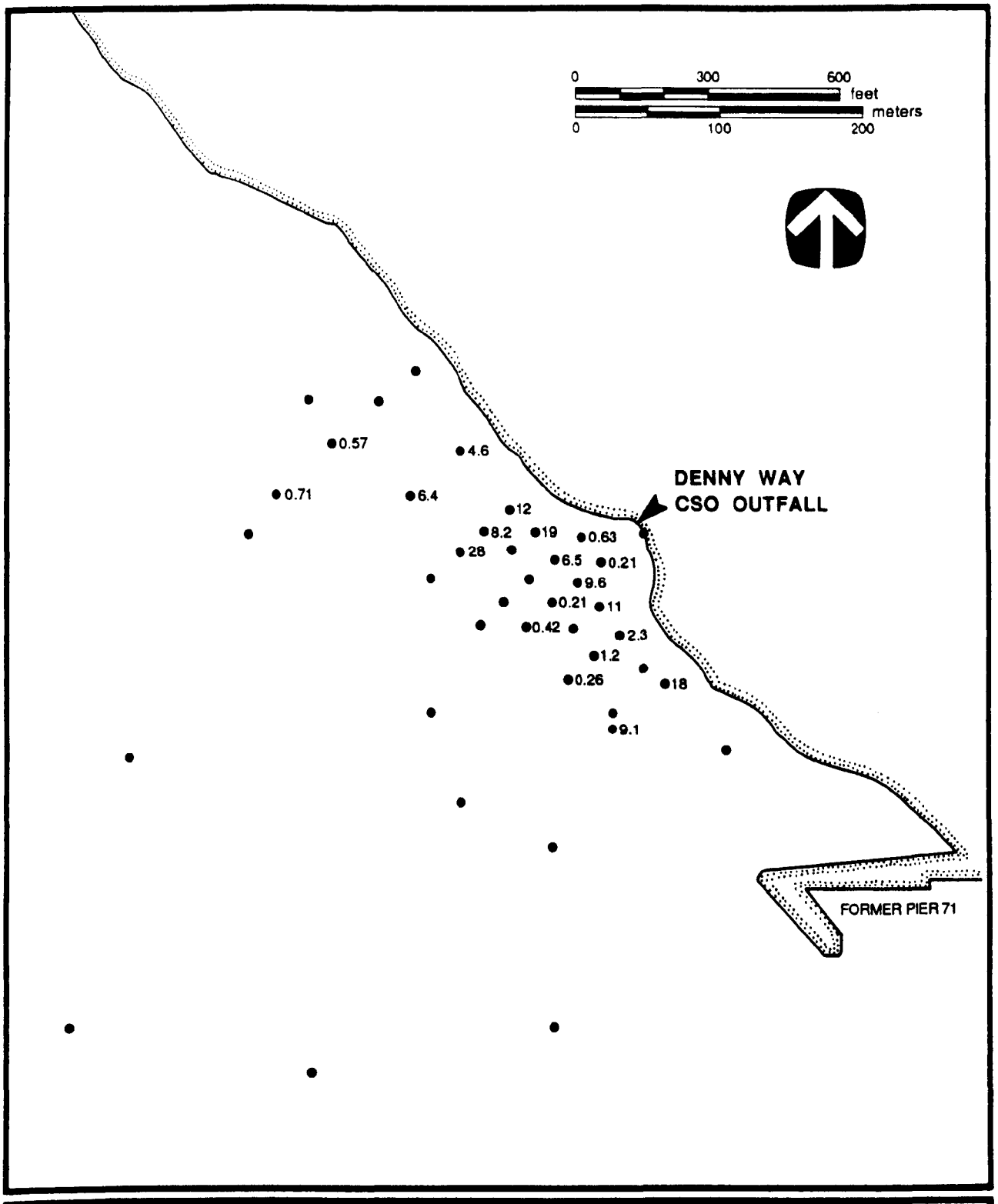


Figure 14. Areal distribution of bis(2-ethylhexyl)phthalate concentration in Denny Way surficial sediments, normalized to the target cleanup goal (C_O/C_G).

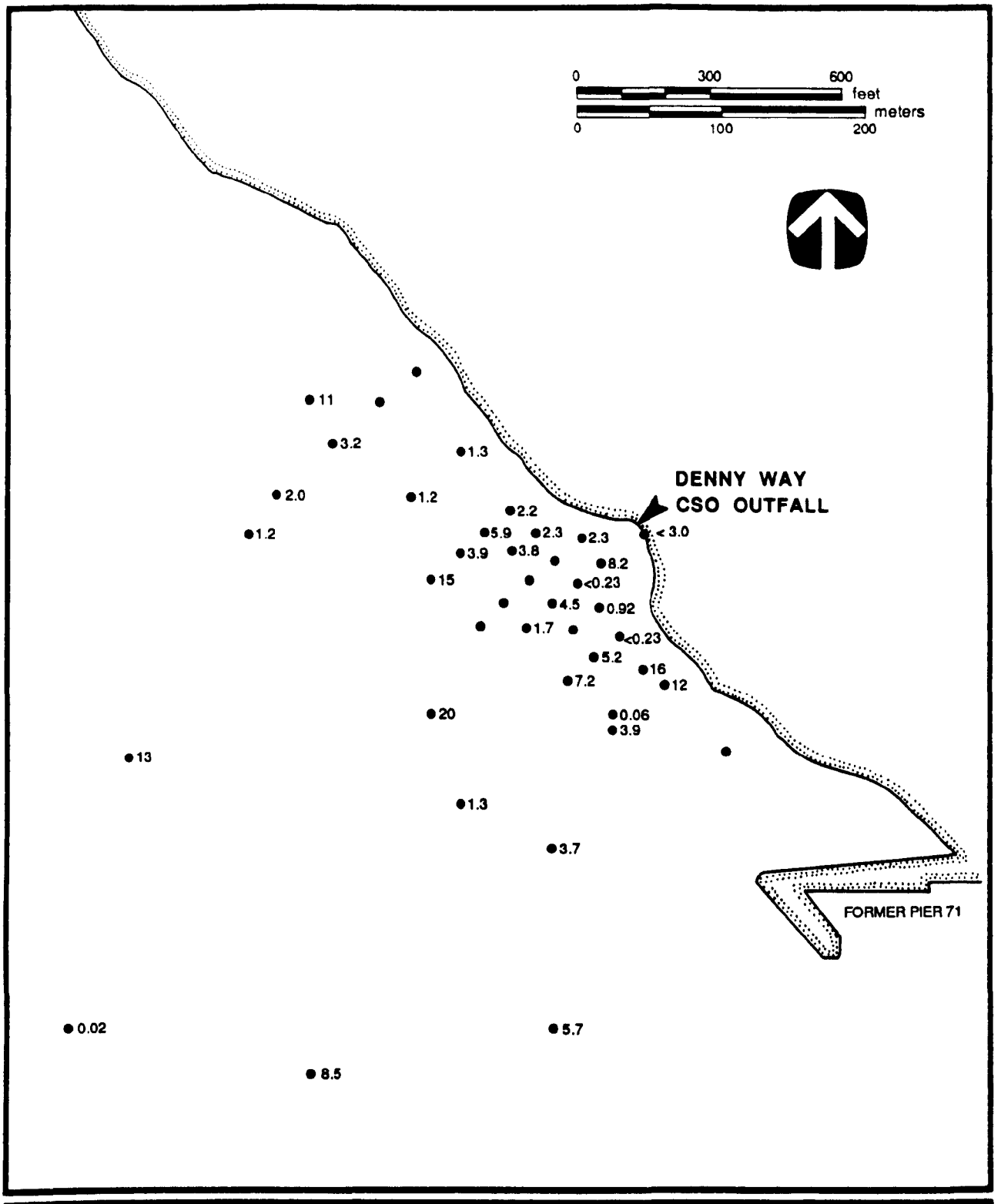


Figure 15. Areal distribution of total PCB concentrations in Denny Way surficial sediments, normalized to the target cleanup goal (C_O/C_G).

Background deposition rates in the area directly offshore from the Denny Way CSO are not available. However, sedimentation rates derived from excess Pb-210 in sediment cores collected from central Puget Sound shallow bays ranged from 0.22 to 0.66 cm/yr (Carpenter et al. 1985). Because of the inability to accurately predict a sedimentation rate in the area after source control, sedimentation rates of 0.2 and 0.7 cm/yr were used in the application of SEDCAM. Use of two sedimentation rates was expected to provide a range of sediment recovery scenarios in this area. The lower rate is conservative and results in the longest sediment recovery time estimates. If source control measures substantially reduce the sediment discharged from the Denny Way CSO, the lower sedimentation rate may reflect the deposition process more closely than the higher rate. However, if the implementation of source control reduces the contaminant load to the offshore sediments but does not reduce the amount of particulate discharged than the higher sedimentation rate may be appropriate.

3.2.4 Sediment Recovery Scenarios

Sedimentation rates of 0.2 cm/yr and 0.7 cm/yr and a mixing depth of 10 cm were selected for the model. The relationship between source control and sediment recovery was evaluated for mercury, fluoranthene, chrysene, butyl benzyl phthalate, bis(2-ethylhexyl)phthalate, 4,4'-DDT, and total PCBs. These chemicals had the greatest enrichment ratios over the greatest area for their respective chemical groups. Source loading and sediment accumulation are assumed to be in steady-state. None of the indicator chemicals was expected to display losses due to biodegradation or diffusion.

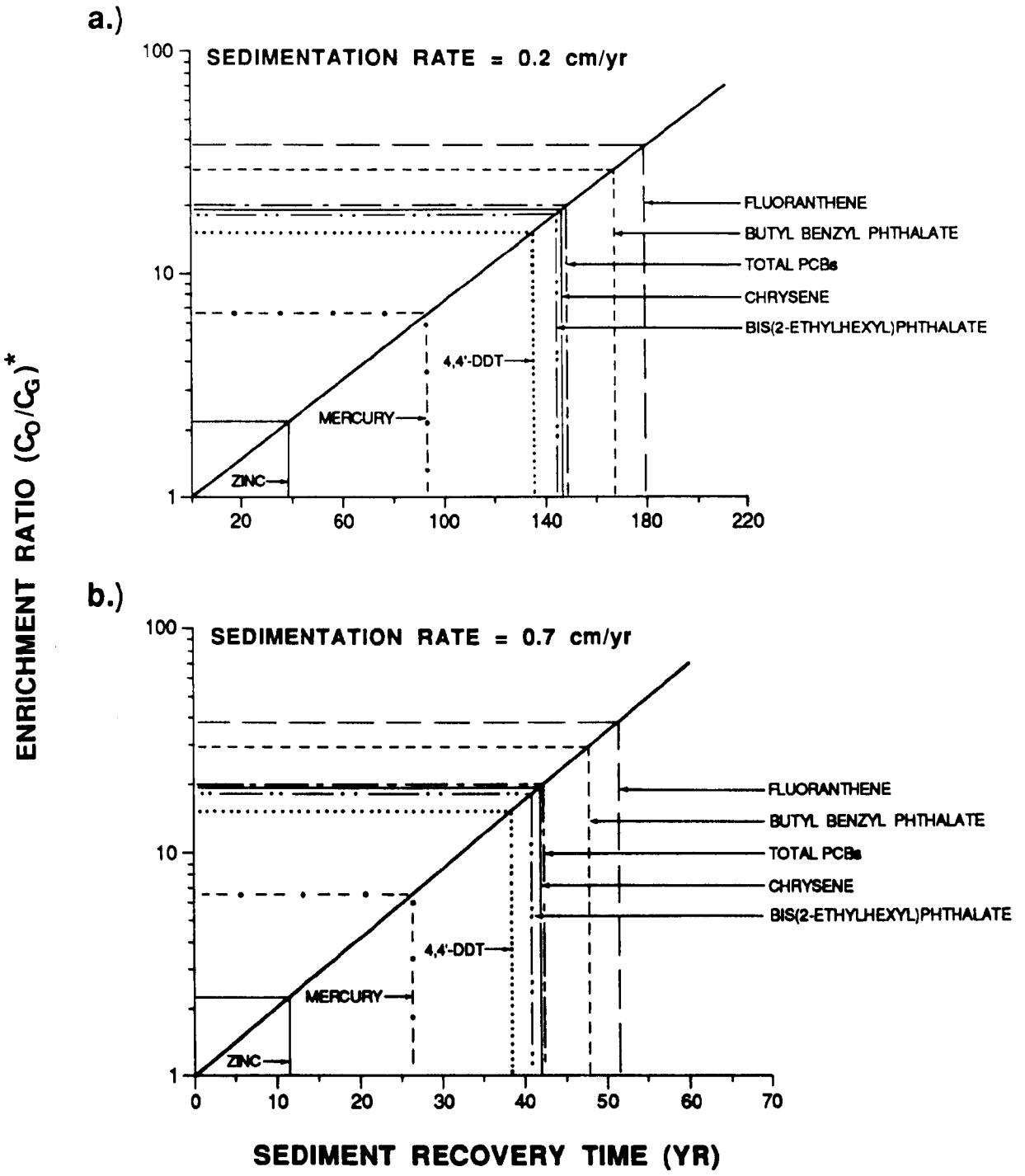
3.2.4.1 Effect of No Source Control--

Evaluation of the effect of not controlling sources is only meaningful for ongoing sources where the relationship between source loading and sediment accumulation is not in steady-state. For sources where the relationship is in steady-state, as was assumed for the Denny Way CSO, the absence of source control will result in no change in the level of problem chemicals in surface sediments.

3.2.4.2 Effect of Complete Source Elimination--

The predicted effect of complete source elimination on the recovery time of the indicator chemicals is based on a single enrichment ratio for each indicator chemical (Figure 16). Each enrichment ratio used to project a recovery time in Figure 16 is based on the maximum concentration observed in the surface sediments for the specific indicator chemical. At a sedimentation rate of 0.2 cm/yr, it is estimated that acceptable surface sediment concentrations of mercury will not be achieved before 90 yr after loading has been eliminated (100 percent source control implementation). Zinc on the other hand could recover in approximately 40 yr. Based on the maximum concentrations observed for each of the other indicator chemicals, it is also predicted that acceptable surface sediment concentrations of these chemicals will be achieved between 135 and 180 yr (Figure 16). In contrast, given 100 percent source control and a sedimentation rate of 0.7 cm/yr, acceptable surface sediment concentrations of mercury are expected to be achieved in approximately 27 years (Figure 16). Zinc could recover in 12 yr. At this sedimentation rate concentrations of the other indicator chemicals are predicted to be at acceptable levels between 37 and 52 yr.

Projection of sediment recovery scenarios using enrichment ratios based on the maximum concentration is conservative and results in maximum recovery time estimates. In some cases, the maximum concentration occurs at a hot-spot in the problem area. That is, the maximum concentration is significantly greater than the concentrations observed at surrounding stations. Therefore, it can be informative to develop recovery time scenarios using enrichment ratios that may be more representative of the overall contamination in the area. Butyl benzyl phthalate displayed the greatest enrichment ratio over the greatest area in the Denny Way CSO problem area. Sediment recovery times at 100 percent source control were estimated for butyl benzyl phthalate using the five largest enrichment ratios observed in the problem area. These recovery times are presented in Figure 17 and suggest that in the absence of sediment remediation, sediment contamination will persist over a large area for decades.



* Mercury and zinc enrichment ratios = C_O'/C_G'.

Figure 16. Sediment recovery model results for the Denny Way problem area: enrichment ratio based on maximum concentration vs. sediment recovery given 100 percent source control for sedimentation rates of 0.2 cm/yr (a) and 0.7 cm/yr (b).

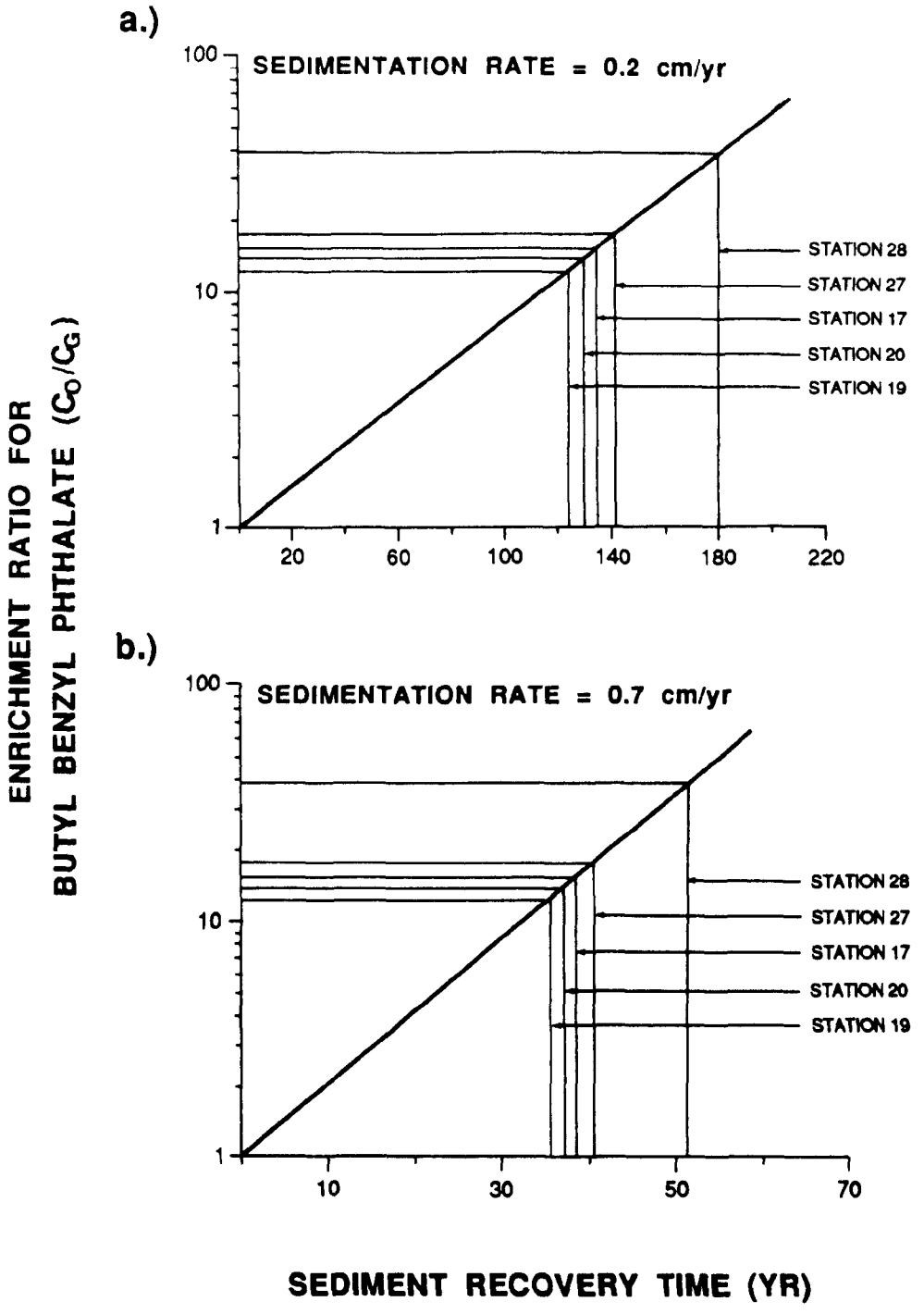


Figure 17. Sediment recovery model results using five concentrations of butyl benzyl phthalate found in the Denny Way problem area: enrichment ratio vs. sediment recovery time given 100 percent source control for sedimentation rates of 0.2 cm/yr (a) and 0.7 cm/yr (b).

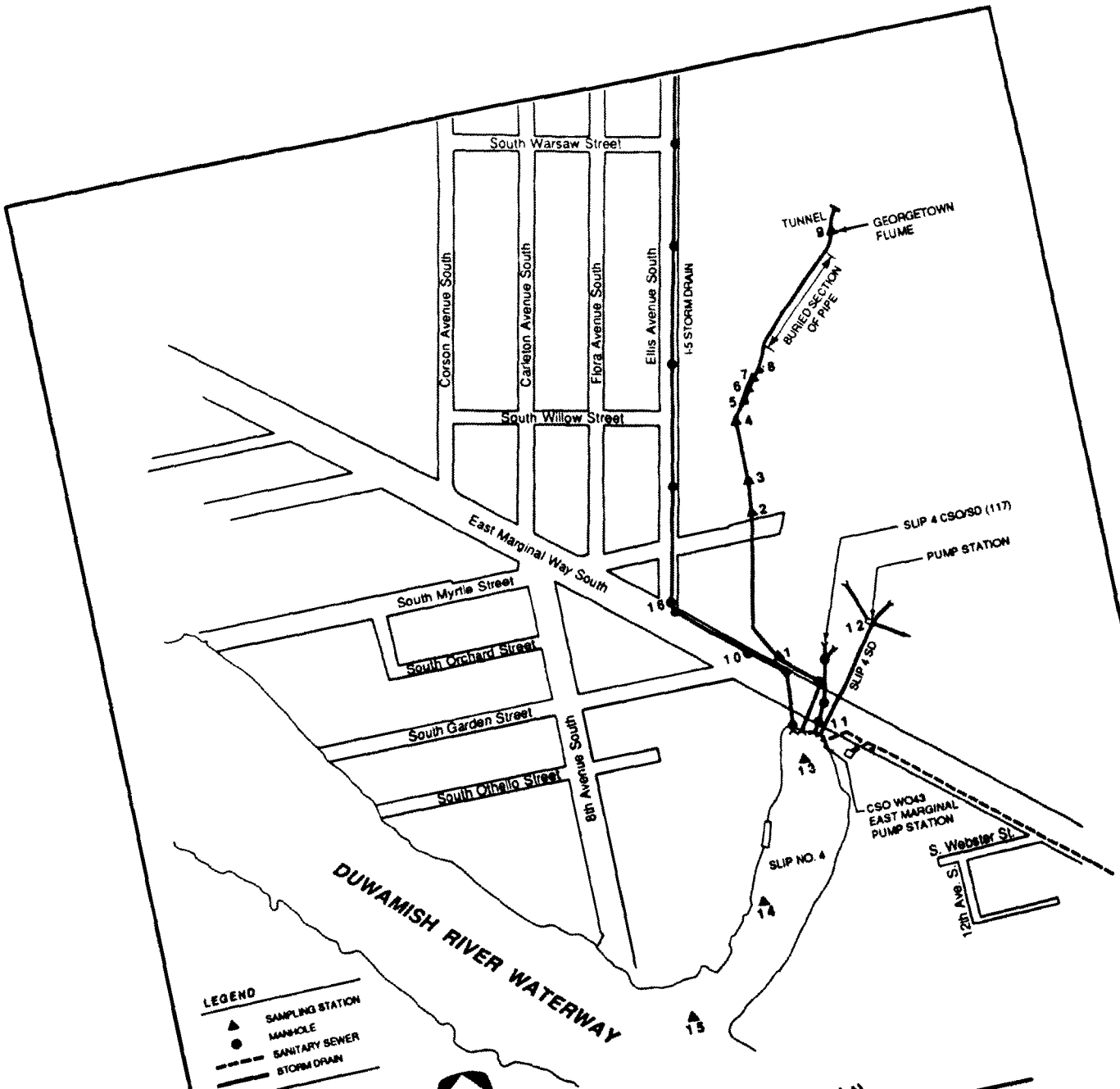
3.2.4.3 Source Control Required for Long-Term Sediment Recovery--

The degree of source control required for long-term sediment recovery is directly proportional to the enrichment ratio for sources that are in steady-state. The relationship between source loading and sediment accumulation is assumed to be in steady-state. Thus, regardless of sedimentation rate, 84 percent of the mercury and more than 94 percent of the total PCBs, fluoranthene, butyl benzyl phthalate, bis(2-ethylhexyl)phthalate, and chrysene presently being supplied to the Denny Way CSO problem area would have to be eliminated to maintain acceptable sediment concentrations after sediment remediation. These predictions are based on each contaminant's level of exceedance of the target cleanup goal, and therefore do not take into account any recent reduction in contaminant loading to the area.

3.3 DUWAMISH RIVER SLIP 4

3.3.1 Source Summary

Elevated concentrations of PCBs have been measured in the surficial sediments in Slip 4 (Figure 18). Samples collected by U.S. EPA from the head of Slip 4 in 1982 and 1983 exhibited PCB concentrations between 1,600 and 5,600 ug/kg. Five drains discharge into Slip 4 [I-5 storm drain (SD), Slip 4 CSO/SD #117, Slip 4 SD, Georgetown Flume, and East Marginal Pump Station CSO W043]. Descriptions of each drain are presented in Table 3. In 1984, Metro collected sediment samples from the four storm drains discharging into Slip 4 to determine the source of the PCB contamination in offshore sediments (Sample, T., 23 October 1987, personal communication). The results indicated that three of the four storm drains (i.e., Georgetown Flume, Slip 4 CSO/SD #117, and Slip 4 SD) were contaminated with PCBs (Figure 18). PCB levels were measured at 17,900-160,000 ug/kg in the Georgetown Flume, 103,000 ug/kg in Slip 4 CSO/SD, and 19,500 ug/kg in Slip 4 SD. These concentrations exceed the average level reported for urban street dust from eight cities in the U.S. (770 ug/kg; Galvin and Moore 1982) by 2-3 orders of magnitude. PCB concentrations in the sediments collected from the



PCB DATA (µg/kg dry weight)

STATION NUMBER	U.S. EPA 1982[a]	U.S. EPA 1983[a]	METRO 4/18/84[b]	METRO 4/16/84[b]	CITY LIGHT 11/19/84[b]	TETRA TECH 9/85[c]
1	-	-	-	-	15,000	-
2	-	-	-	17,900	17,000	-
3	-	-	-	-	19,000	-
4	-	-	-	160,000	79,000	-
5	-	-	-	-	19,000	-
6	-	-	-	-	12,000	-
7	-	-	-	600	340,000	-
8	-	-	-	103,000	452,000	-
9	-	-	-	19,500	1,800,000	-
10	-	-	-	-	-	260,000E
11	-	-	6,000	-	-	390E
12	-	-	4,000	-	-	-
13(SL-01)	1,600	5,600	3,000	-	-	-
14(SL-02)	-	1,590	-	-	-	275E
15	-	-	-	-	-	-
16	-	-	-	-	-	-

a U.S. EPA (1982-1983)
b Sample, T. (23 October 1987, personal communication).
c Tetra Tech (1988a)
E Estimated value

Figure 18. Summary of PCB data for Slip 4 drains.

TABLE 3. DESCRIPTION OF DRAINS DISCHARGING INTO SLIP 4

Name	Outfall Diameter (in)	Drainage Basin Area (ac)	Description of Service Area
I-5 SD[a]	66	30	Drains approximately 1.5 mi of I-5 between S. Dawson and S. Myrtle Streets and part of Georgetown area.
Georgetown Flume	60	--	Open wood flume originally installed to discharge cooling water from Seattle City Light's Georgetown Steam Plant. Exact service area unknown. Numerous other side connections have been identified. All side connections have been plugged by Seattle City Light.
Slip 4 CSO[b]/SD #117	24	150 (SD) 74.6 (CSO)	Drains the north end of King County Airport (i.e., Boeing Field).
Slip 4 SD	60	170	Serves portions of King County Airport.
East Marginal Pump Station CSO W043	36	318	Emergency sewer overflow for Metro pump station.

[a] SD = Storm drain.

[b] CSO = Combined sewer overflow.

I-5 SD were 2-3 orders of magnitude lower than the concentrations measured for the other three storm drains, and did not exceed levels reported for urban street dust. Therefore, I-5 SD has not been considered a source of PCBs to Slip 4.

Seattle City Light (City Light) collected sediment samples in 1984 from various locations along the Georgetown Flume to trace contamination (Figure 18). The highest PCB concentration (1,800 ug/kg) was found in sediments collected from the downstream side of the tunnel in the flume (Figure 18) (Geissinger, L., 9 December 1987, personal communication). PCB contamination was subsequently traced to a City Light property at the head of the flume where soil contained PCBs in concentrations as high as 91,000,000 ug/kg. These soils were excavated to depths of 4-6 ft to attain cleanup levels of 150-200 ug/kg (Geissinger, L., 9 December 1987, personal communication) and contaminated sediment deposits were removed from the flume. City Light has plugged all side connections to the flume to prevent future contamination, and sediment traps were installed in the flume to collect sediments prior to discharge to Slip 4. City Light plans to fill the flume to prevent its use in the future (Geissinger, L., 9 December 1987, personal communication).

The source of PCBs in Slip 4 CSO/SD #117 has not been identified to date. During cleanup activities in Georgetown Flume, City Light collected sediment samples from Slip 4 CSO/SD and found PCB concentrations as high as 10,000 ug/kg (Smukowski, D., 14 December 1987, personal communication). The Boeing Company worked with Metro to trace contamination in this storm drain line, which crosses their property. However, they were not able to locate a PCB source in the area. In 1985, Boeing removed contaminated sediments from the Slip 4 CSO/SD. This drain has since been rerouted to the pump station on the Slip 4 SD system and discharges to Slip 4 via this 60-in line (Smukowski, D., 14 December 1987, personal communication).

PCB contamination has not been fully investigated in the Slip 4 SD system to date. Consequently, it is not known whether there is an ongoing source of PCBs in this drainage basin.

3.3.2 Identification of Indicator Chemicals

Chromium, fluoranthene, PCBs, and 4,4'-DDD were selected as indicator chemicals to develop sediment recovery scenarios in the Duwamish River Slip 4. Compounds with enrichment ratios greater than 1, based on maximum concentrations, are presented in Table 4. Compounds that had a method detection limit greater than the target cleanup goal are also identified. Locations of the sampling stations in the slip are shown in Figure 19. Areal distributions of the indicator chemicals are presented in Figures 20-23. Data were not available for all indicator chemicals at all sampling stations.

3.3.3 Sediment Accumulation Rate

Determination of a sediment accumulation rate for Slip 4 was difficult because of lack of available sediment core data and the complexity of the deposition process in riverine systems. Measurement of sedimentation rates through Pb-210 dating in the Duwamish River has not been performed to date. The use of alternative methods to estimate sedimentation rates (i.e., core discontinuities, dredging records, bathymetric records) also proved to be unsuccessful primarily because of insufficient information. A rough estimate of the sediment accumulation rate was determined using unpublished sediment core data collected by Ecology in 1985 (Schlender, M., 16 April 1985, personal communication). Three sediment samples were collected in the slip at low tide to depths of 6, 12, and 18 in (Brugger, G., 15 March 1988, personal communication). One sample (#102) was taken directly off of the Georgetown Flume outfall, a second sample (#109) was collected on a sandbar approximately 20 ft off of the flume outfall, and the third sample (#105) was taken approximately 20 ft from the Slip 4 CSO/SD #117 outfall. The data from the analysis of the top 6 in of these samples for PCBs are presented in Table B-1. PCB concentrations in all three samples increased with depth, with the maximum concentration occurring at 18 in.

One technique used to calculate a sediment deposition rate entailed dividing 18 in (PCB contamination known to be present at this depth) by the number of years that elapsed between the time the samples were collected and

TABLE 4. IDENTIFICATION OF INDICATOR CHEMICALS IN DUWAMISH RIVER SLIP 4 SEDIMENTS

Compound	Largest Enrichment Ratio	Number of Historical Analyses with Ratio ≥1	Number of Tetra Tech Analyses with Ratio ≥1	Total No. of Analyses with Ratio ≥1	Number of Samples Analyzed	Percent of Samples with Ratio ≥1
METALS						
Chromium	3.2	4	1	5	6	83
Zinc	1.7	2	1	3	6	50
Lead	3.0	1	0	1	6	17
Mercury	1.5	0	1	1	6	17
LPAH						
Acenaphthene	2.0	1	0	1	3	33
Phenanthrene	1.5	1	0	1	3	33
Anthracene	1.0	2	0	2	3	67
HPAH						
Fluoranthene	2.5	2	0	2	3	67
Pyrene	1.5	1	0	1	3	33
Chrysene	1.4	2	0	2	3	67
Indeno(1,2,3-cd)pyrene	1.8	0	1	1	3	33
Dibenzo(a,h)anthracene	1.2	0	1	1	3	33
Phthalates						
Butylbenzylphthalate	4.6	0	1	1	3	33
Bis(2-ethylhexyl)phthalate	2.1	1	**[b]	1	2	50
Miscellaneous						
Pentachlorophenol	--	--	DL > LAET[a]	--	1	--
Benzyl Alcohol	--	--	DL > LAET	--	1	--
1,2-dichlorobenzene	--	DL > LAET	DL > LAET	--	3	--
1,2,4-trichlorobenzene	--	DL > LAET	DL > LAET	--	3	--
Hexachlorobenzene	--	DL > LAET	DL > LAET	--	3	--
Pesticides/PCBs						
4,4'-DDE	6	0	1	1	3	33
4,4'-DDD	19	0	1	1	3	33
4,4'-DDT	--	DL > LAET	DL > LAET	--	3	--
Total PCBs	46	5	1	6	6	100

[a] Method detection limit exceeded cleanup goal.

[b] Data rejected.

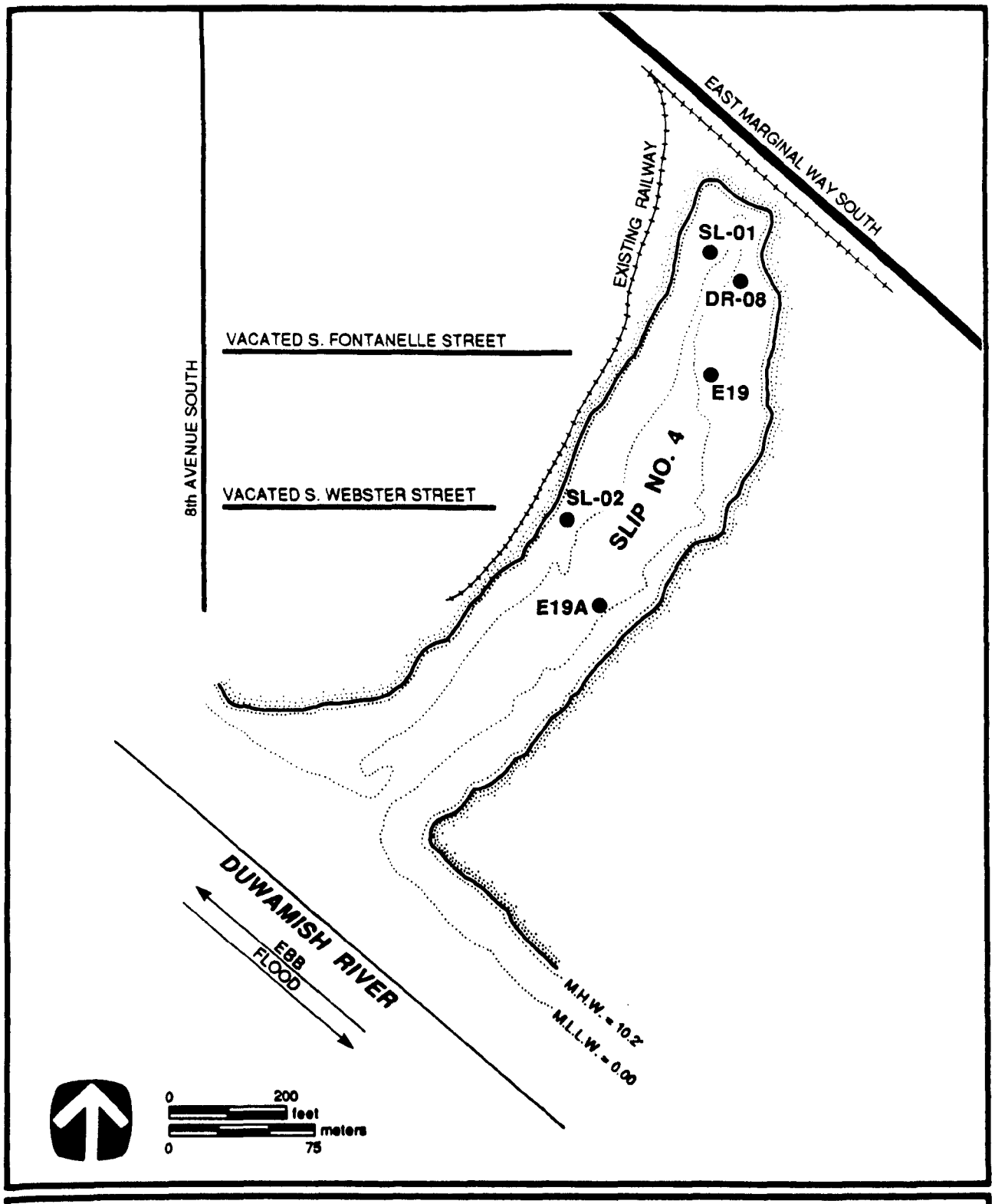


Figure 19. Location of sampling stations in Slip 4.

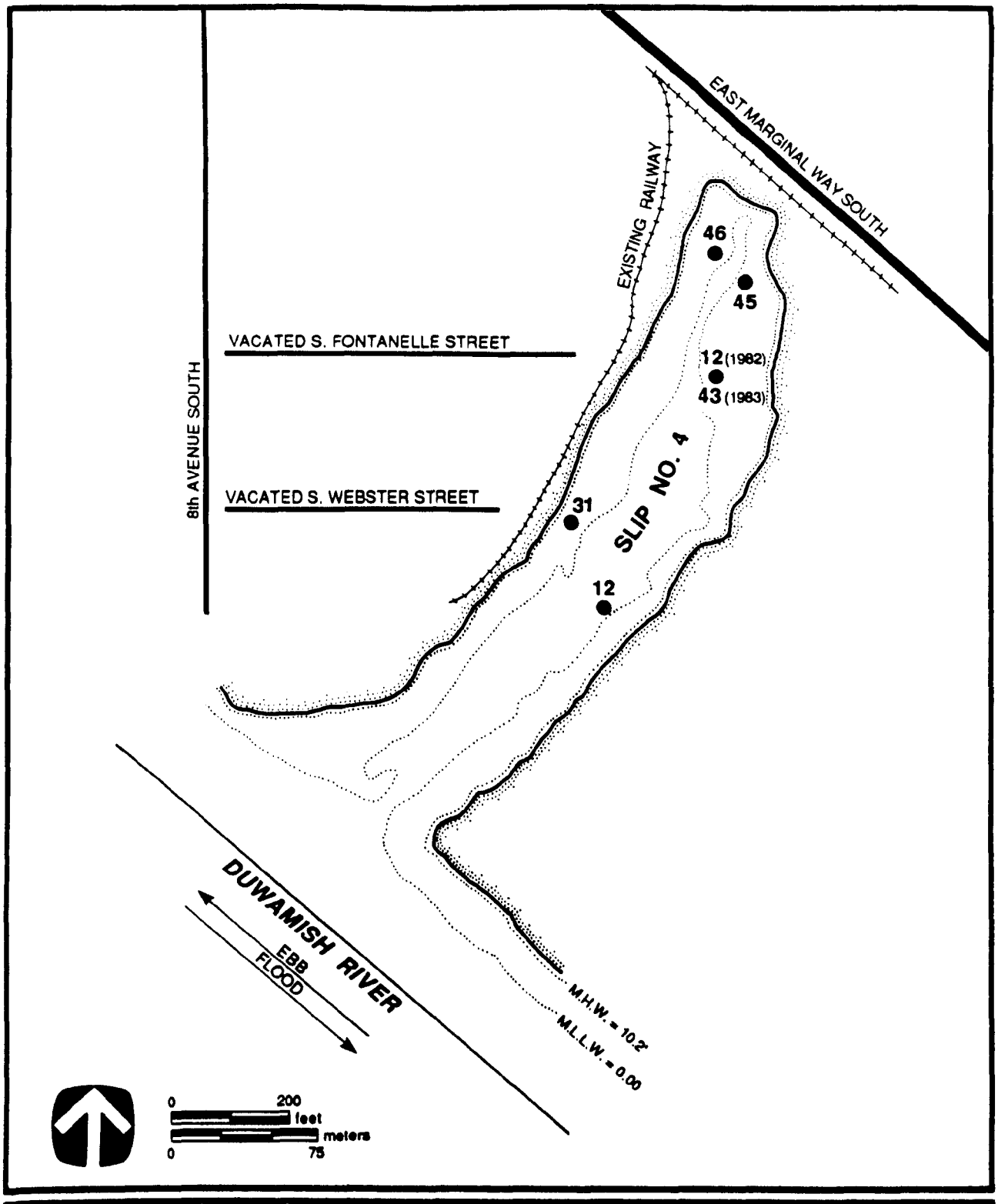


Figure 20. Areal distribution of total PCB concentrations in Slip 4 sediments, normalized to the target cleanup goal (C_O/C_G).

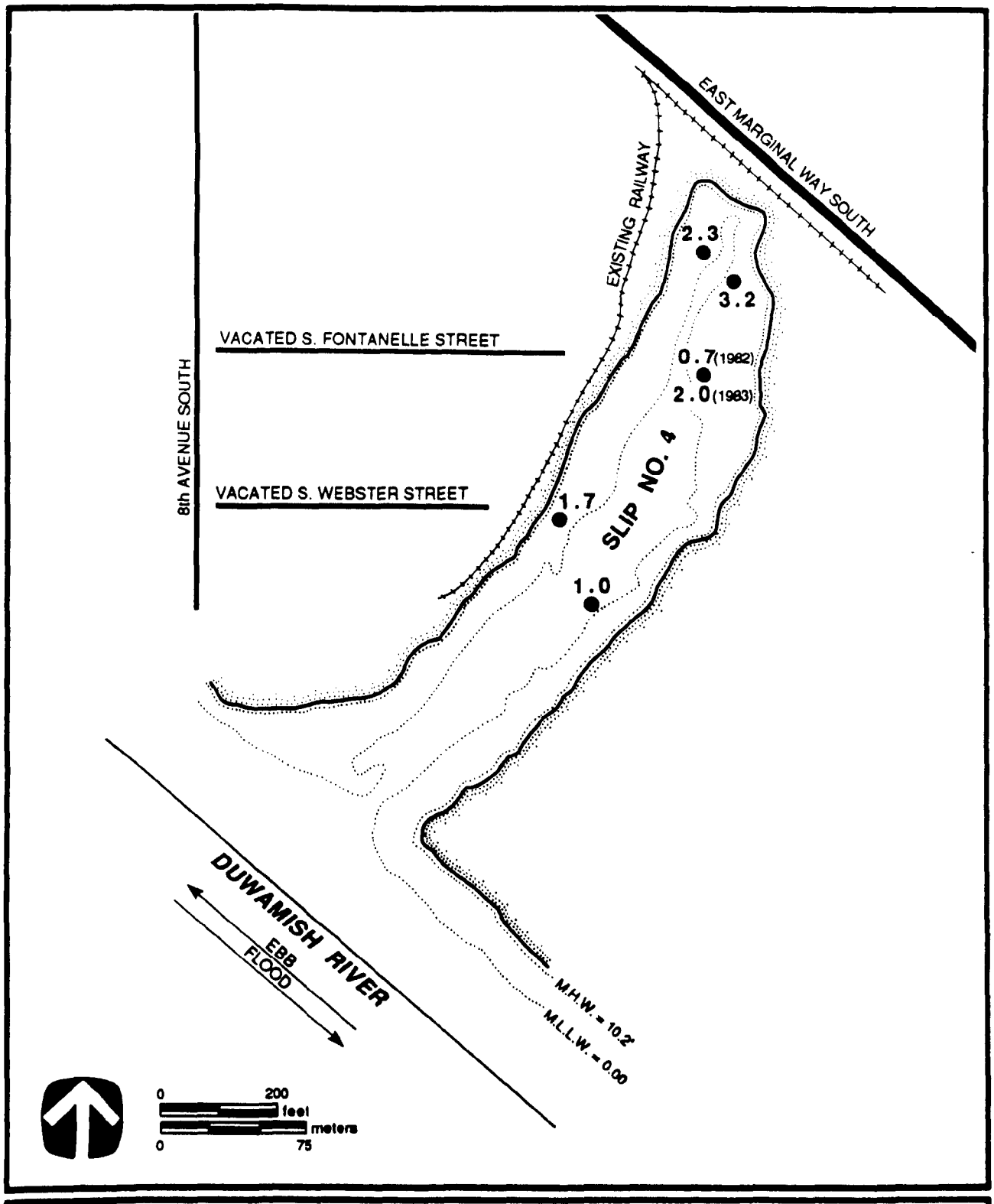


Figure 21. Areal distribution of chromium concentrations in Slip 4 sediments, normalized to the target cleanup goal (C_O/C_G).

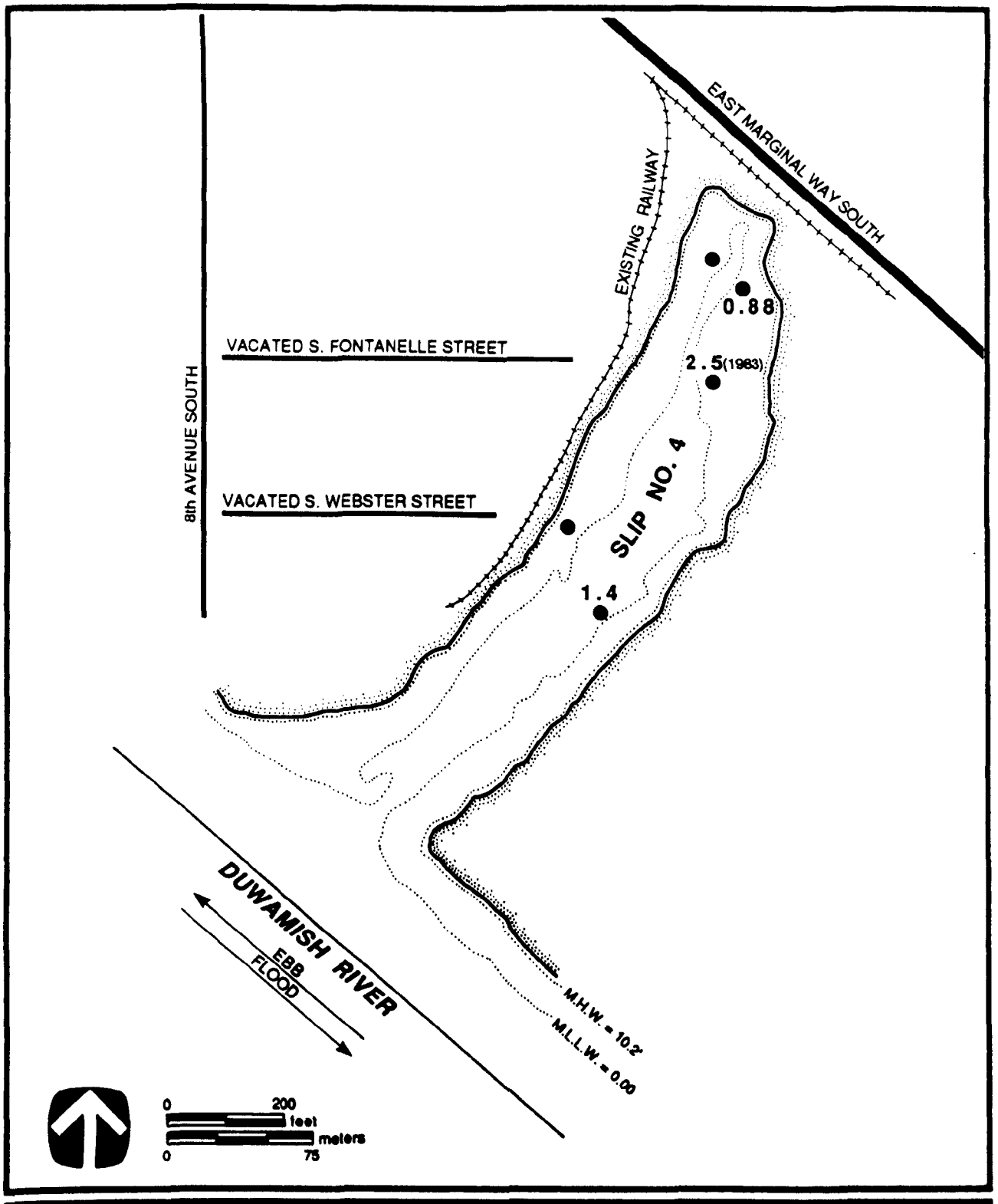


Figure 22. Areal distribution of fluoranthene concentrations in Slip 4 sediments, normalized to the target cleanup goal (C_O/C_G).

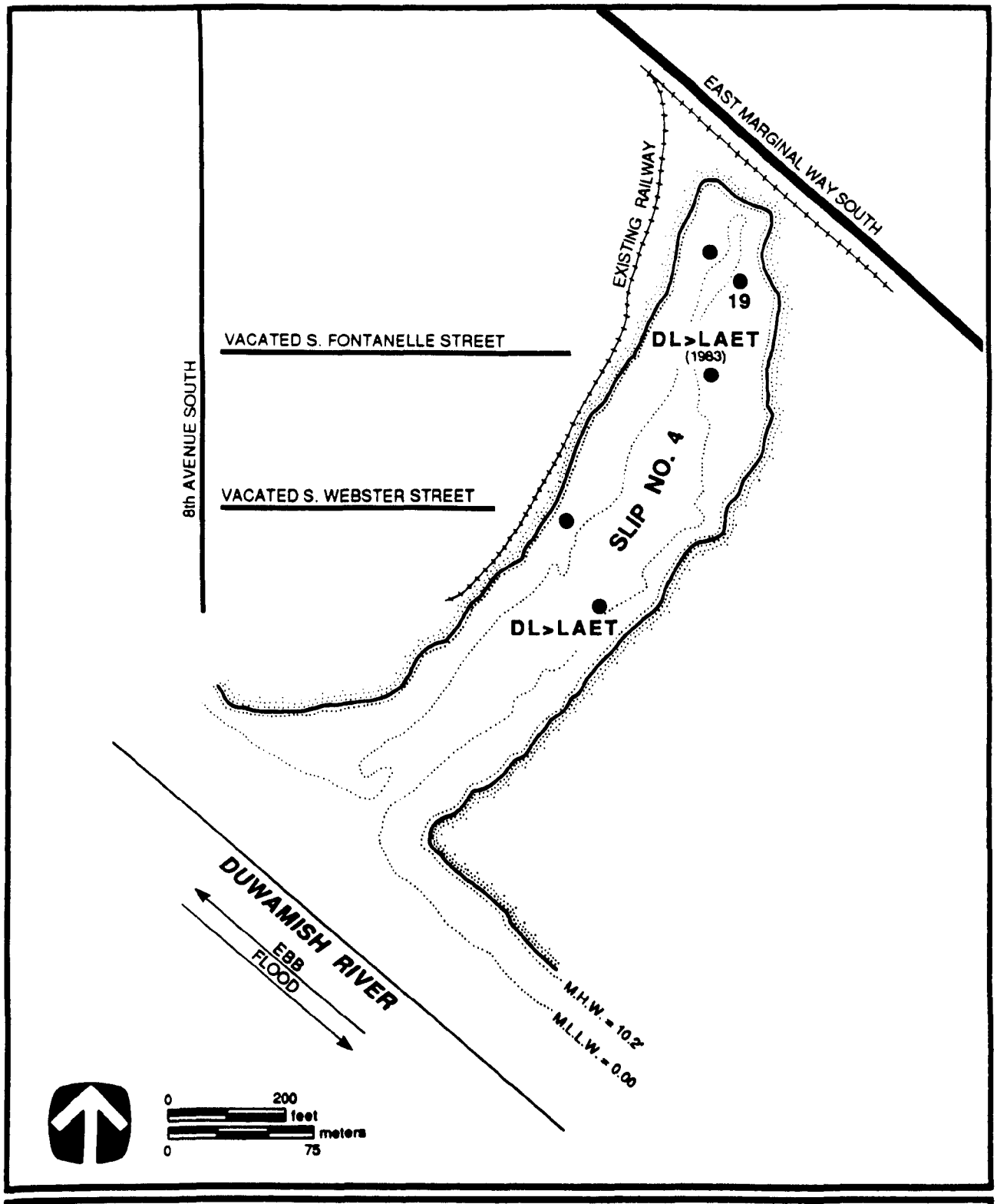


Figure 23. Areal distribution of 4,4'-DDD concentrations in Slip 4 sediments, normalized to the target cleanup goal (C_O/C_G).

the year established as being the earliest possible date that PCBs could have been handled in the vicinity of Slip 4. The marketing of PCBs under the tradename Aroclor began in 1930 (Erickson 1986). Therefore, one estimated sedimentation rate in Slip 4 is 0.8 cm/yr. If PCBs were not handled in or around Slip 4 until some time after 1930, the estimated deposition rate of 0.8 cm/yr is an underestimate. In addition, if PCB contamination is present at a depth greater than 18 in (which is possible since the maximum PCB concentration was observed at 18 in), then the estimated rate of accumulation is also an underestimate. Dredging is not known to have been conducted at the locations where the three samples were collected based on available dredging permits (Tetra Tech 1988a). However, at least one dredging operation has occurred in the slip since 1930 (Tetra Tech 1988a), which could have influenced the deposition process. The estimated sedimentation rate of 0.8 cm/yr represents a minimum accumulation rate. If the sediments accumulate at a faster rate, the sediments are expected to recover in a shorter time period than is predicted. In addition, a sedimentation rate of 2.0 cm/yr was applied to the Slip 4 problem area to illustrate the model's sensitivity to this parameter.

3.3.4 Sediment Recovery Scenarios

Sedimentation rates of 0.8 and 2.0 cm/yr and a mixing depth of 10 cm were selected to represent the problem area. Chromium, fluoranthene, PCBs, and 4,4'-DDD where chosen as indicator chemicals and the maximum concentration of each contaminant observed in the problem area was applied in the development of the sediment recovery scenarios. Chromium, fluoranthene, and PCBs where selected because they displayed the greatest enrichment ratios over the greatest area. The contaminant 4,4'-DDD was selected as an indicator chemical even though two of the three analyses resulted in a method detection limit greater than the target cleanup goal. None of the chemicals were assumed to display losses due to biodegradation or diffusion. The steady-state approximation was used to characterize the relationship between source loading of chromium, fluoranthene, PCBs, and 4,4'-DDD and sediment accumulation.

3.3.4.1 Effect of No Source Control--

An evaluation of the effect of not controlling sources is only meaningful for ongoing sources where the relationship between source loading and sediment accumulation is not in steady-state. For sources where the relationship is in steady-state, as was assumed for Slip 4 sources, the absence of source control will result in no change in the concentration of problem chemicals in surface sediments.

3.3.4.2 Effect of Complete Source Elimination--

The predicted effect of completely eliminating source input to Slip 4 on the recovery time of sediments contaminated with chromium, fluoranthene, PCBs, and 4,4'-DDD is based on a single enrichment ratio for each of these indicator chemicals (Figure 24). Each enrichment ratio used to project a recovery time in Figure 24 is based on the maximum concentration of the specific indicator chemical observed in the surface sediments. At a sedimentation rate of 0.8 cm/yr and 100 percent source control, the model predicts that the concentration of chromium and fluoranthene will reach acceptable levels between 11 and 15 yr (Figure 24a). Based on the only enrichment ratio available for 4,4'-DDD, the concentration of 4,4'-DDD will reach an acceptable level in approximately 37 yr at a sedimentation rate of 0.8 cm. However, given the level of PCB contamination in the area, without sediment remedial actions, acceptable levels of PCBs in Slip 4 are not expected to be achieved for 48 yr (Figure 24a). In contrast, at a sedimentation rate of 2.0 cm/yr, it is estimated that acceptable surface sediment concentrations of PCBs could be achieved 19 yr after loading has been eliminated (Figure 24b). Based on the maximum concentrations observed for each of the other indicator chemicals, it is predicted that acceptable surface concentrations of these chemicals will be achieved between 5 and 15 yr.

Projecting sediment recovery scenarios using enrichment ratios based on the maximum concentration is conservative and results in maximum recovery time estimates. In some cases, the maximum concentration of an indicator chemical occurs at a hotspot in the area. That is, the maximum concentra-

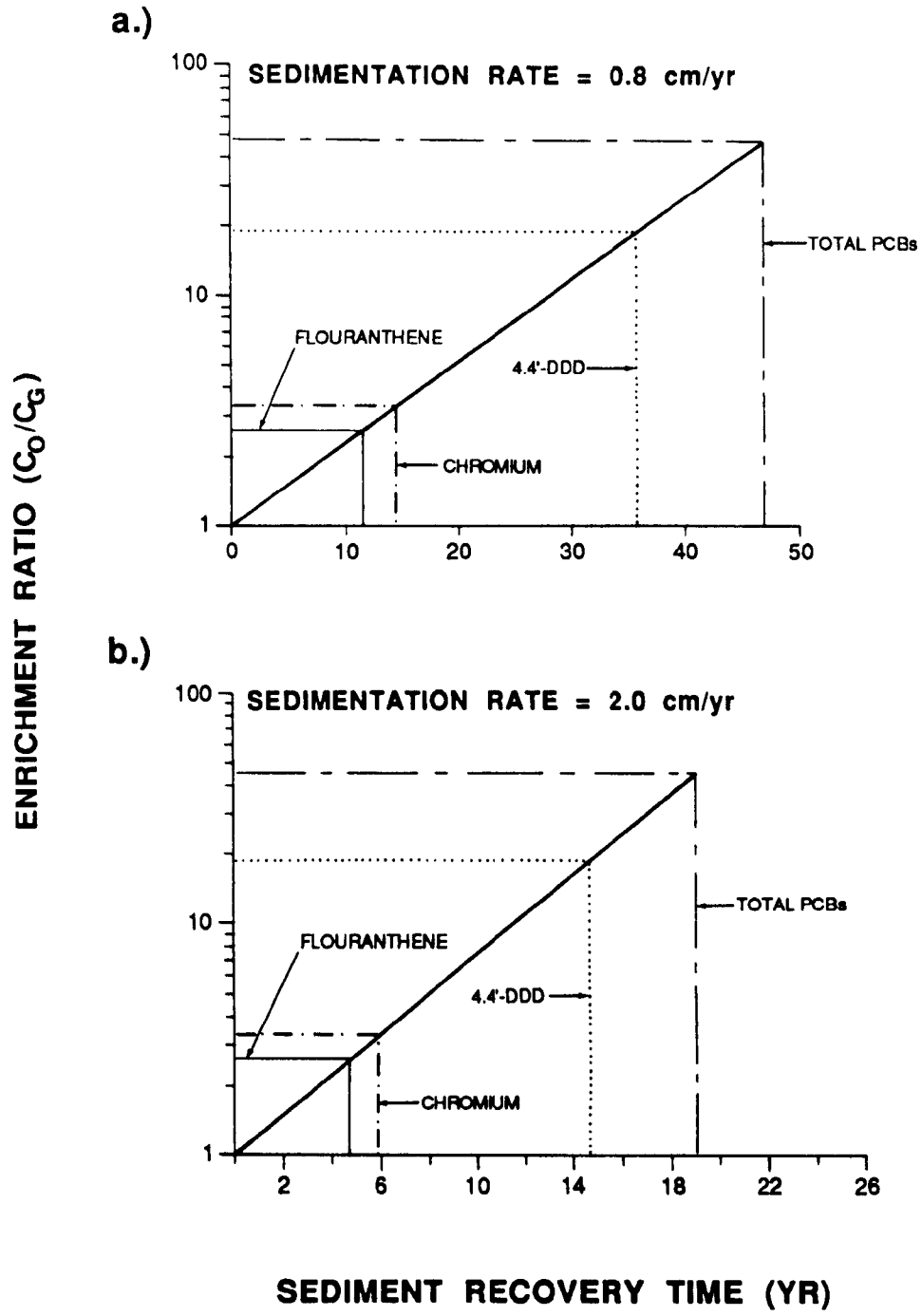


Figure 24. Sediment recovery model results for Slip 4: enrichment ratios based on maximum concentrations vs. sediment recovery time given100 percent source control for sedimentation rates of 0.8 cm/yr (a) and 2.0 cm/yr (b).

tion is significantly greater at one station than at adjacent stations. Therefore, it can be informative to develop recovery time scenarios using enrichment ratios that may be more representative of the overall contamination in the area. PCBs displayed the greatest enrichment ratio over the greatest area in Slip 4. Sediment recovery times at 100 percent source control were estimated for PCBs using the enrichment ratios from all five stations in Slip 4 for sedimentation rates of 0.8 cm/yr and 2.0 cm/yr. These estimated recovery times are presented in Figure 25.

3.3.4.3 Source Control Required for Long-Term Sediment Recovery--

The degree of source control required for long-term sediment recovery is directly proportional to the enrichment ratios for sources that are in steady-state. The relationship between source loading and sediment accumulation is assumed to be in steady-state. Therefore, to maintain acceptable sediment concentration of these chemicals after sediment remediation, 98 percent of the PCBs, 95 percent of the 4,4'-DDD, 69 percent of the chromium, and 60 percent of the fluoranthene presently supplied to the slip must be eliminated.

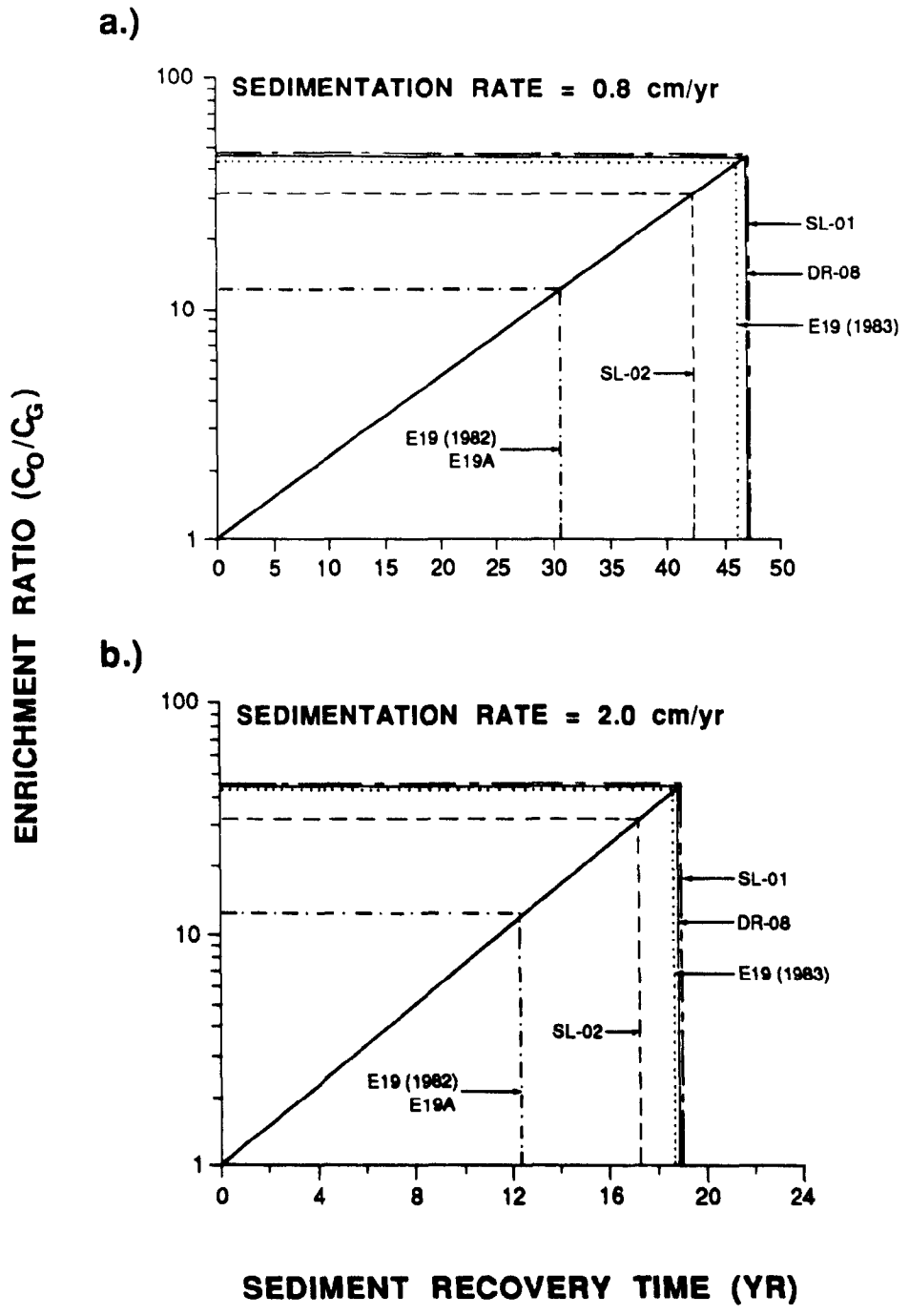


Figure 25. Sediment recovery model results for Slip 4: enrichment ratio vs. sediment recovery time given100 percent source control for sedimentation rates of 0.8 cm/yr (a) and 2.0 cm/yr (b).

4.0 MODEL LIMITATIONS AND RECOMMENDATIONS

SEDCAM uses a mass balance equation to predict the sediment concentration of contaminants in relation to source loading, sedimentation rate, mixing, biodegradation, and diffusive loss across the sediment-water interface. Several factors limit the model's ability to precisely reproduce real-world conditions. Some of the limitations are inherent in the formulation of the model while others are based on the lack of available data. The most significant limitations of the model include the following:

- Difficulty in evaluating recent sediment accumulation rates
- Accurate quantification of chemical-specific decay rates due to biodegradation and diffusion
- Assumption that mixing in the surface mixed layer occurs instantaneously
- Availability of source loading and ancillary data
- Appropriateness of the steady-state assumption.

Depositional patterns and accumulation rates of sediments in embayments and riverine slips vary in time and by location. The rate of sediment deposition in the Denny Way CSO problem area may be substantially reduced by the implementation of source control measures. Sedimentation in Slip 4 is expected to occur in irregular intervals with the majority of sediment being deposited during storm events. The application of SEDCAM is more appropriate in areas where sedimentation rates are more uniform. However, the average rates used in this analysis provide some useful indications of the potential for sediment recovery.

In situ degradation and diffusion, like sediment dilution and the mixing process, can effectively reduce sediment contaminant concentrations over time, and thus are important when estimating recovery times. However, data that accurately quantify chemical-specific decay rates due to biodegradation and diffusion are not readily available. The combined first-order decay rate constants selected resulted in upper estimates of recovery times. Because the successful application of SEDCAM depends, in part, on decay rate constants that reflect the real decay process as closely as possible, the values assigned should be revised if and when empirical data become available.

The formulation of the model is based on the assumption that mixing in the surface mixed layer occurs instantaneously. This assumption is a simplification that allows for an analytical solution to the differential equation describing the variation in contaminant concentration in the mixed layer with time.

Characterization of the volumes of contaminants supplied by different sources is required to accurately predict sediment recovery scenarios. Few detailed assessments of toxicant loading from sources have been attempted primarily because chemistry data from a large number of CSO events would be required to generate a representative average concentration for each contaminant. The concentration of a problem chemical in recently deposited sediments following source control is difficult to determine. The information necessary to determine the concentration is not always available. The steady-state assumption (i.e., that the input rate of the contaminant equals the removal rate of the contaminant prior to source control) is a simplification that eliminates the need to specify information that is not available. However, this assumption may not reflect the true process and may result in an underestimate or overestimate of the concentration in recently deposited sediments, depending on whether source loading has increased or decreased recently. The steady-state assumption is probably most questionable when applied to environmental settings, such as Slip 4, where the bulk of the sediment accumulated yearly can be deposited in a matter of days.

During the Commencement Bay Nearshore/Tideflats Feasibility Study (Tetra Tech in preparation), a sensitivity analysis was performed to evaluate the effect of changing the depth of the mixed layer used in the sediment recovery time calculations. A mixed layer depth of 20 cm was used in the sensitivity analysis, representing the maximum value of all mixed layer measurements. Increasing the mixing depth from 10 to 20 cm has the same effect as reducing the sedimentation rate used by 50 percent. Increasing the mixed layer depth or decreasing the sedimentation rate would lengthen the recovery time of the sediments. Similarly, decreasing the mixed layer depth or increasing the sedimentation rate would reduce the length of time required for contaminant concentrations in surficial sediments to be reduced to an acceptable level (i.e., the target cleanup goal).

SEDCAM is a useful tool to assess the relationship between source control and the recovery of contaminated sediments. Several factors have been identified that would facilitate the refinement of the model:

- Improved contaminant loading data
- Well-characterized sediment accumulation rates and sediment depositional patterns
- Applicable chemical-specific decay rates due to biodegradation and diffusion
- Validation of sediment recovery predictions through monitoring.

In spite of the limitations associated with the formulation and application of SEDCAM, the following conclusions can be drawn:

- Source elimination alone is not expected to result in sediment recovery in either the Denny Way CSO problem area or Slip 4 within a reasonable timeframe because of the current level of contamination

- Following sediment remediation, source control levels of 94 percent or greater in the Denny Way CSO and 98 percent or greater in Slip 4 will be required to maintain acceptable sediment quality in each problem area.

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APPENDIX A

DENNY WAY CSO PROBLEM AREA

SEDIMENT CONTAMINANT DATA

TABLE A-1. CONCENTRATION OF INORGANICS IN DENNY WAY CSO OFFSHORE SEDIMENTS
(mg/kg DRY WEIGHT = ppm)

Survey	Station	Sample	Rep	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper	Iron
PTI and Tetra Tech 1988	NS-01	NS-01		23.9	4.9		1.14	E104	251	29000
Malins et al. 1980	10041	10041					6.5		58.8	
Romberg et al. 1984	1406	1406			11.9				108.5	
	1512	1512			12.5				53.5	
	1603	1603			16.7				113	
	1606	1606			10.6				45.5	
	1612	1612			15				58	
	1706	1706			12.3				52	
	1810	1810			11.5				70	
	A060	A060		0.87	0.5	0.79	2.8	39	94	11000
	B060	B060		1.3	12	1.1	1.5	50	140	32000
	C060	C060		U0.03	44	0.89	1.5	51	61	24000
	S0032	S0032		0.45	9.3	0.33	0.86	52	49	18000
Romberg et al. 1987	BC-09	1					0.2		35	
	BC-33	2					0.6		60	
	BC-26	3					1.0		68	
	BC-19	4					1.1		73	
	BD-17	5					2.4		72	
	BC-25	6					1.1		72	
	BC-30	7					2.4		102	
	BC-22	8					2.0		109	
	BC-18	9					1.7		101	
	BC-16	10					2.3		92	
	BD-13	11					1.6		70	
	BD-10	12					1.9		86	
	BC-28	13					0.5		58	
	BC-32	14A					0.6		55	
	BC-23	15					0.5		42	
	BC-29	16					1.7		116	
	BC-21	17					2.6		132	
	BC-17	18					3.2		140	
	BD-15	19	01				2.8		212	
	BD-15	19	02				3.4		147	
	BD-15	19	Mean				3.1		179	
	BD-12	20					2.7		162	
	BD-09	21					2.3		112	
	BD-08	22					2.4		106	
	BD-07	23					2.3		94	
	BC-24	24					1.9		70	
	BC-31	25A					1.6		90	
	BC-27	26A					0.8		609	
	BD-16	27					3.2		264	
	BD-14	28					6.1		302	
	BD-18	30A					1.8		87	

TABLE A-1. (Continued)

Survey	Station	Sample	Rep	Lead	Manganese	Nickel	Selenium	Silver	Thallium	Zinc	Mercury
PTI and Tetra Tech 1988	NS-01	NS-01		217	E525	43.5	U0.11	E8.27		E158	E0.405
Malins 1980	10041	10041		74.3				3.8		97.8	1.1
Romberg et al. 1984	1406	1406		149.5						155	
	1512	1512		74						105	
	1603	1603		530						433.3	
	1606	1606		68.5						118	
	1612	1612		94						115	
	1706	1706		115						193.3	
	1810	1810		101						120	
	A060	A060		220	220	54	0.07	0.72	U0.007	210	0.71
	B060	B060		120	280	58	0.65	1.2	U0.015	140	U0.012
	C060	C060		110	290	63	0.02	0.89	U0.01	180	U0.007
	S0032	S0032		120	200	38	U0.2	1.9	U0.1	100	0.06
Romberg et al. 1987	BC-09	1		48						150	0.49
	BC-33	2		78						232	0.59
	BC-26	3		111						205	0.66
	BC-19	4		147						179	0.69
	BD-17	5		176						376	0.76
	BC-25	6		136						234	0.88
	BC-30	7		256						271	0.97
	BC-22	8		246						271	1.2
	BC-18	9		199						260	1.2
	BC-16	10		196						294	1.0
	BD-13	11		124						319	0.58
	BD-10	12		193						224	1.2
	BC-28	13		84						187	0.42
	BC-32	14A		97						143	0.47
	BC-23	15		95						165	0.23
	BC-29	16		241						241	0.57
	BC-21	17		398						273	1.8
	BC-17	18		398						374	0.99
	BD-15	19	01	340						248	2.2
	BD-15	19	02	407						307	1.1
	BD-15	19	Mean	373						277	1.7
	BD-12	20		267						257	1.1
	BD-09	21		304						268	1.7
	BD-08	22		148						262	1.1
	BD-07	23		260						258	0.98
	BC-24	24		149						188	0.74
	BC-31	25A		178						295	0.72
	BC-27	26A		109						170	0.44
	BD-16	27		350						445	0.70
	BD-14	28		478						472	2.2
	BD-18	30A		186						272	1.0

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

E = Quantity listed is an estimated value.

TABLE A-2. CONCENTRATION OF LOW MOLECULAR WEIGHT AROMATIC HYDROCARBONS IN DENNY WAY CSO OFFSHORE SEDIMENTS (ug/kg DRY WEIGHT = ppb)

Survey	Station	Sample	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene
PTI and Tetra Tech 1988	NS-01	NS-01	U36	E1.7	E29	E15	E230	E50
Malins 1980	10041	10041	220	20	50	60	400	230
Romberg et al. 1984	A060	A060					E17	E17
	S0032	S0032	560		E51	430	5400	E2100
Romberg et al. 1987	BC-33	2	U80	U180	U100	U100	U270	U100
	BC-26	3	120	U180	U100	U100	580	210
	BD-17	5	140	U180	U100	130	1050	360
	BC-30	7	500	U180	120	C80	1900	580
	BC-16	10	170	U180	140	130	1200	400
	BD-10	12	110	U180	U100	U100	550	250
	BC-32	14A	110	U180	U100	U100	400	U100
	BC-23	15	U80	U180	U100	U100	450	240
	BC-29	16	130	U180	120	1500	1220	240
	BC-21	17	170	U180	200	U100	4400	1170
	BC-17	18	140	U180	U100	300	2280	1170
	BD-15	19	250	U180	170	640	3700	260
	BD-12	20	150	U180	130	150	1470	250
	BD-09	21	U80	U180	U100	160	800	210
	BD-08	22	120	U180	120	260	1810	2260
	CC-31	25A	U80	U180	140	U100	350	U100
	BC-27	26A	U80	U180	U100	U100	240	U100
	BD-16	27	1340	U180	12800	31500	98600	40700
	BD-14	28	350	U180	410	900	6400	3510
	BD-18	30A	U80	U180	U100	U100	550	200

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

E = Quantity listed is an estimated value.

TABLE A-3. CONCENTRATION OF HIGH MOLECULAR WEIGHT AROMATIC HYDROCARBONS IN DENNY WAY CSO OFFSHORE SEDIMENTS
(ug/kg DRY WEIGHT = ppb)

Survey	Station	Sample	Fluor-anthene	Pyrene	Benzo(a)-anthracene	Chrysene	Benzo(b)-fluor-anthene	Benzo(k)-fluor-anthene	Benzo(a)-pyrene	Indeno-(1,2,3-cd)-pyrene	Dibenzo-(a,h)-anthra-cene	Benzo-(g,h,i)-perylene	Total Benzo-fluoran-thenes
PTI and Tetra Tech 1988	NS-01	NS-01	E440	E370	U2.1	U2.4	E94	E140	U2.6	U2.8	U4.3	U2.5	
Malins et al. 1980	10041	10041	490	640	310	360			260	150			
Romberg et al. 1984	A060	A060	72	53									
	B060	B060	E610	E610					E610				
	S0032	S0032	10000	12000	5400	8900			1300	640		720	
Romberg et al. 1987	BC-33	2	250	2620	190	360			360	U500	U500	U500	480
	BC-26	3	900	1000	610	1130			850	560	U500	720	1200
	BD-17	5	1590	1600	1070	U130			U130	610	U500	710	2400
	BC-30	7	2170	2020	1730	2400			1700	U500	U500	740	2400
	BC-16	10	1460	1830	1060	1400			1060	560	U500	U500	1680
	BD-10	12	880	890	1100	1200			850	610	U500	680	1500
	BC-32	14A	300	260	250	510			340	U500	U500	U500	520
	BC-23	15	430	370	370	590			780	U500	U500	U500	950
	BC-29	16	1730	1450	1060	1190			950	790	U500	620	1530
	BC-21	17	6800	5200	4000	5000			2400	1300	U500	1400	4500
	BC-17	18	3230	2750	2180	2860			1760	800	U500	800	2700
	BD-15	19	4800	4000	3200	4000			1740	700	U500	U500	3500
	BD-12	20	1900	2000	1200	1530			820	U500	U500	U500	1980
	BD-09	21	690	640	830	470			560	U500	U500	700	1120
	BD-08	22	2500	1840	2720	3140			870	800	U500	U500	2370
	BC-31	25A	460	440	290	480			280	U500	U500	U500	540
	BC-27	26A	240	240	150	280			170	U500	U500	U500	350
	BD-16	27	61500	36200	10700	26500			7500	U500	U500	U500	16400
	BD-14	28	6730	5000	3140	4000			1900	U500	U500	U500	3300
	BD-18	30A	660	630	390	680			490	U500	U500		930

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

E = Quantity listed is an estimated value.

TABLE A-4. CONCENTRATION OF PHENOLS IN DENNY WAY CSO OFFSHORE SEDIMENTS
(ug/kg DRY WEIGHT = ppb)

Survey	Station	Sample	Phenol	2-Methyl-phenol	4-Methyl-phenol	2,4-Dimethyl-phenol
PTI and Tetra Tech 1988	NS-01	NS-01	U6.0	U13	E37	U17
Romberg et al. 1987	BC-33	2	U80			
	BC-26	3	U80			
	BD-17	5	90			
	BC-30	7	U80			
	BC-16	10	U80			
	BD-10	12	U80			
	BC-32	14A	100			
	BC-23	15	U80			
	BC-29	16	580			
	BC-21	17	140			
	BC-17	18	U80			
	BD-15	19	190			
	BD-12	20	240			
	BD-09	21	130			
	BD-08	22	860			
	BC-31	25A	100			
	BC-27	26A	U80			
	BD-16	27	900			
	BD-14	28	1900			
	BD-18	30A	220			

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

E = Quantity listed is an estimated value.

TABLE A-5. CONCENTRATION OF SUBSTITUTED PHENOLS IN DENNY WAY CSO OFFSHORE SEDIMENTS (ug/kg DRY WEIGHT = ppb)

Survey	Station	Sample	2-Chloro-phenol	2,4-Dichloro-phenol	4-Chloro-3-methyl-phenol	2,4,6-Trichloro-phenol	2,4,5-Trichloro-phenol	Penta-chloro-phenol	2-Nitro-phenol
PTI and Tetra Tech 1988	NS-01	NS-01	U12	U33	U16	U31	U35	U2200	
Romberg et al. 1987	BC-33	2						U180	U120
	BC-26	3						U180	U120
	BD-17	5						790	380
	BC-30	7						U180	
	BD-08	22						560	

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

TABLE A-6. CONCENTRATION OF CHLORINATED AROMATIC HYDROCARBONS IN DENNY WAY CSO OFFSHORE SEDIMENTS (ug/kg DRY WEIGHT = ppb)

Survey	Station	Sample	1,3-Dichloro-benzene	1,4-Dichloro-benzene	1,2-Dichloro-benzene	1,2,4-Trichloro-benzene	2-Chloro-naphtha-lene	Hexa-chloro-benzene
PTI and Tetra Tech 1988	NS-01	NS-01	U110	U110	U110	U180	U14	U93
Malins et al. 1980	10041	10041						0.3

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

TABLE A-7. CONCENTRATION OF CHLORINATED ALIPHATIC HYDROCARBONS IN DENNY WAY CSO OFFSHORE SEDIMENTS (ug/kg DRY WT = ppb)

Survey	Station	Sample	Hexachloro-butadiene
PTI and Tetra Tech 1988	NS-01	NS-01	U2200
Romberg et al. 1984	S0032	S0032	5.1

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

TABLE A-8. CONCENTRATION OF PHTHALATES IN
DENNY WAY CSO OFFSHORE SEDIMENTS
(ug/kg DRY WEIGHT = ppb)

Survey	Station	Sample	Dimethyl-phthalate	Di-n-butyl-phthalate	Butyl benzyl phthalate	Bis-(2-ethyl-hexyl)-phthalate	Di-n-octyl-phthalate
PTI and Tetra Tech 1988	NS-01	NS-01	E17		U2.3		U1.4
Romberg et al. 1984	A060	A060	E17				520
	B060	B060					23000
	S0032	S0032		770			13000
Romberg et al. 1987	BC-33	2	U80	U130	U130	1340	U130
	BC-26	3	U80	1670	220	1090	250
	BD-17	5	U80	1420	380	17300	1160
	BC-30	7	U80	790	650	15600	U130
	BC-16	10	U80	1000	500	400	U130
	BD-10	12	U80	700	250	2240	450
	BC-32	14A	U80	U130	U130	12100	U130
	BC-23	15	U80	U130	710	8800	U130
	BC-29	16	U80	400	410	22500	U130
	BC-21	17	U80	940	870	37000	U130
	BC-17	18	U80	1030	310	12400	U130
	BD-15	19	100	1020	680	18200	U130
	BD-12	20	U80	810	810	20800	U130
	BD-09	21	U80	590	230	4300	U130
	BD-08	22	U80	610	540	34100	U130
	BC-31	25A	U80	910	160	53700	U130
	BC-27	26A	U80	U130	U130	800	U130
	BD-16	27	180	340	1100	1200	U130
	BD-14	28	120	280	1830	400	U130
	BD-18	30A	U80	U130	520	500	U130

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

E = Quantity listed is an estimated value.

TABLE A-9. CONCENTRATION OF MISCELLANEOUS OXYGENATED COMPOUNDS IN DENNY WAY CSO OFFSHORE SEDIMENTS (ug/kg DRY WEIGHT = ppb)

Survey	Station	Sample	Isophorone	Benzyl alcohol	Benzoic acid	Dibenzo-furan	2-Methyl-naphthalene
PTI and Tetra Tech 1988	NS-01	NS-01	U22	U310	U110	E18	E7
Malins et al. 1980	10041	10041					90

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

E = Quantity listed is an estimated value.

TABLE A-10. CONCENTRATION OF PESTICIDES AND PCBS IN DENNY WAY CSO OFFSHORE SEDIMENTS
(ug/kg DRY WEIGHT = ppb)

Survey	Station	Sample	4,4'-DDE	4,4'-DDD	4,4'-DDT	Aldrin	Dieldrin	Alpha-BHC	Beta-BHC	Delta-BHC	Gamma-BHC (lindane)
PTI and Tetra Tech 1988	NS-01	NS-01	U4.8	U5.9	U5.3	U4.4	U4.1	U2.7	U6.0	U3.3	U3.1
Romberg et al. 1984	S0032	S0032	21	12	95						

Survey	Station	Sample	Chlordane	Endrin	Endrin-aldehyde	Hepta-chlor	Total PCBs
PTI and Tetra Tech 1988	NS-01	NS-01	U72	U5.5	U7.2	U4.1	U390
Malins et al. 1980	10041	10041					158
Romberg et al. 1984	1406	1406					1930
	1512	1512					1712
	1603	1603					2145
	1606	1606					2624
	1612	1612					1111
	1706	1706					479
	1810	*1810*					*742*
	A060	A060					8.1
	B060	B060					170
	C060	C060					2.3
	S0032	S0032					1448
Romberg et al. 1987	BC-33	2					260
	BC-26	3					410
	BD-17	5					510
	BC-30	7					770
	BC-16	10					580
	BD-10	12					670
	BC-32	14A					160
	BC-23	15					170
	BC-29	16					290
	BC-21	17					300
	BC-17	18					490
	BD-15	19					30
	BD-12	20					120
	BD-09	21					30
	BD-08	22					1510
	BC-31	25A					510
	BC-27	26A					220
	BD-16	27					300
	BD-14	28					1060
	BD-18	30A					930

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

TABLE A-11. CONVENTIONAL PARAMETERS IN DENNY WAY CSO OFFSHORE SEDIMENTS

Survey	Station	Sample	Rep	Percent Total Solids	Percent Volatile Solids	Percent Total Organic Carbon	Percent Nitrogen	Oil and Grease (ppm)	Sulfide (ppm)
PTI and Tetra Tech 1988	NS-01	NS-01		83.03	2.18	E0.43	0.034	790	66
Romberg et al. 1987	BC-09	1		56.17	3.99				
	BC-33	2		51.95	5.23				
	BC-26	3		52.35	5.72				
	BC-19	4		55.42	5.53				
	BD-17	5		49.43	6.60				
	BC-25	6		48.33	7.78				
	BC-30	7		48.88	8.33				
	BC-22	8		56.04	5.18				
	BC-18	9		49.14	7.22				
	BC-16	10		50.40	6.83				
	BD-13	11		57.94	5.47				
	BD-10	12		49.88	6.08				
	BC-28	13		27.81	13.1				
	BC-32	14A		40.15	8.27				
	BC-23	15		62.77	5.13				
	BC-29	16		57.52	7.52				
	BC-29	16		57.52	7.52				
	BC-21	17		59.27	9.63				
	BC-17	18		54.83	8.81				
	BD-15	19	01	50.83	9.48				
	BD-15	*19*	*02*	*48.36*	*11.2*				
	BD-15	19	Mean	49.59	10.3				
	BD-12	20		51.02	7.41				
	BD-09	21		48.91	9.35				
	BD-08	22		54.53	7.38				
	BD-07	23		49.95	7.13				
	BC-24	24		54.86	5.90				
	BC-31	25A		43.39	7.91				
	BC-27	26A		59.57	4.57				
	BD-16	27		70.86	3.84				
	BD-14	28		41.02	14.5				
	BD-18	30A		38.61	8.63				

Data Qualifiers:

E = Quantity listed is an estimated value.

APPENDIX B

DUWAMISH RIVER SLIP 4 PROBLEM AREA

SEDIMENT CONTAMINANT DATA

TABLE B-1. CONCENTRATIONS OF INORGANICS IN DUWAMISH RIVER SLIP 4 SEDIMENTS
(mg/kg DRY WEIGHT = ppm)

Survey	Station	Sample	Antimony	Arsenic	Cadmium	Chromium	Copper	Iron	Lead
PTI and Tetra Tech 1988	DR-08	DR-08	33.2	16.1	4.15	E86	126	53200	257
EPA 1982, 1983	E19	E19(1982)	U0.1	15.0	3.3	E19	E31	19900	218
	E19	E19(1983)	U0.1	16.0	2.3	53	150	44700	298
	E19A	E19A	U0.1	12.0	1.1	28	92	36000	115
Sample 1987[b]	SL-01	8431	--	E21	E4.3	E62	E120	--	E890
	SL-02	8432	--	E12	E0.29	E46	E290	--	E92

Survey	Station	Sample	Manganese	Nickel	Selenium	Silver	Zinc	Mercury
PTI and Tetra Tech 1988	DR-08	DR-08	E569	36.8	0.39	E1.58	E315	E0.605
EPA 1982, 1983	E19	E19(1982)	137	15	--	2.0	251	0.4[a]
	E19	E19(1983)	290	40	0.2	0.42	293	0.210[a]
	E19A	E19A	262	23	0.1	0.12	187	0.122[a]
Sample 1987[b]	SL-01	8431	--	E45	--	--	E450	E0.094
	SL-02	8432	--	E38	--	--	E130	E0.28

Data Qualifers:

U = Substance undetected at the method detection limit.

E = Quantity listed is an estimated value.

[a] Value reported in mg/kg wet weight.

[b] Sample, T., 23 October 1987, personal communication.

TABLE B-2. CONCENTRATIONS OF EXTRACTABLE ORGANIC COMPOUNDS IN DUWAMISH RIVER SLIP 4 SEDIMENTS
(ug/kg DRY WEIGHT = ppb)

PHENOLS AND SUBSTITUTED PHENOLS

Survey	Station	Sample	Phenol	2-methylphenol	4-methylphenol	2,4-dimethylphenol	2-chlorophenol	2,4-dichlorophenol
PTI and Tetra Tech 1988	DR-08	DR-08	E78	U5.0	E60	U4.6	U4.2	U16
EPA 1982-1983	E19	E19(1982)	--	--	U50	--	--	--
	E19	E19(1983)	U200	--	--	U50	--	--
	E19A	E19A	U50	--	U50	U50	--	--

			4-chloro-3-methyl phenol	2,4,6-tri chloro-phenol	2,4,5-tri-chloro-phenol	Penta-chloro-phenol
			U9	U15	U39	U150
	E19	E19(1982)	--	--	--	--
	E19	E19(1983)	--	--	--	U50
	E19A	E19A	--	--	--	U50

LOW MOLECULAR WEIGHT AROMATIC HYDROCARBONS

Survey	Station	Sample	Naph-thalene	Acenaph-thylene	Acenaph-thene	Fluorene	Phenanthrene	Anthracene
PTI and Tetra Tech 1988	DR-08	DR-08	E170	E52	E110	E150	E970	E250
EPA 1982-1983	E19	E19(1982)	--	--	--	--	--	--
	E19	E19(1983)	U100	U100	1000	U100	2300	1000
	E19A	E19A	U100	U100	U100	U100	1100	990

HIGH MOLECULAR WEIGHT AROMATIC HYDROCARBONS

Survey	Station	Sample	Fluoranthene	Pyrene	Benzo(a) anthracene	Chrysene	Benzo(b)-fluoranthene	Benzo(k)-fluoranthene
PTI and Tetra Tech 1988	DR-08	DR-08	E1500	E1100	E820	E930	E48	E550
EPA 1982-1983	E19	E19(1982)	--	--	--	--	--	--
	E19	E19(1983)	4300	3900	1200	1900	1110	1100
	E19A	E19A	2300	2200	900	1400	920	720

Survey	Station	Sample	Indeno-(1,2,3-cd)-pyrene	Dibenzo-(a,h)anthracene	Benzo-(g,h,i)-perylene	Total Benzo-fluoranthene	Benzo(a)-pyrene
PTI and Tetra Tech 1988	DR-08	DR-08	E1100	E270	E660	IE59	E760
EPA 1982-1983	E19	E19(1982)	--	--	--	--	--
	E19	E19(1983)	U100	U100	U100	2200	--
	E19A	E19A	U100	U100	U100	1640	900

TABLE B-2. (Continued)

CHLORINATED AROMATIC HYDROCARBONS

Survey	Station	Sample	1,3-dichlorobenzene	1,4-dichlorobenzene	1,2-dichlorobenzene	1,2,4-trichlorobenzene	2-chloronaphthalene	Hexachlorobenzene
PTI and Tetra Tech 1988	DR-08	DR-08	U100	U100	U67	U95	U7.3	U81
EPA 1982-1983	E19	E19 (1982)	--	--	--	--	--	--
	E19	E19 (1983)	U100	U100	U100	U100	--	U100
	E19A	E19A	U100	U100	U100	U100	--	U100

Survey	Station	Sample	Total Pentachlorobutadienes (# of isomers)
PTI and Tetra Tech 1988	DR-08	DR-08	U260
EPA 1982-1983	E19	E19 (1982)	--
	E19	E19 (1983)	--
	E19A	E19A	--

PHTHALATES

Survey	Station	Sample	Dimethylphthalate	Butylbenzylphthalate	Di-n-octylphthalate	Bis(2-ethylhexyl)-phthalate	Diethylphthalate	Di-n-butyl phthalate
PTI and Tetra Tech 1988	DR-08	DR-08	E50	E290	E120	--	--	--
EPA 1982-1983	E19	E19 (1982)	--	--	--	--	--	--
	E19	E19 (1983)	U100	U100	U100	U100	U100	U100
	E19A	E19A	U100	U100	U100	4000	U100	U100

MISCELLANEOUS COMPOUNDS

Survey	Station	Sample	Isophorone	Benzyl alcohol	Benzoic acid	Dibenzofuran	2-methylnaphthalene
PTI and Tetra Tech 1988	DR-08	DR-08	U7.9	U300	U62	E120	E72
EPA 1982-1983	E19	E19(1982)	--	U100	U50	U100	U100
	E19	E19(1983)	--	--	--	--	--
	E19A	E19A	--	U100	U50	U100	U100

TABLE B-2. (Continued)

PESTICIDES AND PCBs

Survey	Station	Sample	4,4'-DDE	4,4'-DDD	4,4'-DDT	Aldrin	Dieldrin	Alpha-BHC
PTI and Tetra Tech 1988	DR-08	DR-08	52	38	U15	U13	U12	U7.9
EPA 1982-1983	E19	E19 (1982)	--	--	--	--	--	--
	E19	E19 (1983)	U10	U100	U100	U10	U10	U10
	E19A	E19A	U100	U100	U1000	U100	U10	U100

			Beta-BHC	Delta-BHC	BHC(Lindane)	Chlordane	Endrin	Endrinaldehyde
			U17	U9.5	U9.1	U210	U16	68
	E19	E19 (1982)	--	--	--	--	--	--
	E19	E19 (1983)	U10	U10	U10	U100	U10	--
	E19A	E19A	U10	U10	U10	U100	U10	--

			Heptachlor
			U12
	E19	E19 (1982)	--
	E19	E19 (1983)	U10
	E19A	E19A	U100

Survey	Station	Sample	Total PCBs
PTI and Tetra Tech 1988	DR-08	DR-08	E5800
EPA 1982-1983	E19	E19(1982)	I1600
	E19	E19(1983)	I5600
	E19A	E19A	I1600
Sample 1987[a]	SL-01	8431	6000
	SL-02	8432	4000
Schlender 1985[b]		102	E7250
		105	E5200
		109	E6700

Data Qualifiers:

U = Substance undetected at the method of detection limit shown.

E = Quantity listed is an estimated value.

I = Incomplete sum. Data for one or more component compounds are missing.

[a] Sample, T., 23 October 1987, personal communication.

[b] Schlender, M., 16 April 1985, personal communication.