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DEPARTMENT OF
ECOLOGY

Marine Sediment Monitoring Program

I. Chemistry and Toxicity Testing
1989-1995

August 1998

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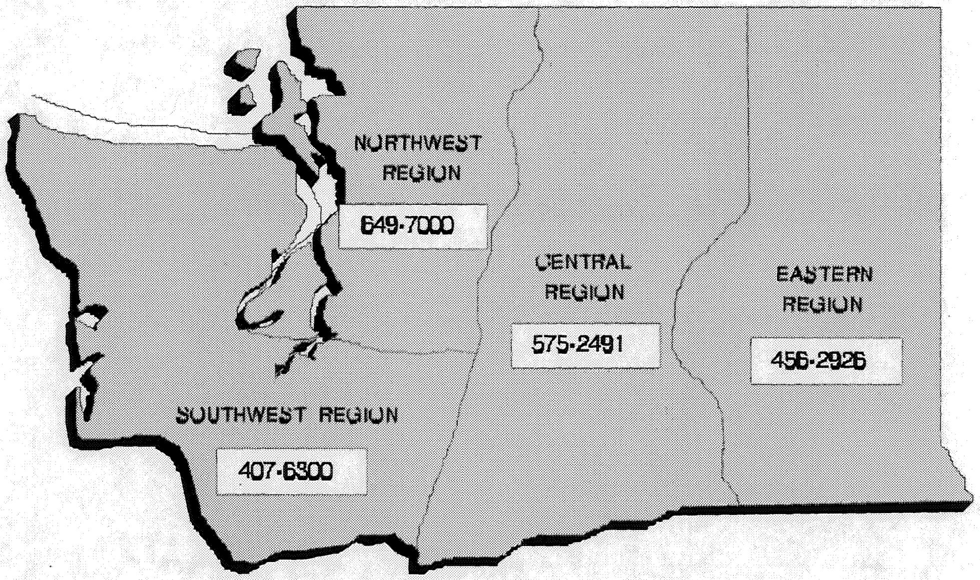

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1989-1995

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Abstract

The Marine Sediment Monitoring Program (MSMP) was implemented in 1989 to characterize baseline sediment quality conditions and trends throughout Puget Sound. The MSMP has adopted the Triad approach to sediment monitoring. Components of the Triad are the measurement of sediment contaminants, the evaluation of biological conditions, and the assessment of potential for sediment toxicity. Individually, the components of the Triad do not provide for an adequate understanding of sediment quality. In combination, the biological significance of actual and potential contaminant levels can be assessed by analysis of benthic community structure and toxicity in laboratory bioassays.

Data were collected annually from 1989-1995. Eighty-six stations were established throughout Puget Sound, Hood Canal, the Strait of Georgia, and the Strait of Juan de Fuca. Locations included centers of major basins, bays and inlets, shallow subtidal areas, and historic sampling sites. Stations were grouped in two categories: core stations sampled annually, and rotating stations sampled once every three years alternating between North, Central and South Puget Sound regions. At each station, replicate sediment samples were collected for the analysis of chemical contaminants, sediment variables, and benthic community structure. In addition, sediments from each station were tested in laboratory bioassays for toxicity to the amphipod *Rhepoxynius abronius.* This volume addresses the chemistry and toxicity testing portions of the MSMP. Volume 2 presents results of benthic community analysis.

Overall, contaminant concentrations at monitoring stations were generally low and below sediment quality standards. Of five chemical groups (metals, VOC, ABN, PCB, pesticides) analyzed for, metals and semi-volatile organic compounds were most frequently detected. The highest metal and organic contamination was found in locations associated with urban and industrial centers. Low metal concentrations were also detected in some rural areas and in deep depositional environments. Contaminant concentrations occasionally exceeded regulatory sediment quality standards. However, there was no consistent pattern across years. A notable exception was mercury in Sinclair Inlet and Dyes Inlet, with concentrations above standards for each of the seven years monitored.

Amphipod bioassay results indicated significant mortality in both rural and urban stations. Mortality from seven samples could be attributed to chemical toxicity, but there was no consistent pattern across years. Sulfides in sediments of Puget Sound were primarily associated with areas where restricted water circulation and density stratification may contribute to low dissolved oxygen episodes.

Because the range of contaminant concentrations was generally low and did not reflect spatial conditions at urban bays, we recommend a comprehensive approach that investigates both ambient sediments and gradients of pollution near sources. Since sediment chemistry reflect multi-year deposition, we recommend that the sampling frequency of contaminants be reduced. Additionally, we recommend the use of alternative sediment bioassays as screening tools, and support of research on the source, transport, and fate of contaminants in Puget Sound.

Introduction

Puget Sound is a deep inlet of the Pacific Ocean which extends from the Strait of Juan de Fuca and the Admiralty Inlet south to Olympia. It includes approximately 5,000 square kilometers of wide basins and shallow embayments that were formed by glaciation during the Pleistocene epoch.

The bottom sediments of Puget Sound are composed primarily of compact, glacially formed clay layers and relict glacial tills (Crandell *et al.*, 1965). These sediments provide habitat and nutrients for highly diverse benthic and epibenthic invertebrate communities. These communities include numerous ecologically and economically important species, some of which are important prey for commercial fishes (Stober and Chew, 1984). The sediments in which these invertebrates live are repositories for natural and anthropogenic materials (*e.g.*, heavy metals and organic compounds), which can affect the health of the benthic communities they support. Monitoring of changes in sediment quality and benthic communities over time can provide information which expands the general knowledge of Puget Sound and upon which policy decisions may be based.

In 1986, an interdisciplinary group of sediment and water quality professionals, the Monitoring Management Committee (MMC), was appointed by the Puget Sound Water Quality Authority to develop a comprehensive monitoring program for Puget Sound. The Puget Sound Ambient Monitoring Program (PSAMP) was designed to provide long-term comprehensive monitoring of water quality, sediment quality, biological resources, nearshore habitats, and rivers in the Puget Sound Basin. One portion of PSAMP, the Marine Sediment Monitoring Program (MSMP), was implemented in 1989 by the Washington State Department of Ecology. The MSMP was originally intended to establish baseline sediment quality conditions and trends throughout Puget Sound, determine the effects of contaminants on biological communities, and identify potential reference sites for comparison in future studies.

Specifically, the objectives of the MSMP as they were originally stated in the Marine Sediment Quality Implementation Plan (Striplin, 1988) were to:

(1) Collect baseline and long-term data on Puget Sound sediments and macro-invertebrate communities in contaminated and uncontaminated areas.

(2) Identify areas of Puget Sound that are accumulating toxic chemicals.

(3) Assess the potential sediment toxicity resulting from accumulating toxic chemicals.

(4) Evaluate the condition of Puget Sound benthic macro-invertebrate communities in relation to the concentration of toxic chemicals in sediments.

(5) Document both natural and anthropogenic changes to sediment quality.

Limitations of the sampling design required modification of some of the original MSMP goals and objectives. Because most of the sampled stations were located away from sources of contamination and were not selected randomly, some of the objectives could only be partially met. For example, baseline conditions have been established for sediment chemistry at the sampling stations; however, we have little information about the areal extent of contamination. An evaluation of the MSMP and recommendations for program redesign are covered in the Recommendations section of this report.

Report Organization

This report, which summarizes and interprets the results of the MSMP from 1989 through 1995, is divided in two volumes. Seven years (1989-1995) of chemistry data and five years (1989-1993) of bioassay data are presented in this volume.

Volume 1 describes sampling and analytical methods for the chemistry, results, discussion of findings, conclusions, and recommendations. Volume 2 presents the biological findings for 1989 to 1993, and includes sampling methods and laboratory procedures for the benthic organisms, results, discussion of findings, conclusions, and recommendations. In addition, Volume 2 looks at the correspondence between chemistry and the benthos, and evaluates the current MSMP design.

In order that each volume be self-contained, some repetition of methods was unavoidable. Thus, a description of the sampling design and the list of station locations are presented in both volumes.

Methods

Study Approach

Over the past two decades, federal and state agencies and local governments have collected a substantial amount of information on chemical concentrations in Puget Sound urban sediments. While these data allow for an initial assessment of the degree and extent of contamination in sediments near sources of pollution, they do not provide an adequate understanding of overall sediment conditions. Sediment chemistry alone provides no information about the biological effects of contaminant concentrations.

To evaluate sediment quality, the MSMP used the Sediment Quality Triad developed by Chapman and Long (1983). The Triad approach investigates sediment quality from three perspectives: the analysis of sediment for contamination by organic compounds and metals, the analysis of benthic community condition, and the analysis of sediment toxicity through bioassay procedures. Measurements in these three categories have been shown to have good overall correspondence, and have been effective in determining sediment quality (Long and Chapman, 1985).

Procedures used by the MSMP in the measurement of sediment chemistry and toxicity of sediment samples are described below. Procedures used in the analysis of benthic community structure are presented in Volume 2 of this report.

Sampling Design

Eighty-six stations were established throughout Puget Sound, Hood Canal, the Strait of Georgia, and the Strait of Juan De Fuca (Table 1). Station locations were selected based on criteria established by the Monitoring Management Committee (MMC, 1988). Locations were chosen to include centers of major basins, bays and inlets, shallow subtidal areas, and historic sampling sites. In addition, some sediment stations were located to correspond with sampling locations of other PSAMP components, such as the marine waters monitoring and the fish monitoring programs.

A main focus of the MSMP was to monitor ambient conditions in order to characterize background sediments. Stations were deliberately located away from major sources of pollution. In addition, most stations (66 stations or 77%) were located in shallow areas at about 20 m or less in depth (Table 1). It was thought at the onset of the program that these areas would be most important in terms of the highest total abundance of benthic organisms (MMC, 1988).

Of the original 86 stations, 76 were kept in the program and 10 were dropped or moved because of difficulties in sampling (Table 1). Stations with very coarse sediments were eliminated because gravel and rocks prevented adequate sample collection. Ecology's sediment monitoring strategy over the first seven years of the program identified stations as "core" and "rotating". Core stations (34) were sampled annually, and rotating stations (42) were sampled once every three years in sets of fourteen, alternating among northern, central, and southern areas of the Puget Sound region (Table 1; Figure 1). Rotating stations were developed in the second year (1990) of the program to provide more concentrated (though less frequent) coverage of all portions of Puget Sound. All sampling occurred during three weeks in late March or early April to allow for the measurement of the stable adult invertebrate population that had survived over the winter (Tetra Tech, 1987).

Station Positioning

Stations were positioned according to Puget Sound Estuary Program (PSEP) recommended protocols (Tetra Tech, 1986) using LORAN C, a Global Positioning System (GPS), variable radar ranging, water depth, and visual fixes on stationary land objects. Latitude and longitude coordinates determined by GPS were used to establish positions of new stations. After 1995, differential GPS (DGPS) was used. The accuracy of station positioning depended on the available navigation systems for a given year and location.

Sampling Procedures

Sampling was conducted according to the Puget Sound Estuary Program (PSEP) protocols (Tetra Tech, 1986; 1987) and procedures outlined in the MSMP Implementation Plan (Striplin, 1988). Five replicate sediment samples were collected at each station using a double 0.1 m^2 stainless steel van Veen grab sampler. The double van Veen consists of two separate compartments which allow simultaneous collection of chemistry and biological samples.

The grabs were examined upon retrieval. Samples with obvious disturbance on the sediment surface or with shallow penetration were rejected and the sample was retaken. If the grab was acceptable, the top two centimeters of sediment in one compartment was collected for analysis of particle size distribution, total organic carbon (TOC), total sulfide (TS), a maximum of 185 target chemical compounds, and toxicity testing. The physical and olfactory character of the sample was also recorded. A Redox Potential Discontinuity (RPD) depth was measured visually for each sample in 1994 and 1995. The RPD marks the transition from oxidizing to reducing conditions in the sediment. This transition is characterized by a change in the color of the sediment, from light brown to gray or black. The thickness of the brown layer provides a relative measure of the penetration of oxygen into the sediment. RPD depths were measured by

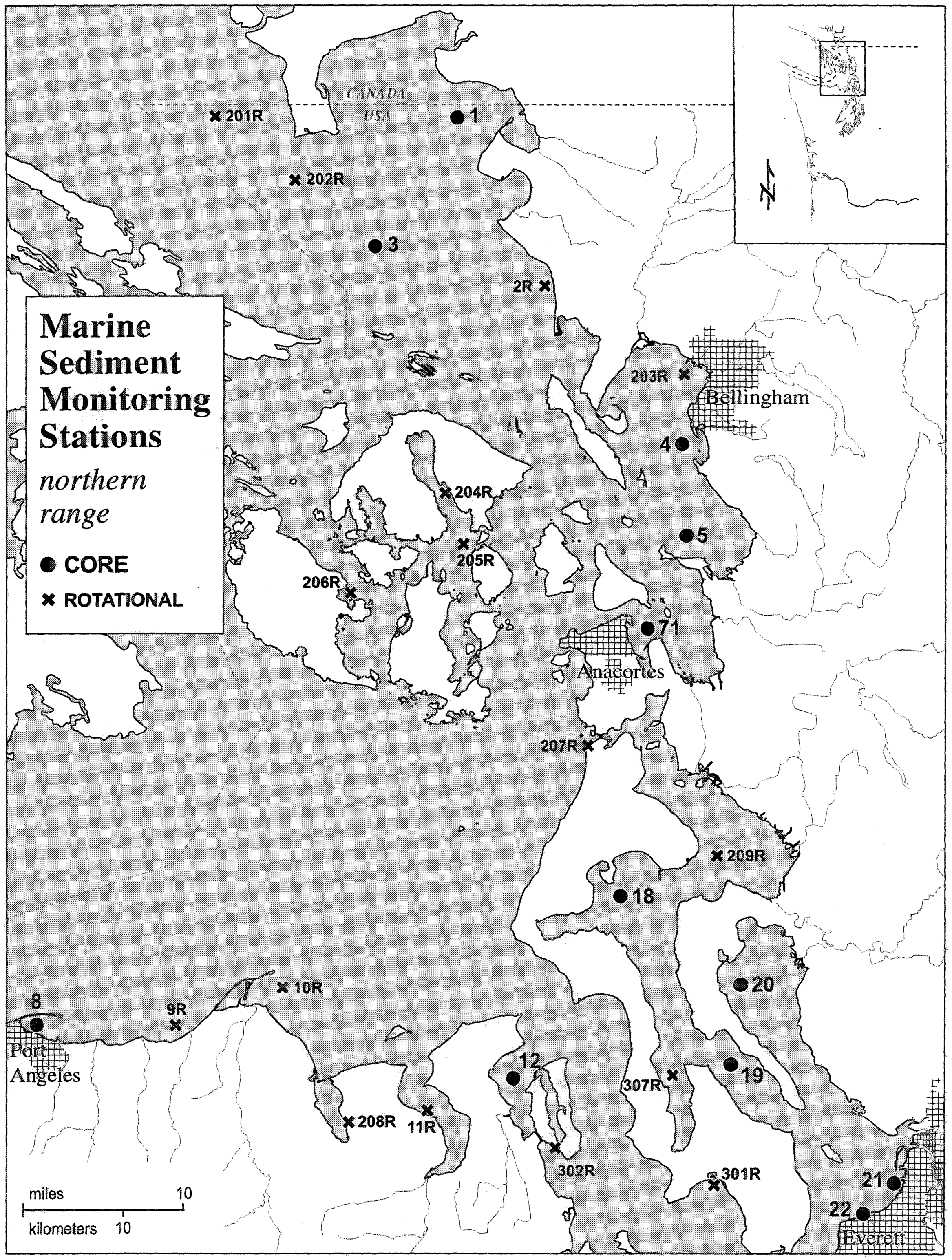

Figure 1A. Northern range of Puget Sound stations monitored by the MSMP.

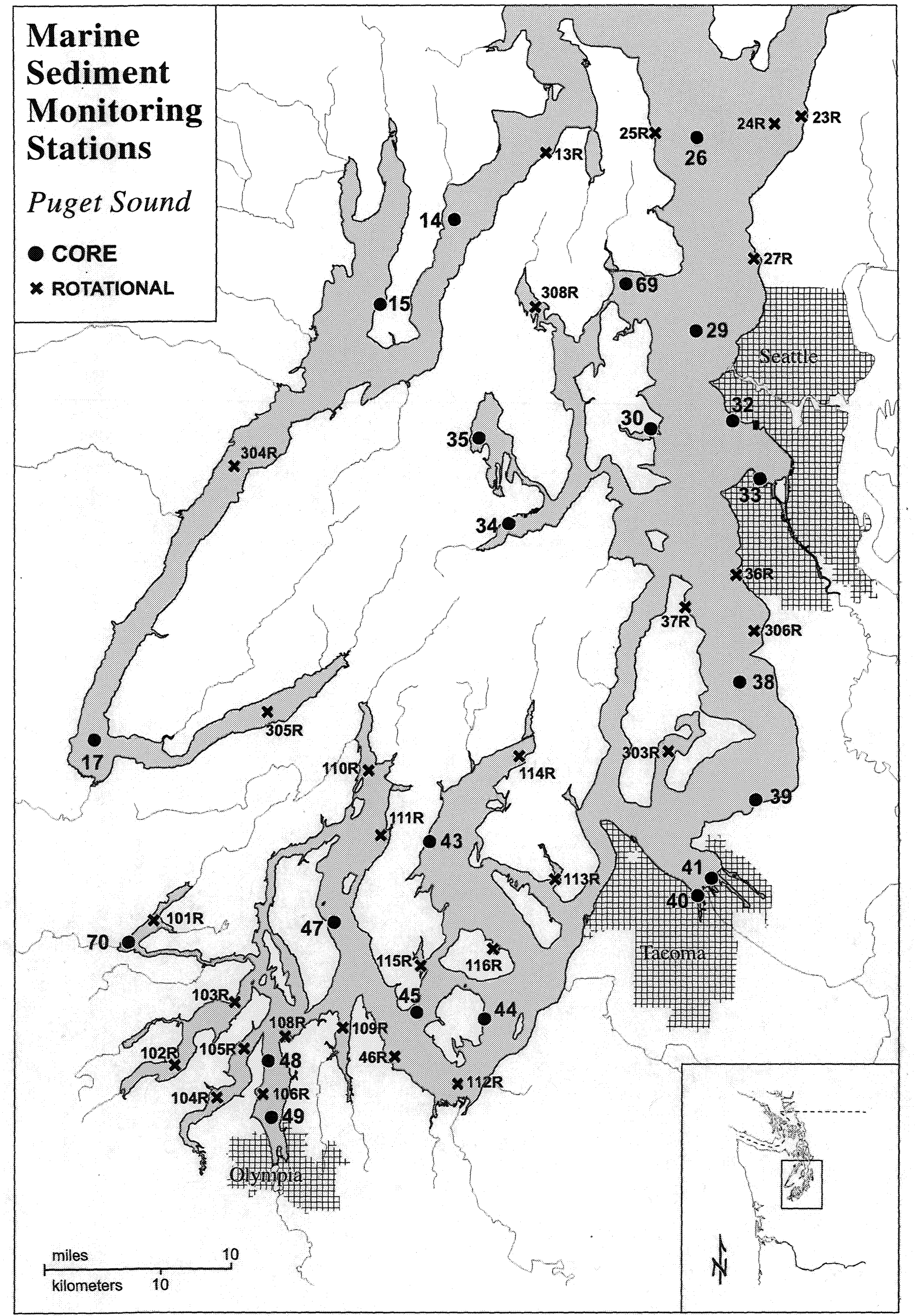

Figure 1B. Southern range of Puget Sound stations monitored by the MSMP.

Table 1. Designation, location and sampling schedule of marine sediment monitoring stations. An “X” denotes yearly data in the Marine Sediment Monitoring database. Core stations are sampled annually. Rotating stations are sampled in a 3 year rotation, and are designated with the letter "R".

Station Number	Station Name	Rotation Schedule	Latitude (deg min N)	Longitude (deg min W)	Approx. Water Depth (Meters)	Year						
						89	90	91	92	93	94	95
1	Semiahmoo Bay, Blaine	Core	48 59.46	122 51.73	23	X	X	X	X	X	X	X
2R	Cherry Point	North	48 50.04	122 44.11	20	X		X			X	
3	Strait of Georgia (North of Patos Is.)	Core	48 52.22	122 58.71	223	X	X	X	X	X	X	X
4	Bellingham Bay	Core	48 41.04	122 32.29	24	X	X	X	X	X	X	X
5	Samish Bay	Core	48 35.85	122 32.00	21	X	X	X	X	X	X	X
6	East of Anacortes	Core	48 31.05	122 34.35	20	X(1)						
7	Strait of Juan de Fuca	Core	48 12.10	123 14.34	133	X(1)						
8	Port Angeles	Core	48 07.89	123 26.94	21	X	X	X	X	X	X	X
9	Green Point	Core	48 08.10	123 17.20	20	X(2)						
9R	East of Green Point	North	48 08.02	123 14.94	14			X			X	
10R	Dungeness Bay	North	48 10.18	123 06.05	21	X		X			X	
11R	Discovery Bay	North	48 03.26	122 53.70	20	X		X			X	
12	Port Townsend Bay	Core	48 05.05	122 46.59	21	X	X	X	X	X	X	X

Table 1. Continued.

Station Number	Station Name	Rotation Schedule	Latitude (deg min N)	Longitude (deg min W)	Approx. Water Depth (Meters)	Year 89	90	91	92	93	94	95
13R	North Hood Canal (South of Bridge)	North	47 50.26	122 37.74	20	X		X			X	
16	South Hood Canal	Core	47 22.81	123 06.87	20	X(1)						
17	South Hood Canal, Great Bend	Core	47 22.18	123 07.78	81	X	X	X	X	X	X	X
18	Oak Harbor	Core	48 15.37	122 37.49	19	X	X	X	X	X	X	X
19	Saratoga Passage	Core	48 05.86	122 28.29	123.5	X	X	X	X	X	X	X
20	Port Susan	Core	48 10.37	122 27.48	10.5	X	X	X	X	X	X	X
21	Port Gardner (Everett)	Core	47 59.13	122 14.57	20	X	X	X	X	X	X	X
22	Mukilteo	Core	47 57.33	122 17.18	20.5	X	X	X	X	X	X	X
23R	East Central Basin (South of Picnic Point)	Central	47 52.24	122 20.07	20	X			X			X
24R	East Central Basin (West of Norma Beach)	Central	47 51.86	122 21.93	182	X			X			X
25R	West Central Basin (Whidbey Basin)	Central	47 51.31	122 30.21	20	X			X			X
26	Central Basin	Core	47 51.05	122 27.46	268	X	X	X	X	X	X	X
27R	Richmond Beach	Central	47 45.57	122 23.18	21	X			X			X

Table 1. Continued.

Station Number	Station Name	Rotation Schedule	Latitude (deg min N)	Longitude (deg min W)	Approx. Water Depth (Meters)	Year						
						89	90	91	92	93	94	95
28	Jefferson Head	Core	47 43.99	122 29.37	20	X(1)						
29	Shilshole	Core	47 42.05	122 27.24	199	X	X	X	X	X	X	X
30	Eagle Harbor	Core	47 37.43	122 30.18	13.5	X	X	X	X	X	X	X
31	West Point	Core	47 39.28	122 26.12	22	X(1)						
32	Magnolia Bluff	Core	47 37.91	122 24.52	21	X	X	X	X	X	X	X
33	Elliott Bay (SE of Duwamish Head)	Core	47 35.23	122 22.55	20	X	X	X	X	X	X	X
34	Sinclair Inlet	Core	47 32.83	122 39.73	9.5	X	X	X	X	X	X	X
35	Dyes Inlet	Core	47 36.81	122 41.92	12.5	X	X	X	X	X	X	X
36R	Brace Point	Central	47 30.81	122 23.85	15	X			X			X
37R	North Vashon Island (South of Dolphin Point)	Central	47 29.26	122 27.35	20.5	X			X			X
38	Point Pully (3-Tree Point)	Core	47 25.70	122 23.62	199	X	X	X	X	X	X	X
39	Dash Point (East of Dumas Bay)	Core	47 20.23	122 22.32	14.5	X	X	X	X	X	X	X
40	City Waterway (Commencement Bay)	Core	47 15.68	122 26.24	10	X	X	X	X	X	X	X

Table 1. Continued.

Station Number	Station Name	Rotation Schedule	Latitude (deg min N)	Longitude (deg min W)	Approx. Water Depth (Meters)	Year 89	90	91	92	93	94	95
41	Blair/Sitcum Waterways (Commencement Bay)	Core	47 16.49	122 25.27	20.5	X	X	X	X	X	X	X
42	Ruston (Commencement Bay)	Core	47 18.24	122 29.95	39	X(1)						
43	Carr Inlet	Core	47 17.87	122 44.55	19	X	X	X	X	X	X	X
44	East Anderson Island	Core	47 09.68	122 40.42	20	X	X	X	X	X	X	X
45	Devil's Head	Core	47 09.88	122 45.10	52	X	X	X	X	X	X	X
46R	West Nisqually (Johnson Point)	South	47 07.91	122 46.97	22	X	X			X		
47	Case Inlet (Fudge Point)	Core	47 13.98	122 50.98	20	X	X	X	X	X	X	X
48	Outer Budd Inlet	Core	47 07.44	122 55.16	21.5	X	X	X	X	X	X	X
49	Inner Budd Inlet	Core	47 04.79	122 54.81	5.25	X	X	X	X	X	X	X
50	Oakland Bay, Shelton	Core	47 12.61	123 04.55	7	X(3)						
69	Port Madison	Core	47 44.15	122 32.11	33.5		X	X	X	X	X	X
70	Oakland Bay, Shelton	Core	47 12.77	123 04.96	5.3		X	X	X	X	X	X
71	Fidalgo Bay, Cap Sante	Core	48 30.55	122 35.23	6.5		X	X	X	X	X	X
101R	North Oakland Bay	South	47 13.92	123 03.17	5		X			X		

Table 1. Continued.

Station Number	Station Name	Rotation Schedule	Latitude (deg min N)	Longitude (deg min W)	Approx. Water Depth (Meters)	Year 89	90	91	92	93	94	95
102R	Inner Totten Inlet	South	47 07.21	123 01.36	12		X			X		
103R	Mid Totten Inlet	South	47 10.24	122 57.46	20		X			X		
104R	Inner Eld Inlet	South	47 05.77	122 58.45	7		X			X		
105R	Outer Eld Inlet	South	47 08.08	122 56.70	16		X			X		
106R	Mid Budd Inlet (East of Tykle Cove)	South	47 05.99	122 55.32	12		X			X		
108R	Budd Inlet (West of Dover Point)	South	47 08.70	122 53.93	20		X(4)					
109R	Henderson Inlet	South	47 09.19	122 50.02	20		X			X		
110R	Inner Case Inlet	South	47 21.23	122 48.78	20		X			X		
111R	Mid Case Inlet	South	47 18.22	122 47.80	21		X			X		
112R	Nisqually Delta	South	47 06.74	122 41.94	20		X			X		
113R	Willochet Bay	South	47 16.39	122 35.75	24		X			X		
114R	Henderson Bay	South	47 22.08	122 38.85	18		X			X		
115R	Outer Filucy Bay	South	47 12.19	122 44.75	18		X			X		
116R	Carr Inlet (North of McNeil Island)	South	47 13.06	122 39.83	20		X(4)					

Table 1. Continued.

Station Number	Station Name	Rotation Schedule	Latitude (deg min N)	Longitude (deg min W)	Approx. Water Depth (Meters)	Year						
						89	90	91	92	93	94	95
201R	Strait of Georgia, Roberts Bank	North	48 59.47	123 12.41	121			X			X	
202R	Point Roberts	North	48 55.91	123 05.59	117			X			X	
203R	Bellingham Bay	North	48 45.00	122 32.00	12			X			X	
204R	East Sound	North	48 38.31	122 52.57	31			X			X	
205R	NW Blakely Island (West of Obstruction Island)	North	48 35.37	122 50.95	33			X			X	
206R	Friday Harbor	North	48 32.58	123 00.78	18			X			X	
207R	West Beach, Whidbey Island	North	48 23.96	122 40.26	28.5			X			X	
208R	Sequim Bay	North	48 02.52	123 00.37	13.5			X			X	
209R	Skagit Bay	North	48 17.72	122 29.31	21			X			X	
301R	Useless Bay	Central	47 59.12	122 29.49	20				X			X
302R	Oak Bay	Central	48 01.16	122 42.87	19.5				X			X
303R	Quartermaster Harbor	Central	47 22.47	122 28.29	13.5				X			X
304R	Hood Canal, Tekiu Point	Central	47 35.26	122 58.74	175				X			X

Table 1. Concluded.

Station Number	Station Name	Rotation Schedule	Latitude (deg min N)	Longitude (deg min W)	Approx. Water Depth (Meters)	Year						
						89	90	91	92	93	94	95
305R	Hood Canal, Outer Lynch Cove	Central	47 23.82	122 55.90	20				X			X
306R	Seahurst, East Passage	Central	47 28.23	122 22.56	75				X			X
307R	Holmes Harbor, Whidbey Island	Central	48 05.27	122 33.04	58				X			X
308R	Liberty Bay, Poulsbo	Central	47 43.06	122 38.21	16.5				X			X

(1) Station discontinued after 1989. (2) Station relocated and renumbered as 9R. (3) Station relocated and renumbered as 70. (4) Station discontinued after 1990.

determining the thickness of the top brown layer of sediment with a ruler inserted vertically in areas where the profile of the sediment could be observed.

The contents of the second compartment of each grab were gently sieved *in situ* through a 1.0-mm mesh screen using seawater. Benthic organisms retained in the screen were transferred to 10% buffered formalin in seawater. The vital stain Rose Bengal was added from 1993 through 1995.

Sampling equipment was decontaminated between stations and between composites at stations where samples were collected for replicate chemistry measurements. Except for equipment used to collect sediment for analysis of volatile organic compounds (VOCs), decontamination included an Alconox wash in the laboratory, a hot water and methanol rinse in the field, and a final rinse with seawater *in situ*. In 1989 and 1990, acetone and methylene chloride were used as a rinse, but were discontinued because of potential contamination of VOC samples on shipboard. Utensils for VOC sampling were rinsed with organic-free water following the Alconox wash. All equipment was wrapped in aluminum foil and stored away from organic solvents and other sampling equipment.

For each chemistry and toxicity test sample, the top two centimeters of sediment from several grabs was placed in a decontaminated stainless steel bowl, homogenized, and placed in acid-cleaned sample containers. A sample for total sulfides was taken from a single grab, not homogenized, and placed in a sample container with zinc acetate added. Total sulfide analysis was discontinued in 1994. Likewise, samples for VOCs were collected without homogenization. Samples were stored on ice until off-loaded for transport to the laboratory. No samples were stored on the boat for more than three days.

Replicate chemistry samples (separate, not composite samples) were collected at approximately 10% of the stations. From 1989 through 1993, replicate samples were collected as follows. Replicates 1 and 2 were generated by splitting composited and homogenized sediment from the first set of grabs (collected as described above). The number of grabs in a set varied between stations and years. Grabs were taken until a sufficient volume of sediment was collected. The first replicate was assigned the actual station number. The second replicate was assigned an artificial station number and served as a blind laboratory replicate. Two additional sets of grab samples from the same location were collected and processed separately as replicates 3 and 4. These third and fourth replicates were given artificial station numbers and analyzed as blind field replicates. Replicate samples for VOCs and total sulfide analysis did not represent true blind laboratory replicates as they could not be composited. Replicate samples for these compounds were collected from four separate grabs, each representing a single replicate.

For 1994 and 1995, the method of replicate collection was changed in order to provide information about between-grab variability. Homogenized sediment from a single grab was divided for replicates 1 and 2. A second grab was taken for replicate 3 and a third grab was taken for replicate 4.

Laboratory Procedures

Chemical Analysis

From 1989 through 1993, most of the chemical analyses for this project were performed by Analytical Resources, Inc. (Seattle, Washington). Other consultants performed different tests in different years (Table 2).

A review of chemistry results and data quality was provided by a different independent contractor from 1989 through 1992. Since 1993, Ecology's Manchester Environmental Laboratory provided data validation services. Data validation reports and specific details on analytical methods can be found in Ecology's annual MSMP reports (Dutch *et al.*, 1993; Striplin *et al.*, 1991; Tetra Tech, 1990; WDOE, 1994), and will not be repeated here.

Chemical analyses were conducted in accordance with the U.S. EPA Contract Laboratory Program (CLP) methods as modified by the PSEP protocols (Tetra Tech, 1986) to obtain lower detection limits. Sediment particle size analysis followed procedures recommended by the PSEP protocols (Tetra Tech, 1986) and described in Folk (1980). Sand was separated from mud by wet sieving, and the mud fraction was analyzed for percent silt and clay by pipette. TOC was measured by high temperature combustion using a carbon analyzer. Samples for TS were preserved in a solution of zinc acetate, and the TS determined by distillation of the acid-labile sulfide followed by spectrophotometric analysis (methylene blue method). In 1990, however, a titrimetric analysis was used to determine sulfide content. Because of difficulties in the method (see Results), TS was not determined in 1994 or 1995.

Metals were analyzed by either graphite furnace atomic absorption (GFAA) or inductively coupled plasma (ICP) atomic emission spectroscopy (Table 3). The analysis of some metals by GFAA was conducted to achieve lower detection limits. The choice of technique was also based on expected concentration of the samples. Mercury was analyzed by cold vapor atomic absorption (CVAA) spectrophotometry. Method detection limits were lowered by strong acid digestion of large samples. Samples were digested in nitric acid and hydrogen peroxide, and the digestate was refluxed with either nitric acid or hydrochloric acid. Mercury analysis was conducted using concentrated nitric and sulfuric acid digestions.

Volatile and semi-volatile organic compounds were analyzed by gas chromatography followed by mass spectrometry (GCMS) (Table 3). Analysis for volatile organic compounds were discontinued in 1994 because of low and inconsistent detection in samples. Chlorinated pesticides and polycyclic chlorinated biphenyls (PCBs) were analyzed by alumina column

Table 2. Analytical services for MSMP samples.

Year	Laboratory	Parameters analyzed
1989	Analytical Resources, Inc.	Metals, organics, total organic carbon
	Columbia Analytical Services, Inc.	Total sulfides, grain size
1990	Analytical Resources, Inc.	Metals, organics, total sulfides, total organic carbon
	Hart Crowser	Grain size
1991	Analytical Resources, Inc.	Metals, organics, total sulfides, total organic carbon
	Soil Technology, Inc.	Grain size
1992	Analytical Resources, Inc.	Metals, organics, total sulfides, total organic carbon
	Soil Technology, Inc.	Grain size
1993	Analytical Resources, Inc.	Metals, organics, total sulfides, total organic carbon
	Soil Technology, Inc.	Grain size
1994	Manchester Environmental Laboratory	Metals, organics, total sulfides
	Soil Technology, Inc.	Grain size
	Analytical Resources, Inc.	Total Organic Carbon
1995	Manchester Environmental Laboratory	Metals, organics, total sulfides
	Columbia Analytical Services, Inc.	Grain size
	Analytical Resources, Inc.	Total Organic Carbon

Table 3. Laboratory analysis methods for target (excluding conventional) chemical compounds in MSMP samples.

Compound	Reporting Units (dry weight)	Method
METALS		
Antimony	mg/kg	GFAA (1989-1993), ICP (1995)(1)
Arsenic	mg/kg	GFAA (1989-1993), ICP (1994), GFAA (1995)
Cadmium	mg/kg	GFAA (1989-1993), ICP (1994, 1995)
Lead	mg/kg	GFAA (1989-1993), ICP (1994), GFAA (1995)(2)
Selenium	mg/kg	GFAA (1989-1991, 1995)(3)
Silver	mg/kg	GFAA (1989-1993), ICP (1994, 1995)
Thallium	mg/kg	GFAA (1989-1991, 1995)(3)
Beryllium	mg/kg	ICP (1989-1993, 1995)(1)
Chromium	mg/kg	ICP (1989-1995)
Copper	mg/kg	ICP (1989-1995)
Nickel	mg/kg	ICP (1989-1993, 1995)(1) (4)
Zinc	mg/kg	ICP (1989-1995)
Ancillary	mg/kg	ICP (1989-1993) (5)
Mercury	mg/kg	CVAA (1989-1995)
ORGANICS		
Volatile Organics	µg/kg	Purge and Trap, GCMS
Acids, Base/Neutrals	µg/kg	Extraction, GCMS
Pesticides/PCBs	µg/kg	Extraction, GC-ECD (1989-1993, 1995), AED (1994)

(1) Not analyzed for in 1994.

(2) Exceptions: 1989 Sta. 32, 33, 34, 35, and 1995 Sta. 34, 35 (ICP).

(3) Not analyzed for in 1992-1994.

(4) Exceptions: 1989 Sta. 5, 32, 44 (GFAA).

(5) Not analyzed for in 1994-1995.

chromatography followed by gas chromatography-electron capture detection (GC-ECD). Pesticide analysis was modified in 1994 to include an expanded target compound list and use of atomic emission detection (AED) with confirmation by ion-trap mass spectrometry.

Quality control procedures included initial and continuing calibration, blanks, spiked samples, standards, and duplicate or triplicate analyses. Sequim Bay standard reference materials were used in all years except in 1994.

Target chemicals for sediment analysis (Table 4) were monitored at all stations except for volatile compounds (10-15 stations), and resin acids and guaiacols (3-4 stations near pulp mills). The number of target compounds was reduced in 1994 (Table 4) because many compounds were consistently undetected in the first five years of monitoring. Target chemicals were selected for screening purposes and for the estimation of anthropogenic contaminant accumulation in selected areas of Puget Sound. An account of sources and uses of these contaminants can be found in Atkinson (1992).

Sediment Bioassay

Amphipod (*Rhepoxynius abronius*) bioassays were conducted on sediments collected from each station. Laboratory services were provided by Invert Aid (Tacoma, Washington) in 1989 and 1991, Parametrix, Inc. (Seattle, Washington) in 1990, and by Ecology's Manchester Laboratory in 1992 and 1993. Bioassays were not conducted in 1994 or 1995. Mortality of the amphipod was used as a measure of acute sediment toxicity following procedures recommended by the PSEP protocols (Tetra Tech, 1986).

Test organisms were collected in the subtidal zone at West Beach (Whidbey Island) by benthic dredge. Amphipods retained in a 1.0-mm mesh screen were transferred to trays with sieved West Beach sediment and placed in ice chests for transportation to the laboratory. In the laboratory, trays were maintained in flowing seawater with aeration and continuous lighting for four to ten days prior to the initiation of the experiments. Testing of 63 samples was accomplished in four experiments initiated weekly. Fresh West Beach sediment and test organisms were collected weekly prior to each experiment.

Each experiment consisted of a batch of test sediments (six replicate beakers per sediment, see below), West Beach sediment as controls (negative control), and a reference toxicant bioassay (positive control).

For each test sediment, six 1-liter glass beakers each containing 2 cm of pre-weighed test sediment were randomly assigned to an environmental chamber. Beakers were filled with 10-µm-filtered seawater, covered with a watch-glass, and allowed to equilibrate overnight. Twenty amphipods were placed in each of five beakers and maintained at 28‰ salinity

Table 4. Parameters monitored in the MSMP, reporting units, stations sampled, and years for which sampling and analysis were conducted. Not all parameters were sampled at every station or every year.

PARAMETER	UNITS	STATION SAMPLED	YEAR
BENTHOS	individuals/0.1m^2	All	1989-1995
AMPHIPOD BIOASSAY	mean no. of amphipods surviving and % mortality	All	1989-1993
SAND, SILT AND CLAY	percent	All	1989-1995
TOTAL SULFIDES	mg/kg	All	1989-1993
TOTAL ORGANIC CARBON	percent	All	1989-1995
CHEMICALS			
METALS	mg/kg	All	
Priority Pollutant Metals			
Antimony (Sb)			1989-1993, 95
Arsenic (As)			1989-1995
Beryllium (Be)			1989-1993, 95
Cadmium (Cd)			1989-1995
Chromium (Cr)			1989-1995
Copper (Cu)			1989-1995
Lead (Pb)			1989-1995
Mercury (Hg)			1989-1995
Nickel (Ni)			1989-1993, 95
Selenium (Se)			1989-1991, 95
Silver (Ag)			1989-1995
Thallium (Tl)			1989-1991, 95
Zinc (Zn)			1989-1995
Ancillary Metals			
Aluminum (Al)			1989-1993
Barium (Ba)			1989-1993
Calcium (Ca)			1989-1993
Cobalt (Co)			1989-1993
Iron (Fe)			1989-1993
Magnesium (Mg)			1989-1993
Manganese (Mn)			1989-1993
Potassium (K)			1989-1991
Sodium (Na)			1989-1991
Vanadium (V)			1989-1993
VOLATILE ORGANICS	µg/kg	1989: 3, 5, 10R, 14, 17, 19, 26, 29, 38, 45	
Halogenated Alkanes (Alkyl halides)			
Bromodichloromethane			1989-1993
Bromoform		1990: 3, 5, 8, 14, 17, 19, 29, 35, 38, 45	1989-1993
Bromomethane			1989-1993

Table 4. Continued.

PARAMETER	UNITS	STATION SAMPLED	YEAR
Carbon tetrachloride	µg/kg	1991: 3, 8, 11R, 12,	1989-1993
Chlorodibromomethane		17, 26, 29, 34, 35, 38,	1989-1993
Chloroethane (ethyl chloride)		45, 48, 201R, 202R,	1989-1993
Chloroform		204R	1989-1993
Chloromethane			1989-1993
Dichloromethane (methylene chloride)		1992: 3, 8, 17, 26,	1989-1993
1,1-dichloroethane		29, 34, 35, 38, 45, 48,	1989-1993
1,2-dichloroethane		302R	1989-1993
1,2-dichloropropane			1989-1993
1,1,2,2-tetratchloroethane		1993: 3, 8, 17, 26, 29,	1989-1993
1,1,1-trichloroethane (methyl chloroform)		34, 35, 38, 45, 48,	1989-1993
1,1,2-trichloroethane		102R	1989-1993
Trichlorofluoromethane			1991-1993
1,1,2-trichloro-1,2,2-trifluoroethane			1989-1993
Halogenated Alkenes (Alkenyl halides)			
1,1-dichloroethene (1,1-dichloroethylene)			1989-1993
Cis-1,2-dichloroethene			1989, 91-93
Trans-1,2-dichloroethene			1989-1993
Cis-1,3-dichloropropene			1989-1993
Trans-1,3-dichloropropene			1989-1993
Monochloroethylene (vinyl chloride)			1989-1993
Tetrachloroethene			1989-1993
Trichloroethene			1989-1993
Aromatic and Chlorinated Aromatic Compounds			
Benzene			1989-1993
Chlorobenzene			1989-1993
Ethylbenzene			1989-1993
Styrene (vinylbenzene)			1989-1993
Toluene			1989-1993
Total xylenes			1989-1993
Ketones			
Acetone			1989-1993
2-butanone			1989-1993
2-hexanone			1989-1993
4-methyl-2-pentanone			1989-1993
Ethers			
2-chloro-ethyl vinyl ether			1989-1993
Esters			
Vinyl acetate			1989-1993
Organosulfur Compounds			
Carbon disulfide	↓	↓	1989-1993

Table 4. Continued.

PARAMETER	UNITS	STATION SAMPLED	YEAR
SEMIVOLATILE ORGANICS			
A) ACID EXTRACTABLES			
Phenols	µg/kg	All	
2,4-dimethylphenol	↓	↓	1989-1993
2-methylphenol (*o*-Cresol)	↓	↓	1989-1993
4-methylphenol (*p*-Cresol)	↓	↓	1989-1993
Phenol	↓	↓	1989-1993
Chlorinated and Nitro-Substituted Phenols	↓	↓	
4-chloro-3-methylphenol	↓	↓	1989-1993
2-chlorophenol	↓	↓	1989-1993
2,4-dichlorophenol	↓	↓	1989-1993
4,6-dinitro-o-cresol	↓	↓	1989-1993
2,4-dinitrophenol	↓	↓	1989-1993
2-nitrophenol	↓	↓	1989-1993
4-nitrophenol	↓	↓	1989-1993
Pentachlorophenol	↓	↓	1989-1993
2,4,5-trichlorophenol	↓	↓	1989-1993
2,4,6-trichlorophenol	↓	↓	1989-1993
Resin Acids and Guaiacols	↓	1989: 4, 8, 21	
Abietic acid	↓		1989-1993
Chlorodehydroabietic acid	↓	1990: 5, 8, 21	1989, 1990
12-chlorodehydroabietic acid	↓		1991-1993
14-chlorodehydroabietic acid	↓	1991: 4, 8, 12, 41	1991-1993
Dehydroabietic acid	↓		1989-1993
Dichlorodehydroabietic acid	↓	1992: 4, 8, 12, 41	1989-1993
4,5-dichloroguaiacol (4,5-dichloro-2-methoxyphenol)	↓	1993: 4, 8, 12, 41	1989-1993
Isopimaric acid	↓	↓	1989-1993
2-methoxyphenol (Guaiacol)	↓	↓	1989-1993
Neoabietic acid	↓	↓	1989-1993
Palustric acid	↓	↓	1989-1993
Pimaric acid	↓	↓	1989-1993
Sandacopimaric acid	↓	↓	1989-1993
Tetrachloroguaiacol	↓	↓	1989-1993
3,4,5-trichloroguaiacol	↓	↓	1990-1993
4,5,6-trichloroguaiacol	↓	↓	1989-1993
B) BASE/NEUTRALS	µg/kg	1989-1993: all	
Low-Molecular Weight Polycyclic Aromatic Hydrocarbons	↓	1994: 2R, 8, 9R, 10R,	
Acenaphthene	↓	11R, 13R, 21, 30, 32,	1989-1995
Acenaphthylene	↓	33, 34, 35, 38, 40, 41,	1989-1995
Anthracene	↓	48, 201R, 202R, 203R,	1989-1995
Cymene	↓	204R, 205R, 206R,	1989, 91-93
Fluorene	↓	207R, 208R, 209R	1989-1995

Table 4. Continued.

PARAMETER	UNITS	STATION SAMPLED	YEAR
2-methylnaphthalene	µg/kg	1995: 3, 4, 8, 12, 14 21, 30, 32, 33, 34, 35 38, 40, 41, 48, 49, 23R, 24R, 25R, 27R, 36R, 37R, 301R, 302R, 303R, 304R, 305R, 306R, 307R, 308R	1989, 91-1995
Naphthalene			1989-1995
Phenanthrene			1989-1995
Retene			1989, 91-93, 95
High-Molecular Weight Polycyclic Aromatic Hydrocarbons			
Benzo(a)anthracene			1989-1995
Benzo(a)pyrene			1989-1995
Benzo(b)fluoranthene			1994-1995
Benzo(b+k)fluoranthene			1989-1993
Benzo(g,h,i)perylene			1989-1995
Benzo(k)fluoranthene			1994-1995
Chrysene			1989-1995
Dibenzo(a,h)anthracene			1989-1995
Fluoranthene			1989-1995
Indeno(1,2,3-c,d)pyrene			1989-1995
Perylene			1989, 91-93
Pyrene			1989-1995
Chlorinated Aromatic Compounds			
1,3-dichlorobenzene			1989-1993
1,4-dichlorobenzene			1989-1993
1,2-dichlorobenzene			1989-1993
1,2,4-trichlorobenzene			1989-1993
2-chloronaphthalene			1989-1995
Hexachlorobenzene			1989-1993
Chlorinated Alkanes			
Hexachloroethane			1989-1993
Chlorinated Alkenes			
Hexachlorobutadiene			1989-1993
Hexachlorocyclopentadiene			1989-1993
Pentachlorobutadiene isomers (a)			
Tetrachlorobutadiene isomers (a)			
Trichlorobuatadiene isomers (a)			
Phthalate Esters			
Bis(2-ethylhexyl)phthalate			1989-1993
Butyl benzyl phthalate			1989-1993
Di-*n*-butyl phthalate			1989-1993
Di-*n*-octyl phthalate			1989-1993
Diethyl phthalate			1989-1993
Dimethyl phthalate			1989-1993
Miscellaneous Extractable Compounds			
Benzoic acid			1989-1993
Benzyl alcohol			1989-1993

Table 4. Continued.

PARAMETER	UNITS	STATION SAMPLED	YEAR
beta-Coprostanol	µg/kg	(station list continued from previous page)	1989-1993
beta-Sitosterol			1989, 91-93
Cholesterol			1989, 91-93
Dibenzofuran			1989-1995
Isophorone			1989-1993
Polychlorinated dibenzodioxins [(b)]			
Polychlorinated dibenzofurans [(b)]			
Organonitrogen Compounds			
Caffeine			1989, 91-93
9(H)-carbazole			1989-1995
4-chloroaniline			1989, 91-93
3,3-dichlorobenzidine			1989, 91-93
2,4-dinitrotoluene			1989, 91-93
2,6-dinitrotoluene			1989, 91-93
Diphenylnitrosamine (N-nitrosodiphenylamine)			1989-1993
2-nitroaniline			1989, 91-93
3-nitroaniline			1989, 91-93
4-nitroaniline			1989, 91-93
Nitrobenzene			1989, 91-93
N-nitroso-di-n-propylamine			1989, 91-93
Ethers			
Bis-(2-chloroethoxy) methane			1989, 91-93
Bis-(2-chloroisopropyl) ether			1989, 91-93
4-bromophenyl-phenyl ether			1989, 91-93
4-chlorophenyl-phenyl ether			1989, 91-93
Dichloroethyl ether [bis-(2-chloroethyl) ether]			1989, 91-93
Chlorinated Pesticides	µg/kg	1989-1993: all	
Aldrin			1989-1995
alpha-Chlordane		1994: 5, 21, 30, 32, 33, 34, 35, 38, 208R, 209R	1989-1995
alpha-Endosulfan (Endosulfan I)			1989-1995
alpha-HCH (alpha hexachlorocyclohexane, alpha-BHC, alpha benzene hexachloride)			1989-1995
beta-Endosulfan (Endosulfan II)		1995: 21, 30, 32, 33, 34, 35, 38, 40, 49	1989-1995
beta-HCH (beta-BHC)			1989-1995
delta-HCH (delta-BHC)			1989-1995
Dieldrin			1989-1995
Endosulfan sulfate			1989-1995
Endrin			1989-1995
Endrin aldehyde			1990, 92-95
Endrin ketone			1989-1995
gamma-Chlordane			1989-1995
gamma-HCH (Lindane)			1989-1995
Heptachlor			1989-1995
Heptachlor epoxide			1989-1995
Methoxychlor			1989-1995
p,p'-DDD			1989-1995

Table 4. Concluded.

PARAMETER	UNITS	STATION SAMPLED	YEAR
p,p'-DDE	µg/kg	(station list continued from previous page)	1989-1995
p,p'-DDT			1989-1995
Toxaphene			1989-1995
Nitrogen Pesticides			1994
Organo-Phosphorous Pesticides			1994
Polycyclic Chlorinated Biphenyls			
Arochlor 1016			1993, 1995
Arochlor 1221			1991-1995
Arochlor 1232			1991-1995
Arochlor 1242			1993, 94-95
Arochlor 1248			1989-1995
Arochlor 1254			1989-1995
Arochlor 1260			1989-1995
Arochlor 1016/1242			1989-1993

(a) Chlorinated butadienes were recommended for analysis only where suspected to have a major source; no analysis to date.

(b) Chlorinated dibenzofurans and dioxins were recommended for special analysis only, but were not analyzed for.

(adjusted using deionized water) and 15°C for the duration of the experiment (four-year range: 28‰-34‰, 14°C -16°C). Amphipods that did not burrow were replaced immediately. The sixth beaker (with no test animals) was used for daily measurements of water temperature, salinity, dissolved oxygen, pH, and initial and final ammonium and hydrogen sulfide concentrations. In addition, temperature, salinity, pH, and dissolved oxygen in the overlying water were measured in test beakers at the end of the experiment, and interstitial salinity was measured prior to each experiment. Test beakers were monitored daily for emergence of amphipods.

West Beach sediment controls consisted of six replicate beakers treated in the same manner as the test beakers. In addition, and for each batch of test sediment, a separate bioassay was conducted in which amphipods were exposed for 96 h to cadmium chloride in seawater in the absence of sediment (positive control). For this bioassay, five replicate beakers each containing twenty amphipods were used for each of five $CdCl_2$ concentrations: 3.0, 2.0, 1.5, 1.0, and 0.5 mg/l (1989-1991) or 3.0, 1.5, 0.75, 0.375, and 0 mg/l (1992 and 1993).

Amphipod bioassays were assumed to indicate toxicity when mean survival was significantly (α= 0.05) less than negative controls after 10 days exposure. 96-hour LC_{50} values (*i.e.*, the concentration of cadmium chloride lethal to 50 percent of the test organisms) were determined for each reference toxicant bioassay using Probit analysis (Finney, 1971).

Data Preparation and Analysis

Data Storage and Verification

The PSAMP System Database was developed at the beginning of the program with the goal of compiling many types of data from a variety of sources. However, this database was not a useful adjunct to data analysis, and has not been used since 1992. All data are currently stored in Ecology's SEDQUAL database, which is available to the public.

Sediment chemistry data were converted into Excel (version 5.0) worksheets in either matrix or record format. Revisions of the chemistry data included compiling seven years of chemistry data, making station and sample identifiers consistent between years, verifying qualifiers and values, and providing graphic presentation of all data. Data in this form were readily accessible for further analysis.

Criteria for the Identification of Contaminated Stations

Contaminated stations with potential for biological effects were identified and ranked to assess contaminant effects (if any) on benthic community measures. The criteria used for the selection of these sites were conservative, since it was desirable to include stations with marginally toxic sediments rather than exclude stations with relatively low contaminant concentrations but significant effects. A two-tier approach was used.

First, we compared chemistry values to Washington State Sediment Quality Standards (SQS) (Washington Administrative Code Chapter 173-204) to see if contaminant concentrations exceeded the standards. The SQS are based on Apparent Effects Thresholds (AETs), which are sediment chemical concentrations above which statistically significant biological effects (*e.g.,* depressions in the abundance of indigenous benthic fauna) are always expected (PTI, 1988). Trace metal concentrations were compared to SQS; however, organic compounds were compared directly to AETs (Table 3 in PTI, 1988) expressed on a dry weight basis because the SQS for organic compounds are normalized to total organic carbon. Normalization to organic carbon was not performed because many MSMP stations had low TOC values. Low TOC values may artificially increase organic contaminant concentrations above SQS if normalization is conducted (Michelsen, 1992). Additionally, dry weight values are readily comparable to those from other regional studies and federal monitoring programs.

Second, we identified contaminated sites using threshold concentrations (Effects Range-Low or ER-L values) above which biological effects are possible (Long and Morgan, 1991; Long *et al.*, 1995). The sediment quality guidelines proposed by Long and Morgan (*op. cit.*) are concentrations of contaminants that are anticipated to be occasionally or frequently associated with adverse biological effects, depending on the magnitude of the concentration. Concentrations equal to or above Effects Range-Low values but below Effects Range-Median values, represent a possible-effects range within which effects occur occasionally. This contrasts with the SQS, which represent values above which adverse biological effects are always expected to occur.

We used ER-L values for as many contaminants as listed in Long and Morgan, and Long *et al.* (*op. cit.*). For contaminants not represented in ER-L tables, threshold concentrations were determined using the lowest AET values from amphipod, benthic, oyster, or Microtox (changes in bacterial luminescence) effect studies as reported in Pollutants of Concern in Puget Sound (PTI, 1991). For contaminants not represented in Pollutants of Concern in Puget Sound, threshold concentrations were determined using the lowest AET values reported in the Contaminated Sediments Criteria Report (PTI, 1989a). Using only detected values, sites were ranked according to number of contaminants and contaminant concentration. Where replicate sediment samples for chemistry were taken, we used the highest value to determine if contaminants equaled or exceeded threshold concentrations. The threshold concentrations used to identify contaminated stations are listed in Table 5.

Table 5. Threshold concentrations used to identify and rank contaminated sites with potential for biological effects. Concentrations are in mg/kg dry weight for metals and ug/kg dry weight for organic compounds.

Compound	Threshold Concentration	Source
METALS		
Antimony	2	ER-L concentration (Table 70 in Long and Morgan, 1991)
Arsenic	8.2	ER-L concentration (Table 3 in Long *et al.*, 1995)
Beryllium	0.36	Lowest AET (PTI, 1989a)
Cadmium	1.2	ER-L concentration (Table 3 in Long *et al.*, 1995)
Chromium	81	ER-L concentration (Table 3 in Long *et al.*, 1995)
Copper	34	ER-L concentration (Table 3 in Long *et al.*, 1995)
Lead	46.7	ER-L concentration (Table 3 in Long *et al.*, 1995)
Mercury	0.15	ER-L concentration (Table 3 in Long *et al.*, 1995)
Nickel	20.9	ER-L concentration (Table 3 in Long *et al.*, 1995)
Selenium	1	Lowest AET (PTI, 1989a)
Silver	1	ER-L concentration (Table 3 in Long *et al.*, 1995)
Thallium	0.24	Lowest AET (PTI, 1989a)
Zinc	150	ER-L concentration (Table 3 in Long *et al.*, 1995)
VOLATILE ORGANICS		
1,2-dichloroethene	0.8	Lowest AET (PTI, 1989a)
Ethylbenzene	10	Lowest AET (PTI, 1991)
Tetrachloroethene	57	Lowest AET (PTI, 1991)
Total xylene	40	Lowest AET (PTI, 1991)
Trichloroethene	0.8	Lowest AET (PTI, 1989a)
PHENOLS		
2,4-dimehtylphenol	29	Lowest AET (PTI, 1989a)
2-methylphenol	63	Lowest AET (PTI, 1989a)
4-methylphenol	670	Lowest AET (PTI, 1991)
Pentachlorophenol	140	Lowest AET (PTI, 1991)
Phenol	420	Lowest AET (PTI, 1991)
RESIN ACIDS AND GUAIACOLS		
Abietic acid	450	Lowest AET (PTI, 1989a)
12-chlorodehydroabietic acid	61	Lowest AET (PTI, 1989a)
Dehydroabietic acid	150	Lowest AET (PTI, 1989a)
Isopimaric acid	170	Lowest AET (PTI, 1989a)
2-methoxyphenol	580	Lowest AET (PTI, 1989a)
LOW-MOLECULAR WEIGHT PAH		
Acenaphthene	16	ER-L concentration (Table 4 in Long *et al.*, 1995)
Acenaphthylene	44	ER-L concentration (Table 4 in Long *et al.*, 1995)
Anthracene	85.3	ER-L concentration (Table 4 in Long *et al.*, 1995)
Cymene	600	Lowest AET (PTI, 1989a)
Fluorene	19	ER-L concentration (Table 4 in Long *et al.*, 1995)
2-methylnaphthalene	70	ER-L concentration (Table 4 in Long *et al.*, 1995)
Naphthalene	160	ER-L concentration (Table 4 in Long *et al.*, 1995)

Table 5. Concluded.

Compound	Threshold Concentration	Source
Phenanthrene	240	ER-L concentration (Table 4 in Long *et al.,* 1995)
Retene	1700	Lowest AET (PTI, 1989a)
HIGH-MOLECULAR WEIGHT PAH		
Benzo(a)anthracene	261	ER-L concentration (Table 4 in Long *et al.,* 1995)
Benzo(a)pyrene	430	ER-L concentration (Table 4 in Long *et al.,* 1995)
Benzo(b)fluoranthene	3500	Lowest AET (PTI, 1989a)
Benzo(k)fluoranthene	4300	Lowest AET (PTI, 1989a)
Benzo(g,h,i)perylene	670	Lowest AET (PTI, 1991)
Chrysene	384	ER-L concentration (Table 4 in Long *et al.,* 1995)
Dibenzo(a,h)anthracene	63.4	ER-L concentration (Table 4 in Long *et al.,* 1995)
Fluoranthene	600	ER-L concentration (Table 4 in Long *et al.,* 1995)
Indeno(1,2,3-c,d)pyrene	600	Lowest AET (PTI, 1991)
Pyrene	665	ER-L concentration (Table 4 in Long *et al.,* 1995)
Total benzofluoranthenes	3200	Lowest AET (PTI, 1991)
Total PAH	4022	ER-L concentration (Table 4 in Long *et al.,* 1995)
CHLORINATED COMPOUNDS		
1,2-dichlorobenzene	35	Lowest AET (PTI, 1989a)
1,4-dichlorobenzene	110	Lowest AET (PTI, 1991)
Hexachlorobenzene	22	Lowest AET (PTI, 1991)
Hexachlorobutadiene	11	Lowest AET (PTI, 1991)
PHTHALATES		
Bis(2-ethylhexyl)phthalate	1300	Lowest AET (PTI, 1991)
Butyl benzyl phthalate	63	Lowest AET (PTI, 1989a)
Diethyl phthalate	200	Lowest AET (PTI, 1989a)
Dimethyl phthalate	71	Lowest AET (PTI, 1989a)
Di-n-butyl phthalate	1400	Lowest AET (PTI, 1989a)
Di-n-octyl phthalate	25	Lowest AET (PTI, 1989a)
MISCELLANEOUS EXTRACTABLE		
Benzoic acid	650	Lowest AET (PTI, 1989a)
Benzyl alcohol	57	Lowest AET (PTI, 1989a)
Carbazole	970	Lowest AET (PTI, 1989a)
Cholesterol	160	Lowest AET (PTI, 1989a)
Coprostanol	140	Lowest AET (PTI, 1989a)
Dibenzofuran	540	Lowest AET (PTI, 1991)
PESTICIDES/PCBs		
Chlordane	0.5	ER-L concentration (Table 70 in Long and Morgan, 1991)
p,p'-DDT	1	ER-L concentration (Table 70 in Long and Morgan, 1991)
p,p'-DDD	2	ER-L concentration (Table 70 in Long and Morgan, 1991)
p,p'-DDE	2.2	ER-L concentration (Table 4 in Long *et al.,* 1995)
Endrin	0.02	ER-L concentration (Table 70 in Long and Morgan, 1991)
Total PCBs	22.7	ER-L concentration (Table 4 in Long *et al.,* 1995)

Analysis of Bioassay Data

In 1989, survival data were tested for statistical significance relative to control responses using Mann-Whitney U tests with a comparison-wise alpha level of 0.001. The use of a non-parametric test was necessary because of the departure of data from the assumptions of normality and homogeneity, as indicated by Cochran's C tests on both untransformed and transformed data. No statistical tests were performed in 1990 because of irregularities in the bioassay (see Results). Statistical testing was limited in 1991 to six sediments using Dunnett's procedure in SYSTAT (SPSS Inc., Chicago, IL). In 1992 and 1993, survival data were tested for statistical significance using TOXSTAT version 3.3 (Fish Physiology and Toxicology Laboratory, University of Wyoming, Laramie, WY). Parametric (Bonferroni and Dunnett's tests) and non-parametric procedures (Steels many-one rank test) were used with an alpha level of 0.05 for all tests.

LC_{50}s were calculated for each reference toxicant test using EPA's Probit software (Environmental Monitoring Systems Laboratory, Cincinnati, OH) according to methods described in Finney (1971).

Results

Sediment Characteristics

Grain Size

Sediments sampled in Puget Sound were either muds (>60% silt and clay) (36 stations), sands (<40% silt and clay) (32 stations), or a mixture of approximately equal proportions of sand and mud (8 stations). Muds contained on average 12%-54% clay. Sediments from 20 stations contained various amounts of gravel above 1% (range 1%-54%). In general, samples were similar over time, but inter-annual variability in sediment composition was observed in the Strait of Georgia (Station 3), Oak Harbor (Station 18), Central Basin (Station 26), North Vashon Island (Station 37R), Case Inlet (Station 47), Inner Totten Inlet (Station 102R), and Mid Case Inlet (Station 111R). Central Basin (Station 26) was sampled off station location in 1990 and 1991. Sediment characteristics, including grain size composition, are summarized in Table 6. Appendix A contains tabular and graphic presentations of sediment composition by station and year. All data from the 1995 grain size analysis were rejected during the QC process, and are therefore unavailable.

Visually determined Redox Potential Discontinuity (RPD) layers < 0.5 cm were identified in 13 stations during the 1994 and 1995 field seasons. Sediment surfaces at these stations were brown overlying dark gray to black sediments (Table 6). Hydrogen sulfide odor was frequent in sediments from stations in South Puget Sound inlets, and one station (Eagle Harbor, Station 30) exhibited an oil sheen on the sediment surface (Table 6).

Sulfides

Total sulfide (TS) was detected at 45 stations, but results were inconsistent among years, and showed large fluctuations at some stations (Appendix B). This variability may be inherent to the sampling difficulties associated with the volatile portion of sediment sulfides. In addition, a change of analytical procedures in 1990 (titrimetric analysis) and laboratory check standard recovery problems in 1990 and 1992 may have contributed to the variability. In particular, the 1990 results should be interpreted with caution because of holding time violations (1 to 3 weeks in excess of the recommended 7 day limit). All detected values for 1990, 1992 and 1993 analyses were qualified as estimates. For all years in which TS was measured, detected values ranged from 0.18 to 959 mg/kg. Reporting detection limits ranged from 0.25 to 5.7 mg/kg, except for 1990. Detection limits were higher in 1990, with a range of 4.1 to 37.7 mg/kg. Because TS was difficult to quantify, TS analysis was discontinued in 1993.

Table 6. Sediment characteristics of MSMP stations. Grain size composition is based on a six year (1989-1994) average. Mud, >60% silt and clay (s-c); mixed, 40-60% s-c; sand, <40% s-c. Gravel indicates sediments with >10% coarse material in any one year. Redox Potential Discontinuity (RPD) depths were estimated in 1994 and 1995 by measuring the thickness of the top brown layer of sediment. RPD codes are as follows: 1, <0.5 cm; 2, 0.5-1 cm; 3, >1-2 cm; 4, >2 cm. When differing, codes for both years are given. Question marks indicate uncertainty in the measurement. NM = not measured: stations not sampled in 1994 or 1995. UD = undetermined: a change in color in the top layer of sediment was undistinguishable.

Station	Composition	Sulfide[1]	Visible Organic Material	RPD	Color[2]
1 Semiahmoo Bay, Blaine	mud	odor/detec		2/3 (?)	dark gray/black
2R Cherry Point	mixed			2	light gray
3 Strait of Georgia	mixed and gravel	detec		1	dark gray/black
4 Bellingham Bay	mud	detec		1/3	black/gray
5 Samish Bay	mud			3	gray
8 Port Angeles	mud		wood	3	gray/light gray
9R East of Green Point	sand and gravel			4	--
10R Dungeness Bay	sand			3	light gray
11R Discovery Bay	sand			3	light gray
12 Port Townsend Bay	mud			3/4	gray/light gray
13R North Hood Canal	sand			3	light gray
14 Hood Canal, Bangor	sand			3/4	dark gray
15 Dabob Bay	sand		wood	3/4	light gray
17 S Hood Canal, Great Bend	mud			2	light gray
18 Oak Harbor	mixed	detec		2/3	olive gray/gray
19 Saratoga Passage	mud	odor/detec		2	olive gray/gray
20 Port Susan	mud			UD	olive green/dark gray
21 Port Gardner	mud		wood	2	dark gray
22 Mukilteo	sand			3/4	gray
23R East Central Basin	sand			4	light gray
24R East Central Basin	mud			2	gray
25R West Central Basin	sand			4	dark brown
26 Central Basin	sand and gravel[3]			3/4	light gray/dark gray
27R Richmond Beach	sand			4	dark brown/light gray
29 Shilshole	mud			1/3	dark gray
30 Eagle Harbor	mixed	detec	wood, plant mat., oil	1/3	dark gray/black
32 Magnolia Bluff	sand			3	light gray
33 Elliott Bay	sand		wood, detritus	2	olive gray
34 Sinclair Inlet	mud	detec		1/2	black/gray
35 Dyes Inlet	mud	odor/detec		1	dark gray
36R Brace Point	sand			UD	olive brown
37R North Vashon Island	sand and gravel			UD	olive brown
38 Point Pully	mud	detec		2/3	dark gray/black
39 Dash Point	sand			4	--
40 Commencement Bay	sand		wood	2/4	light gray/gray
41 Commencement Bay	mud	detec		3/4	light gray
43 Carr Inlet	sand			4	dark brown

Table 6. Concluded.

Station	Composition	Sulfide(1)	Visible Organic Material	RPD	Color(2)
44 East Anderson Island	sand			2/4	grayish brown/gray
45 Devil's Head	mixed			3/4	light gray
46R West Nisqually	sand			NM	brown
47 Case Inlet	sand and gravel			2	light gray/gray
48 Outer Budd Inlet	mud	detec	wood	1/2	dark gray/gray
49 Inner Budd Inlet	mud	detec		1/2	dark gray/light gray
69 Port Madison	sand			3	light gray
70 Oakland Bay, Shelton	mixed	detec	wood, plant material	3	gray
71 Fidalgo Bay	mixed		wood, plant material	2/4 (?)	olive gray/gray
101R North Oakland Bay	mud	odor/detec		NM	black
102R Inner Totten Inlet	mud and gravel	odor/detec		NM	black
103R Mid Totten Inlet	sand			NM	gray
104R Inner Eld Inlet	mud	odor		NM	olive
105R Outer Eld Inlet	mud			NM	olive
106R Mid Budd Inlet	mud	odor/detec		NM	olive brown
109R Henderson Inlet	mud	odor		NM	olive brown
110R Inner Case Inlet	mud	odor		NM	olive brown
111R Mid Case Inlet	mixed			NM	olive brown
112R Nisqually Delta	sand		wood	NM	black
113R Willochet Bay	sand			NM	olive
114R Henderson Bay	mud	odor		NM	olive brown
115R Outer Filucy Bay	mud			NM	olive brown
201R Roberts Bank	sand			2	light gray
202R Point Roberts	sand			2	gray
203R Bellingham Bay	mud			2	gray
204R East Sound	mud	odor/detec		1	black
205R NW Blakely Island	mud			1 (?)	gray
206R Friday Harbor	sand			3	light gray
207R West Beach	mud			2 (?)	light gray
208R Sequim Bay	mud	odor/detec	wood	1	black
209R Skagit Bay	sand			3	gray
301R Useless Bay	sand			2	light gray
302R Oak Bay	mud			2	light gray
303R Quartermaster Harbor	mud			4	light brown
304R Hood Canal, Tekiu Point	mud			1	dark gray
305R Hood Canal, Lynch Cove	mud	odor/detec		1	olive gray
306R Seahurst	sand			UD	olive brown
307R Holmes Harbor	mud	detec		UD	--
308R Liberty Bay	sand		wood, detritus	2	gray

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(1) detec = sulfide detected analytically at concentrations of at least 24 ppm. (2) Where the RPD was measured, the color of the sediment is that below the RPD, and the observation was made in 1994 and 1995. Where the observations for the two years differed, both are given. The color in the 100R station series is from observations of bulk sediment made previous to 1994.

(3) Station 26 was sampled off location in 1991, resulting in sediments with a high (53%) proportion of gravel.

Highest TS concentrations tended to occur in areas with restricted water exchange (*i.e.*, terminal inlets and enclosed bays) or areas where fresh water input or other factors restrict mixing of the water column. For example, the Strait of Georgia (Station 3), Inner Totten Inlet (Station 102R), and Sequim Bay (Station 208R), exhibited TS concentrations >500 ppm (Appendix B). The Strait of Georgia is influenced by the discharge plume of the Fraser River, and Sequim Bay is a semi-enclosed bay with restricted water circulation and oxygen exchange (see Discussion). Other stations with 100-500 ppm TS were located in Budd Inlet (Stations 48 and 49), Hood Canal (Station 305R), Sinclair Inlet (Station 34), Dyes Inlet (Station 35), Eagle Harbor (Station 30), Saratoga Passage (Stations 19 and 307R), and Bellingham Bay (Station 4) (Appendix B).

Organic Carbon

Total organic carbon (TOC) ranged from 0.06% to 4.0% (Appendix C). Concentrations ≥3% were measured in sediments of Port Angeles (Station 8), Sinclair Inlet (Station 34), Dyes Inlet (Station 35), Inner Budd Inlet (Station 49), Oakland Bay (Stations 70 and 101R), Inner Eld Inlet (Station 104R), Inner Case Inlet (Station 110R), East Sound (Station 204R), Sequim Bay (Station 208R), and Hood Canal at Lynch Cove (Station 305R). In general, large changes in TOC concentration over time were not observed. Stations with a high percent of silt and clay tended to have a high percent TOC (correlation coefficient r = 0.79).

Chemistry

General Results

Overall, contaminants were detected in only 30 percent of all analyses (Table 7). Metals, however, were detected in most of the analyses for which they were tested (83% detections). Among the organic compounds, sterols (beta-coprostanol, beta-sitosterol, and cholesterol), polycyclic aromatic hydrocarbons (PAH) and resin acids were most frequently detected (83%, 61%, and 27% detections, respectively). Resin acids, however, were sampled only at six stations close to potential sources. Pesticides, polychlorinated biphenyls (PCB) and volatile compounds were largely undetected (0.3%, 5% and 12% detections, respectively). Sixty-one chemical compounds were never detected (Table 8). Concentrations of metals and organics were generally low, near detection limits. However, levels of contaminants in a few samples were significantly above the range of detection limits. Stations where these last contaminants were found are discussed below. Results for detected compounds are summarized in Appendix D. The complete set of chemistry data is available to the public from the authors.

Table 7. Percent detections by chemical group for the sampling period indicated. Number of analyses = number of target compounds (detected and undetected) for which analysis was conducted x number of samples collected in the field.

Chemical Group	Period	No. of Analyses	% Detections
All compounds	1989-1995	43951	30.0
Metals (all)	1989-1995	8156	83.1
Priority Pollutant Metals	1989-1995	5218	73.5
Ancillary Metals	1989-1995	2938	100.0
Volatile Organics	1989-1993	3628	12.4
ABNs	1989-1995	32167	18.2
Phenols (all)	1989-1993	4466	4.5
Phenols (non-substituted)	1989-1993	1276	15.3
Chlorinated and Nitro-substituted Phenols	1989-1993	3190	0.2
Resin acids & Guaiacols	1989-1993	396	27.0
PAHs	1989-1995	6960	60.9
Chlorinated Aromatic Hydrocarbons	1989-1995	1984	0.3
Chlorinated Alkanes	1989-1993	319	0.0
Chlorinated Alkenes	1989-1993	573	0.3
Phthalate Esters	1989-1993	1914	15.9
Miscellaneous Extractables (all)	1989-1995	6437	15.3
PCBs & Pesticides	1989-1995	8864	1.3
Pesticides	1989-1995	7000	0.3
PCBs	1989-1995	1864	4.9

Table 8. Undetected chemical compounds and detection limits, Marine Sediment Monitoring Program, 1989-1995.

	Reported Detection Limits			No. of Samples	
Compound	Minimum	Median	Maximum	Rejected	Total
VOLATILE ORGANIC ANALYSIS (VOA) COMPOUNDS					
carbon tetrachloride	0.01	0.25	3.40	0	92
chlorodibromomethane	0.03	0.26	1.70	0	92
chloroethane	0.14	0.35	5.10	0	92
2-chloro-ethyl vinyl ether	0.07	0.26	3.40	0	92
chloromethane	0.14	0.35	3.40	0	92
dibromochloromethane	0.01	0.25	1.70	0	92
1,2-dichlorobenzene(a)	0.14	0.29	0.59	0	60
1,3-dichlorobenzene(b)	0.14	0.29	0.59	0	60
1,2-dichloroethane	0.03	0.25	3.40	0	92
1,1-dichloroethene	0.01	0.25	1.70	0	92
trans-1,2-dichloroethene	0.03	0.25	1.70	0	92
1,2-dichloropropane	0.05	0.25	1.70	0	92
cis-1,3-dichloropropene	0.03	0.26	1.70	0	92
trans-1,3-dichloropropene	0.03	0.26	3.40	0	92
monochloroethylene	0.14	0.35	5.10	0	92
1,1,2,2-tetrachloroethane	0.03	0.26	3.40	0	92
1,1,2-trichloroethane	0.03	0.26	1.70	0	92
vinyl acetate	0.03	0.25	3.40	0	92
ACID-BASE NEUTRAL (ABN) EXTRACTABLES					
Phenols					
2-methylphenol	5.00	14.00	70.00	0	319
Chlorinated and nitro-substituted phenols					
4-chloro-3-methylphenol	10.00	28.00	270.00	0	319
2-chlorophenol		14.00	140.00	3	319
2,4-dichlorophenol	23.00	42.00	410.00	0	319
4,6-dinitro-2-methylphenol	77.00	140.00	1400.00	0	319
2,4-dinitrophenol	77.00	140.00	1400.00	0	319
2,4,5-trichlorophenol	39.00	71.00	680.00	0	319
2,4,6-trichlorophenol	39.00	71.00	680.00	0	319
Chlorinated aromatic hydrocarbons					
1,3-dichlorobenzene(b)	3.80	14.00	140.00	1	319
1,4-dichlorobenzene(c)	3.80	14.00	68.00	1	319
1,2,4-trichlorobenzene	6.00	14.00	74.00	1	319
Chlorinated alkanes					
hexachloroethane	15.00	28.00	160.00	1	319
Miscellaneous extractable compounds					
bis(2-chloroethoxy)methane	7.90	14.00	68.00	1	254
bis(2-chloroisopropyl)ether	7.90	14.00	68.00	1	254
4-chloroaniline	24.00	49.34	200.00	125	254

Table 8. Concluded.

Compound	Reported Detection Limits			No. of Samples	
	Minimum	Median	Maximum	Rejected	Total
dichloroethyl ether	7.90	14.00	68.00	1	254
diphenylnitrosamine	7.90	14.00	88.00	0	319
2,4-dinitrotoluene	39.00	69.79	340.00	0	254
2,6-dinitrotoluene	39.00	69.79	340.00	0	254
n-nitroso-di-n-propylamine	7.90	14.00	68.00	1	254
nitrobenzene	7.90	14.00	68.00	1	254
RESIN ACIDS AND GUAIACOLS					
4,5-dichloroguaiacol	10.00	19.00	120.00	0	27
tetrachloroguaiacol	10.00	19.00	230.00	0	27
3,4,5-trichloroguaiacol	10.00	18.00	29.00	0	24
4,5,6-trichloroguaiacol	10.00	19.00	230.00	0	27
CHLORINATED PESTICIDES					
aldrin	0.20	1.00	12.00	0	343
alpha-HCH	0.20	1.00	12.00	0	343
alpha-endosulfan	0.20	1.00	11.00	0	331
beta-endosulfan	0.30	2.00	11.00	0	331
delta-HCH	0.20	1.00	12.00	0	343
dieldrin	0.30	2.00	12.00	0	343
endosulfan sulfate	0.60	2.40	22.00	0	343
endrin ketone	0.30	2.00	12.00	0	331
gamma-chlordane	0.30	2.00	12.00	0	331
gamma-HCH (lindane)	0.20	1.00	12.00	0	343
heptachlor	0.20	1.00	12.00	0	343
heptachlor epoxide	0.20	1.00	12.00	0	343
methoxychlor	0.20	1.10	22.00	0	343
toxaphene	0.50	6.90	30.00	0	331
POLYCHLORINATED BIPHENYLS (PCBs)					
Arochlor 1016	8.60	17.00	60.00	0	60
Arochlor 1221	6.00	27.00	120.00	0	213
Arochlor 1232	6.00	16.00	180.00	0	213
Arochlor 1242	8.60	18.50	73.00	0	72
Arochlor 1248	4.00	20.00	80.00	0	343
Arochlor 1016/1242	4.00	20.00	80.00	0	271

[a] [b] [c] Compounds analyzed both as VOA (1991-1993) and as ABN (1989-1993). [a] Not detected as VOA, but detected as ABN in 1989. [b] Never detected. [c] Not detected as ABN, but detected as VOA in 1991.

Metals

Highest metal concentrations were most frequently associated with urban or industrial centers, including Sinclair Inlet and Dyes Inlet for lead (Figure 2), zinc (Figure 3), silver (Figure 4), copper (Figure 5), and mercury (Figure 6). Also, accumulations of trace metals were found in Budd Inlet with cadmium (Figure 7) and silver (Figure 4), and in Port Susan, Bellingham Bay, and Oak Harbor with chromium (Figure 8). Cadmium concentrations above background levels were also detected in Sequim Bay and Lynch Cove (Figure 7). In addition, some metals were detected above average concentrations in deep depositional locations such as Point Pully (200 m) with lead (Figure 2) and zinc (Figure 3). Mercury was also consistently detected at Point Pully.

Metal concentrations found in MSMP sediment samples were generally below Washington State Sediment Quality Standards. Notable exceptions to this pattern included mercury contamination in Sinclair Inlet and Dyes Inlet (Figure 6) and arsenic contamination in Sinclair Inlet (Figure 9). Mercury values for Sinclair Inlet and Dyes Inlet were consistently above Sediment Quality Standards for the seven-year reporting period. Other occasional deviations from an otherwise consistent pattern of low metal concentrations (*e.g.*, lead and cadmium in Point Pully, mercury in Port Gardner, or arsenic in South Hood Canal-Great Bend, Figures 2, 6, 7, and 9) may be attributed to micro-spatial or analytical variability.

All the metal data with elevated concentrations presented in Figures 2-9 were unqualified, with the following exceptions. Arsenic in South Hood Canal-Great Bend (1989), cadmium (1989), mercury (1989 and 1990), silver (1991 and 1995), and zinc (1990 and 1991) were qualified as estimates. Mercury at South Hood Canal-Great Bend (1995) and Cadmium at South Hood Canal-Lynch Cove (1995) were qualified to indicate that the analyte was detected above the instrument detection limit but below the established minimum quantitation limit.

Organics

Highest concentrations of high molecular weight PAHs (HPAH), low molecular weight PAHs (LPAH), and PCBs occurred in sediments near urban and industrial centers in Commencement Bay, Elliott Bay, Eagle Harbor, Sinclair Inlet and Dyes Inlet (Figures 10, 11, and 12). PCBs were rarely detected in the MSMP samples. All detected PCB values were low and below AET levels, except for arochlor 1260 at Sinclair Inlet in 1995 (Figure 12). Similarly, concentrations for PAHs were generally low and below AETs with the exception of Station 40 located at the mouth of City Waterway in Commencement Bay. PAH values at this station were elevated above average monitoring concentrations and exceeded AET levels in 1990 (Figures 10 and 11).

Hydrocarbons contributing to the relatively high PAH concentrations in sediments of Station 40 were anthracene, benzo(a)anthracene, total benzofluoranthenes (b+k), benzo(g,h,i)perylene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-

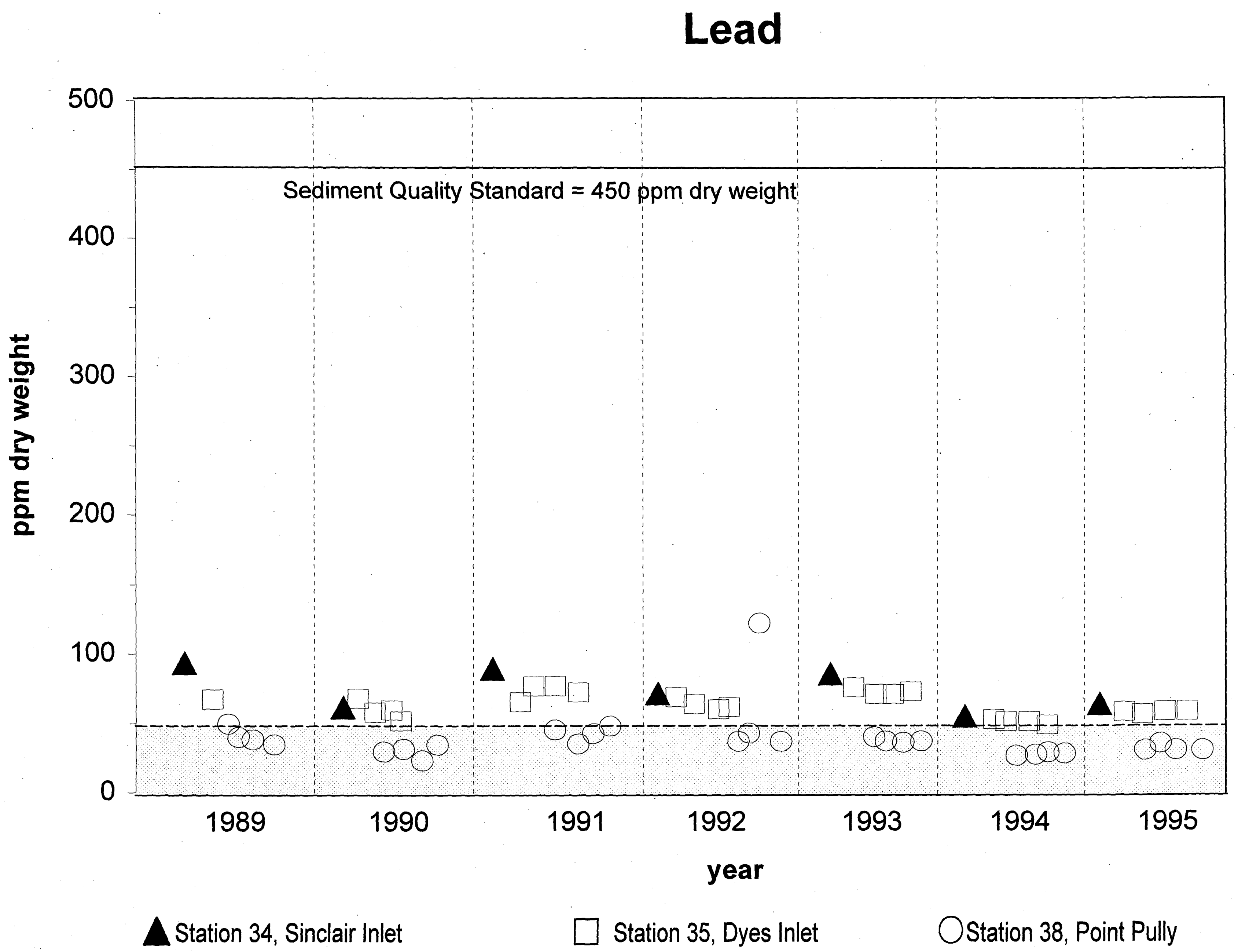


Figure 2. Stations with highest concentrations of lead. Replicate samples are shown for Dyes Inlet and Point Pully. Shaded areas within dashed lines represent the range of all unshown values.

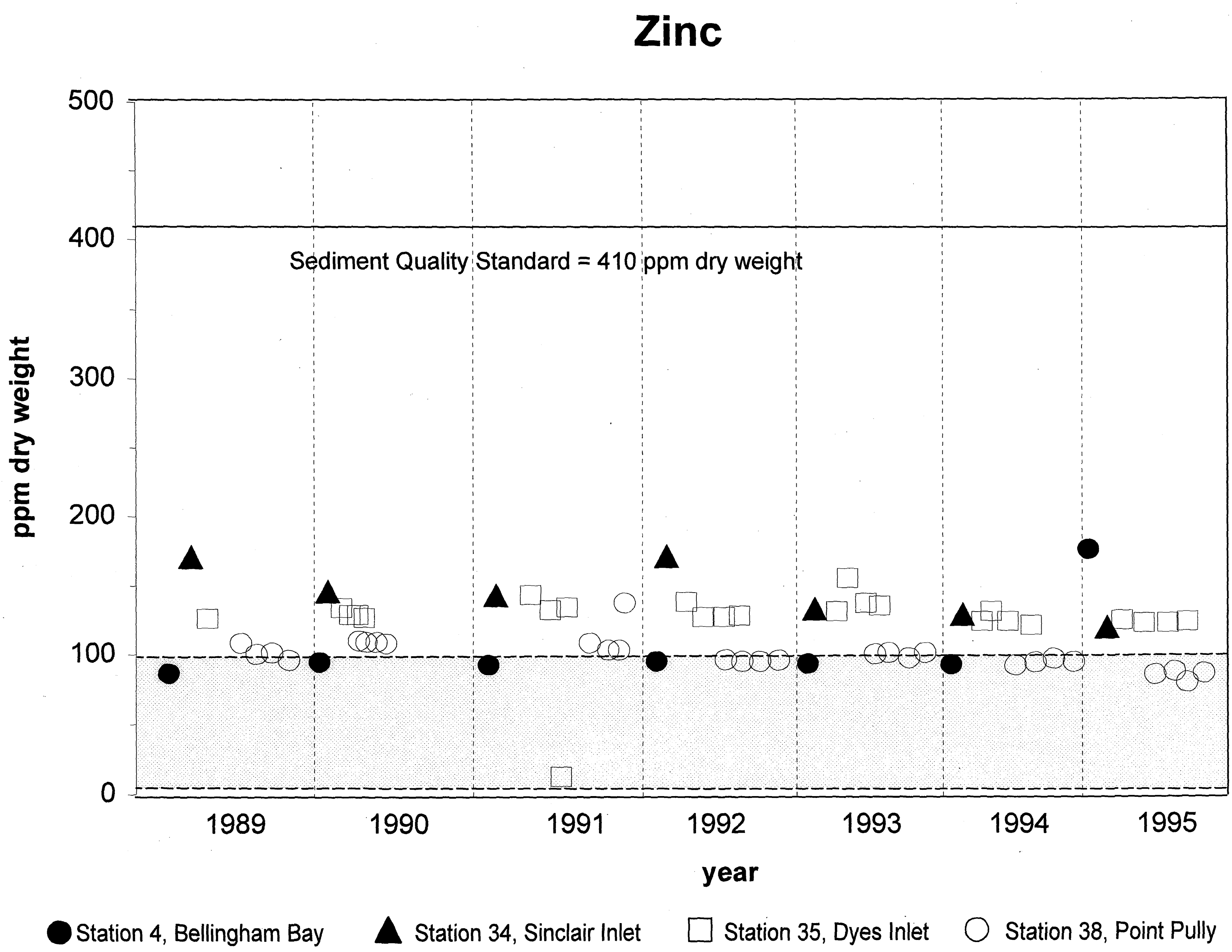


Figure 3. Stations with highest concentrations of zinc. Replicate samples are shown for Dyes Inlet and Point Pully. Shaded areas within dashed lines represent the range of all unshown values.

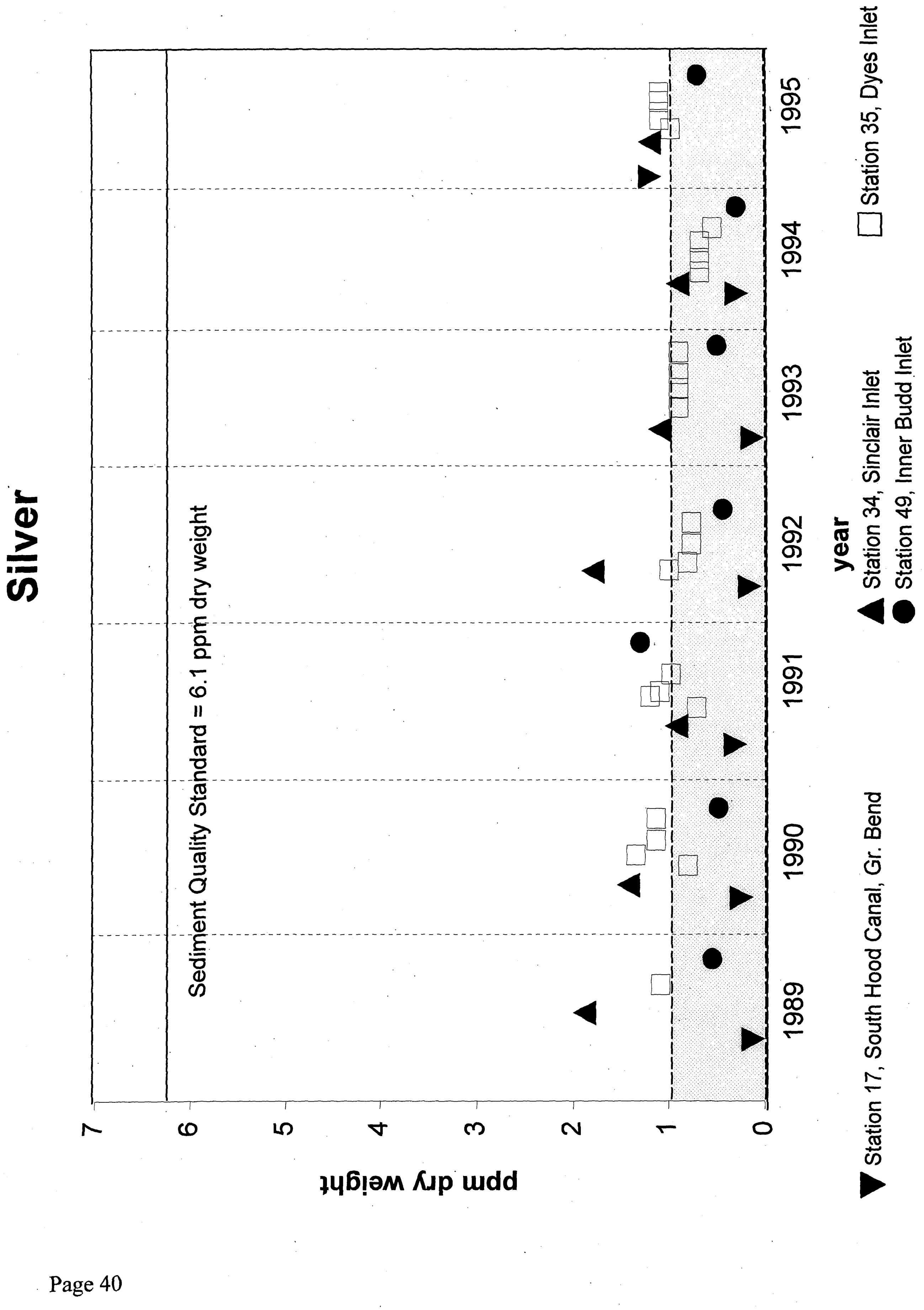


Figure 4. Stations with highest concentrations of silver. Replicate samples are shown for Dyes Inlet. Shaded areas within dashed lines represent the range of all unshown values.

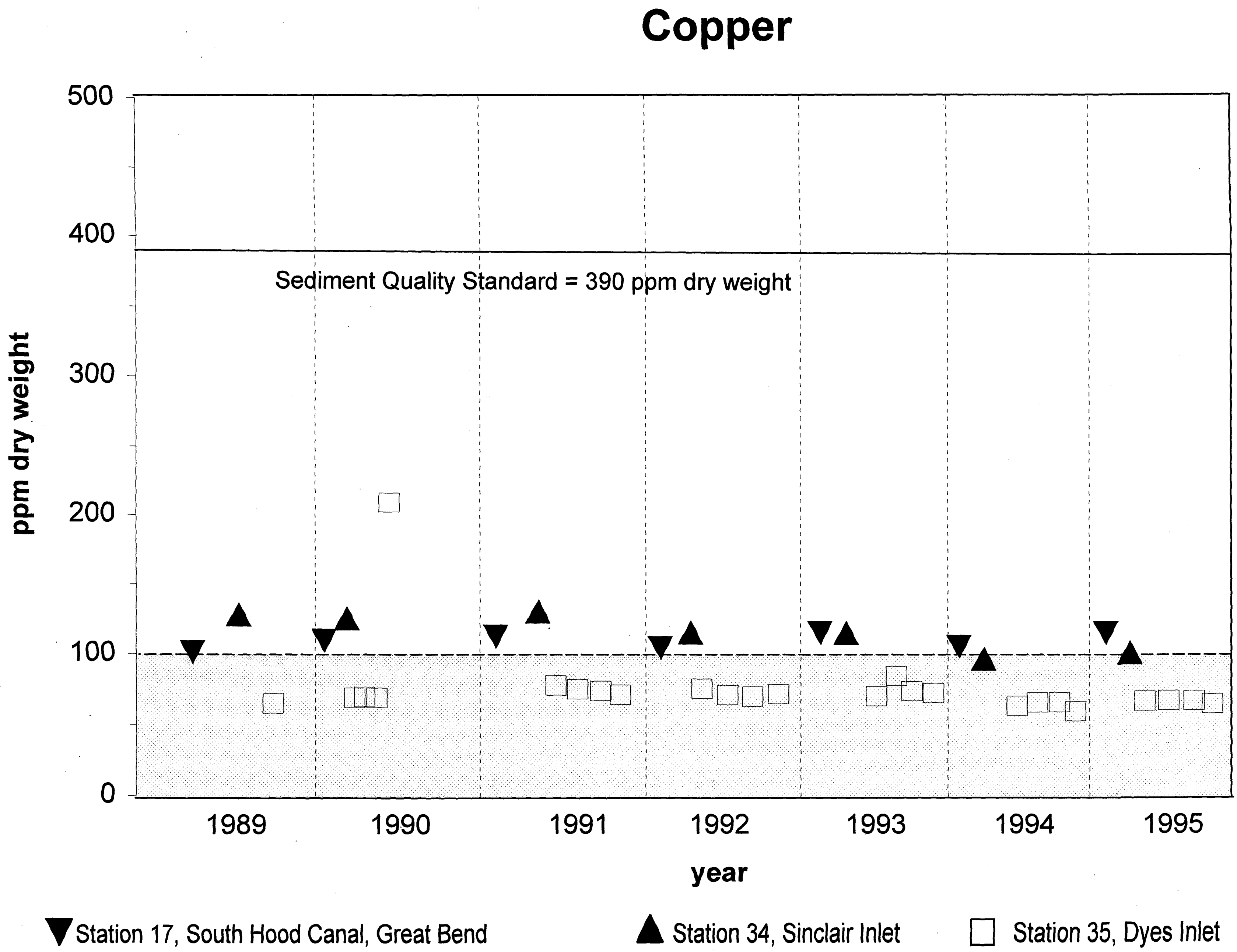


Figure 5. Stations with highest concentrations of copper. Replicate samples are shown for Dyes Inlet. Shaded areas within dashed lines represent the range of all unshown values.

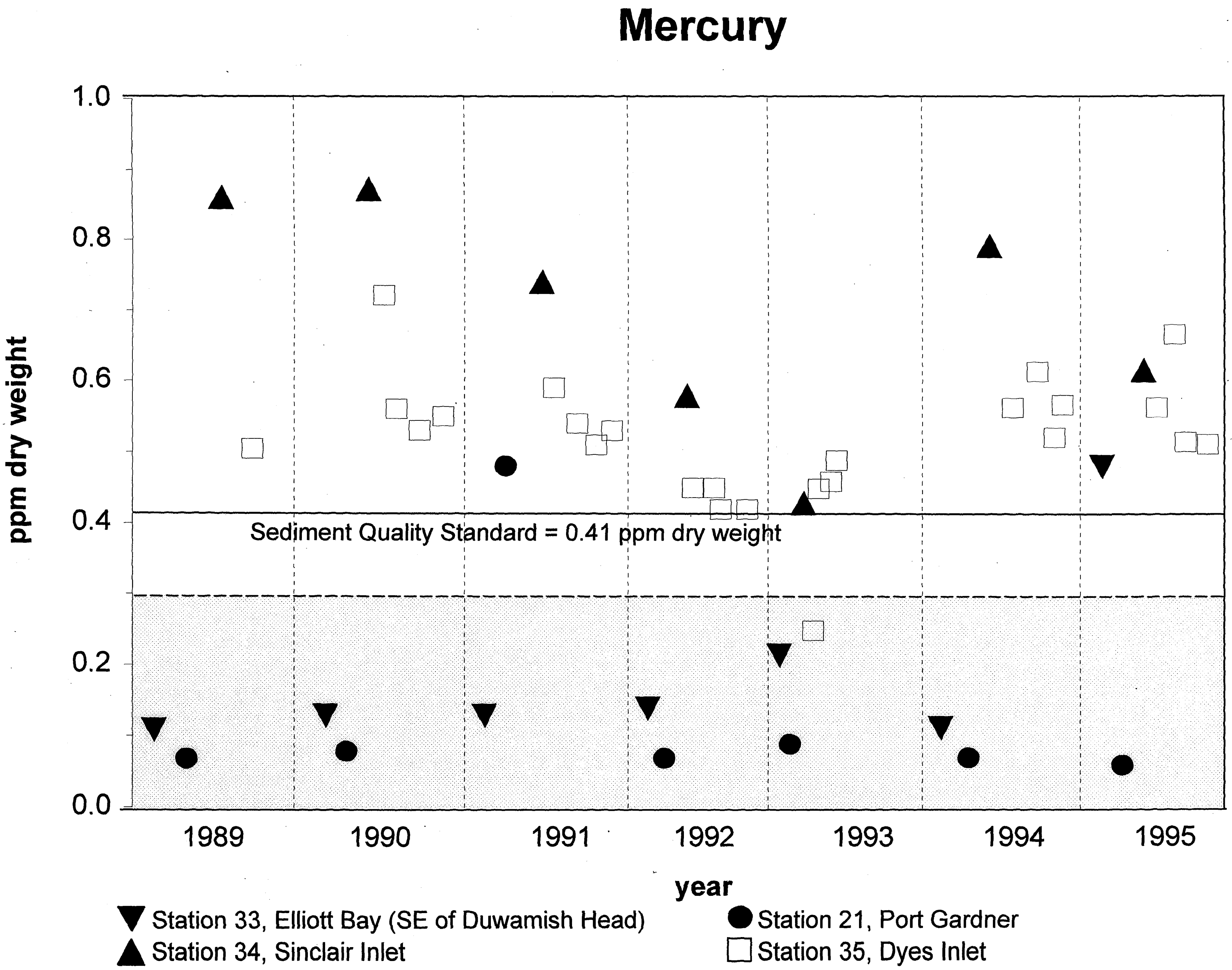


Figure 6. Stations with highest concentrations of mercury. Replicate samples are shown for Dyes Inlet. Shaded areas within dashed lines represent the range of all unshown values.

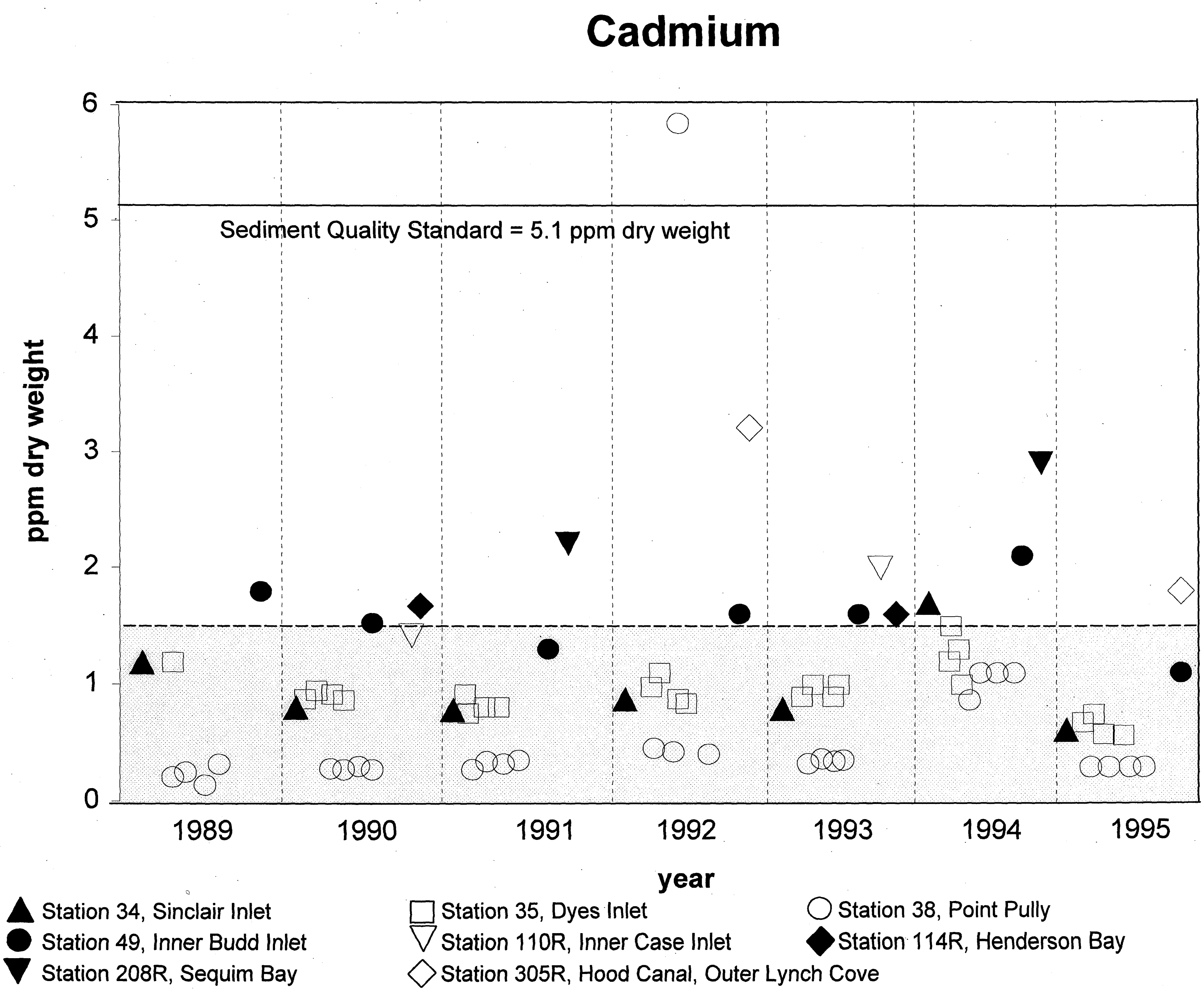


Figure 7. Stations with highest concentrations of cadmium. Replicate samples are shown for Dyes Inlet and Point Pully. Shaded areas within dashed lines represent the range of all unshown values.

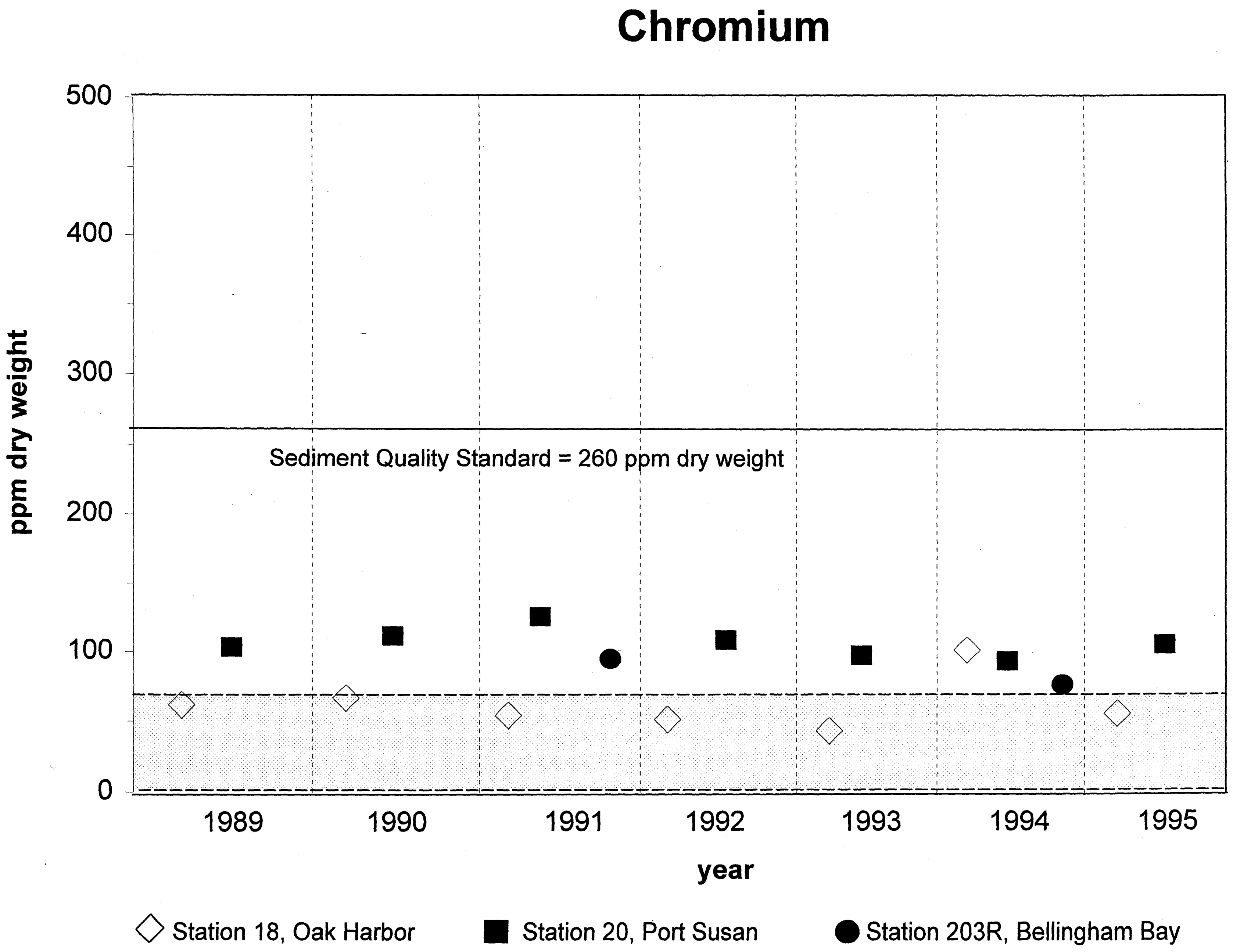


Figure 8. Stations with highest concentrations of chromium. Shaded areas within dashed lines represent the range of all unshown values.

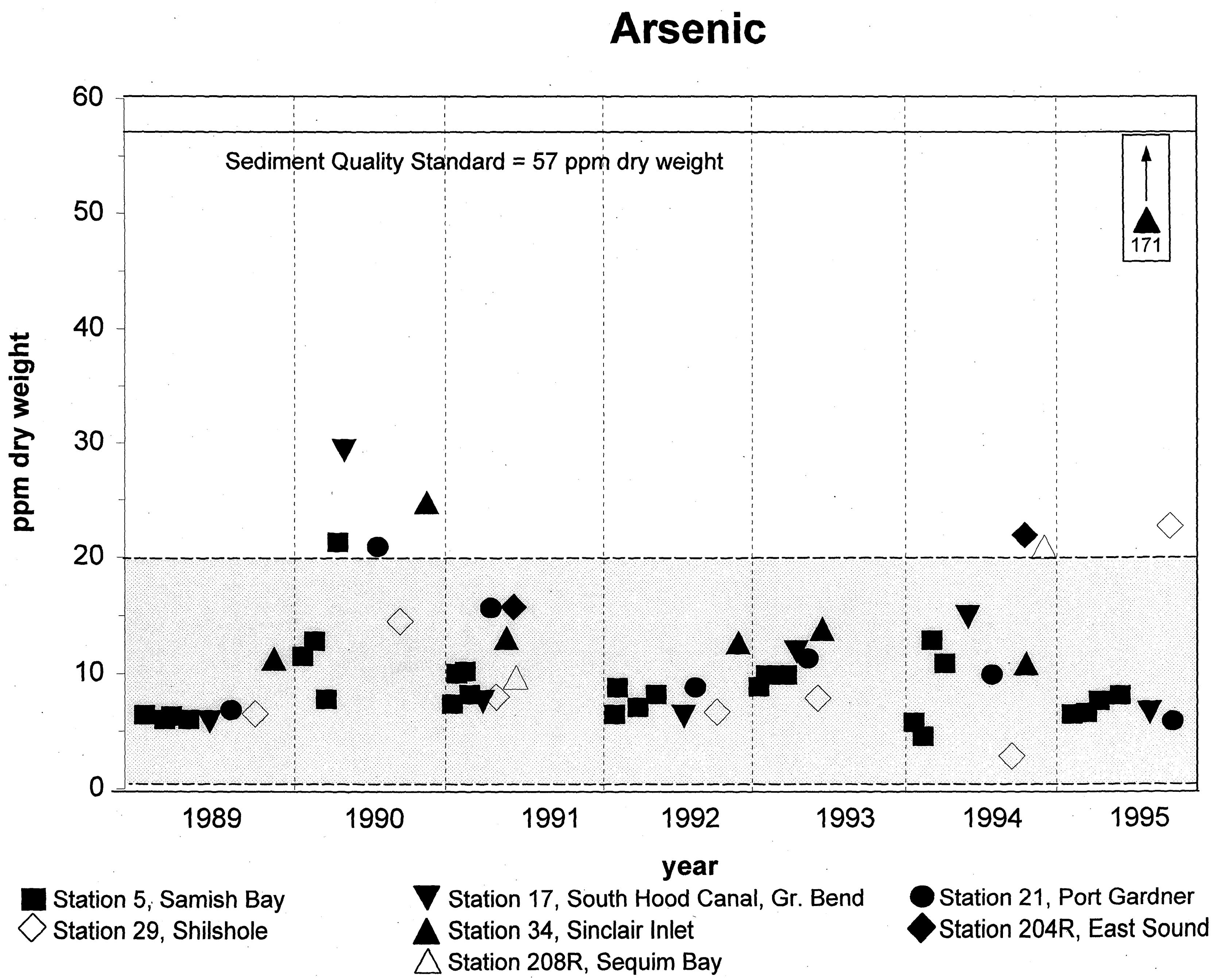


Figure 9. Stations with highest concentrations of arsenic. Replicate samples are shown for Samish Bay. Shaded areas within dashed lines represent the range of all unshown values.

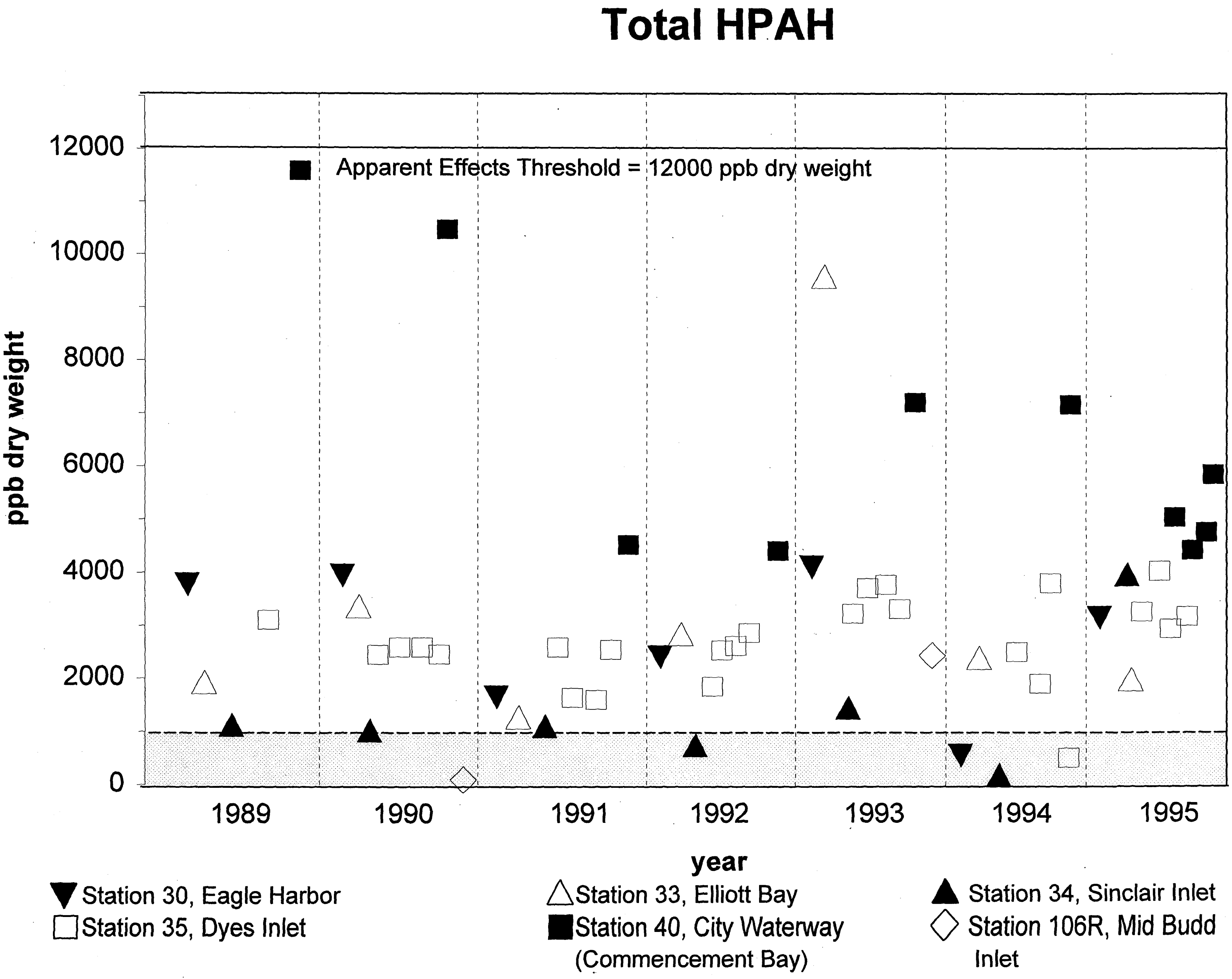


Figure 10. Stations with highest detected concentrations of high-molecular weight polycyclic aromatic hydrocarbons (HPAH). Replicate samples are shown for Dyes Inlet and City Waterway. Shaded areas within dashed lines represent the range of all unshown values.

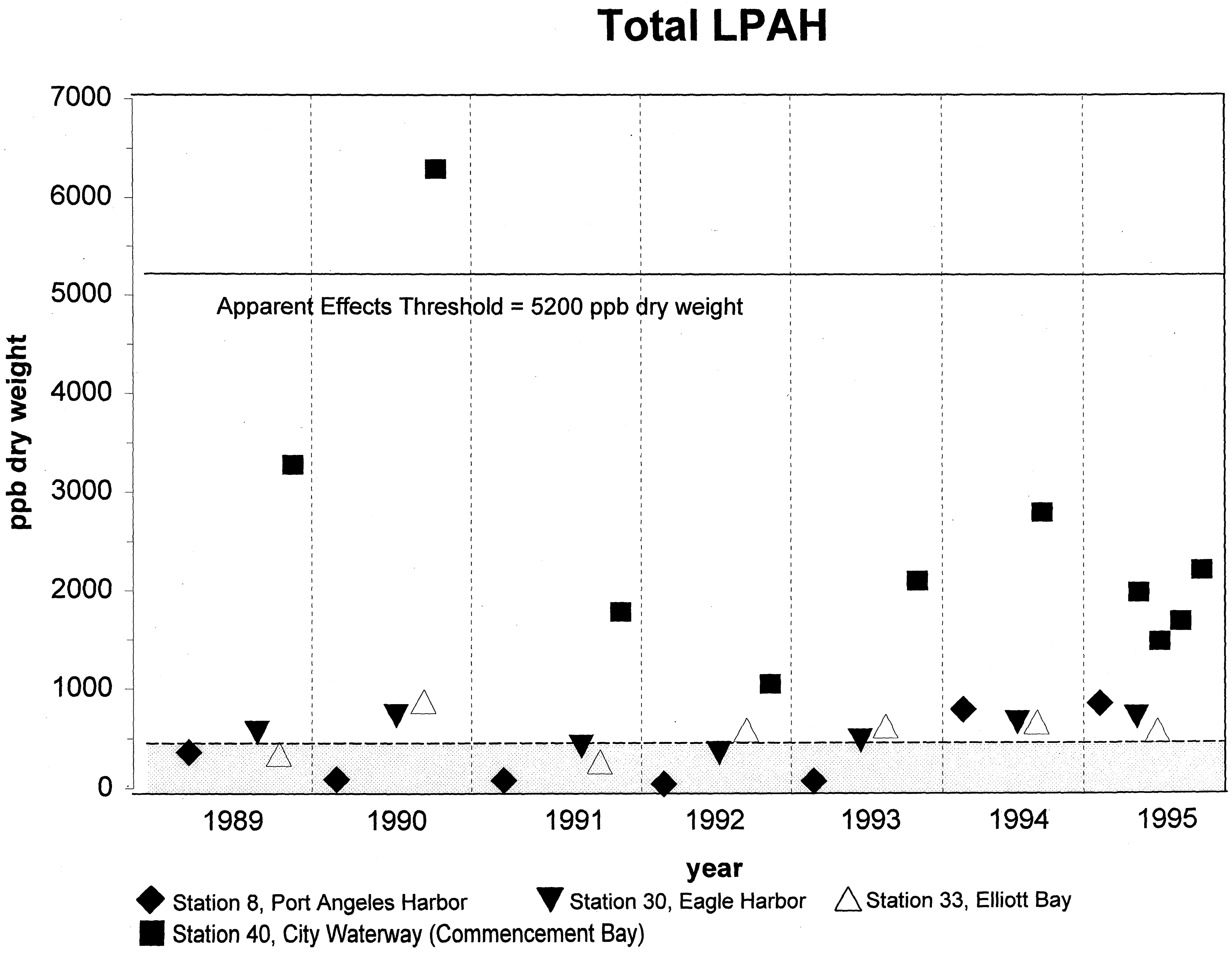


Figure 11. Stations with highest detected concentrations of low-molecular weight polycyclic aromatic hydrocarbons (LPAH). Replicate samples are shown for City Waterway. Shaded areas within dashed lines represent the range of all unshown values.

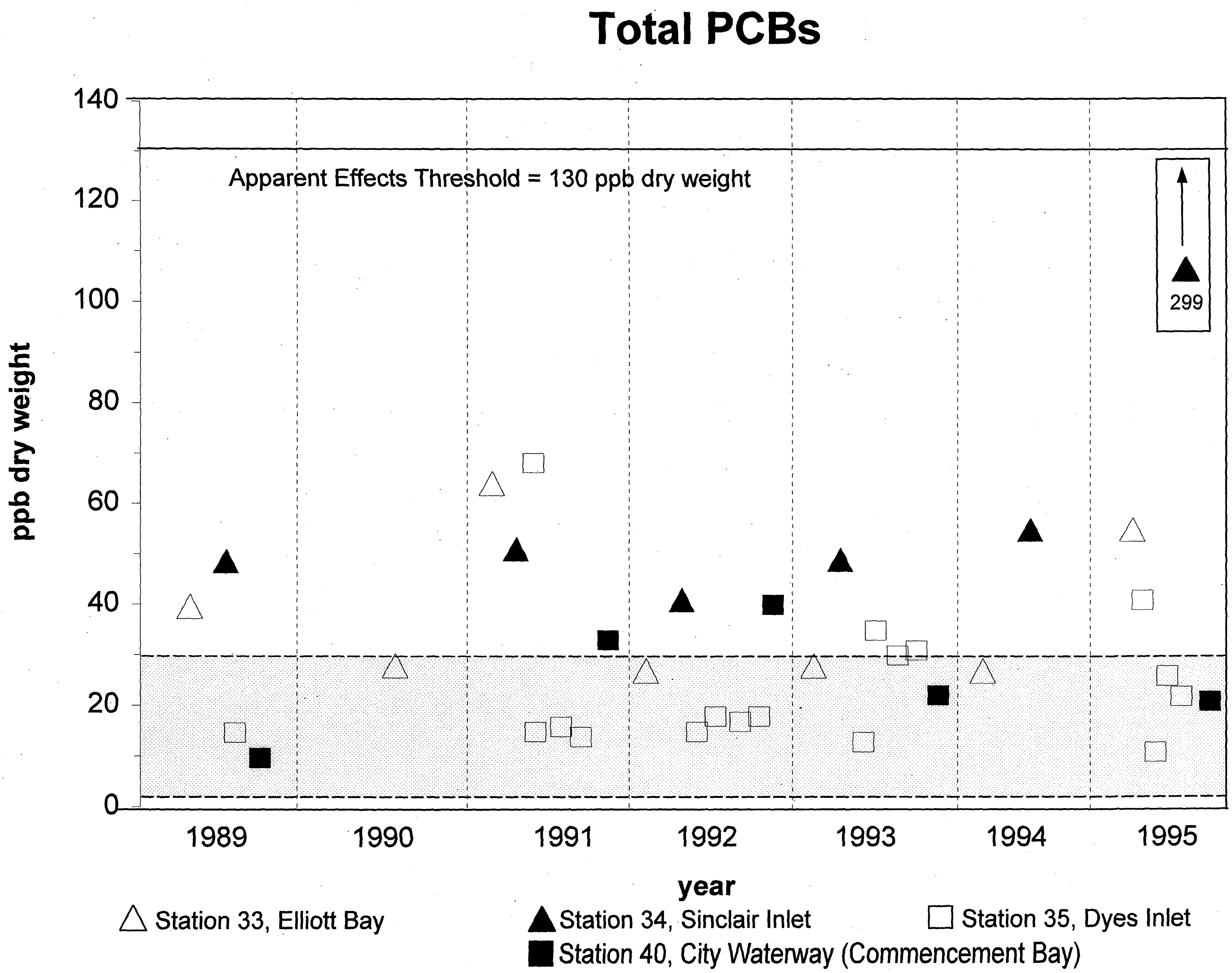


Figure 12. Stations with highest concentrations of polychlorinated biphenyls. Replicate samples are shown for Dyes Inlet. Shaded areas within dashed lines represent the range of all unshown values. PCBs not detected in 1990 at Stations 34, 35 and 40; and in 1994 at Station 35. Station 40 not sampled in 1994.

c,d)pyrene, phenanthrene, and pyrene (Appendix D). Elliott Bay (Station 33) exhibited elevated concentrations of total benzofluoranthenes (b+k), benzo(g,h,i)perylene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-c,d)pyrene in 1993 (Appendix D).

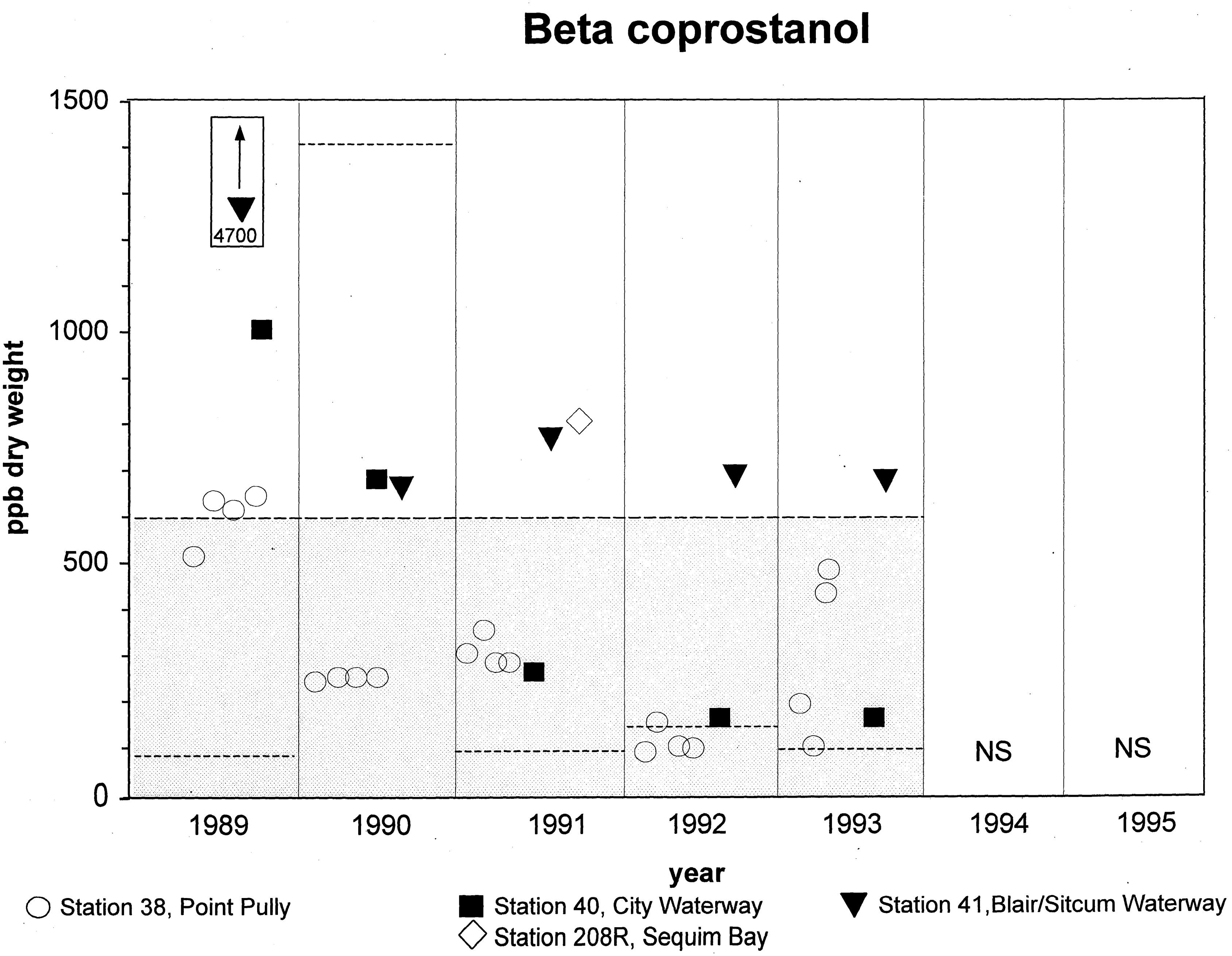
Most hydrocarbon values used in the calculation of Total PAHs for selected stations in Figures 10 and 11 were unqualified. Exceptions were pyrene (1989 and 1992), benzo(a)pyrene (1991), indeno(1,2,3-c,d)pyrene (1991-1993), and benzo(g,h,i)perylene (1991-1992), which were estimates. In 1994 and 1995, hydrocarbon values were more often qualified as estimates, especially at stations in Port Angeles, Eagle Harbor, Sinclair Inlet and Dyes Inlet.

Total PCBs were calculated by summing the detected arochlor values. The number of PCB arochlors analyzed each year was variable. Of the seven PCBs, only arochlor 1254 and arochlor 1260 were detected. The maximum reported undetected value for Total PCBs varied widely from year to year, and ranged from 15 ppb in 1991 to 299 ppb in 1995. Total PCBs at Sinclair Inlet (Station 34) in 1995 exceeded the AET standard. The majority of detected values were qualified as estimates.

Seven of the target chlorinated pesticides were detected in half of one percent of the samples. The majority of these detections were qualified, and concentrations occurred near detection limits. Pesticides (mostly DDD and DDE) were most frequently detected in Elliott Bay (Appendix D). No pesticides were detected in 1994 or 1995.

Resin acids and guaiacols were detected in sediments near pulp mills. However, since these sediments were the only ones analyzed for these compounds, background concentrations in Puget Sound are not known. Port Angeles Harbor consistently exhibited the highest concentrations among the stations sampled (Appendix D), followed by Port Gardner and Commencement Bay near the Blair/Sitcum Waterways. Compounds most frequently detected were abietic acid, dehydroabietic acid, chlorodehydroabietic acid, and isopimaric acid.

Beta-coprostanol (Figure 13), beta-sitosterol (Figure 14), and cholesterol (Appendix D) were detected in 64%-99% of the samples for which they were analyzed, with highest concentrations detected in sediments of Commencement Bay near Blair/Sitcum Waterways. Sequim Bay also showed elevated concentrations of coprostanol in 1991, the only year for which coprostanol was measured in that bay. Concentrations of coprostanol and cholesterol were above AET levels at most stations (AET = 140 ppb and 160 ppb, respectively). One phthalate ester, bis(2-ethylhexyl) phthalate, and phenol were also frequently detected (61% and 53% of the samples, respectively). The highest concentration of the phthalate ester occurred in Port Townsend Bay in 1989 (8,300 ppb, Appendix D), and exceeded AET levels for this compound (AET = 1300 ppb). Phenol concentrations in Saratoga Passage (520 ppb, Appendix D) also exceeded AET levels



Beta coprostanol

Figure 13. Stations with highest concentrations of beta coprostanol. Replicate samples are shown for Point Pully. Shaded areas within dashed lines represent the range of all unshown values. Dotted line shows maximum range of detections limits (undetected values). NS = not sampled.

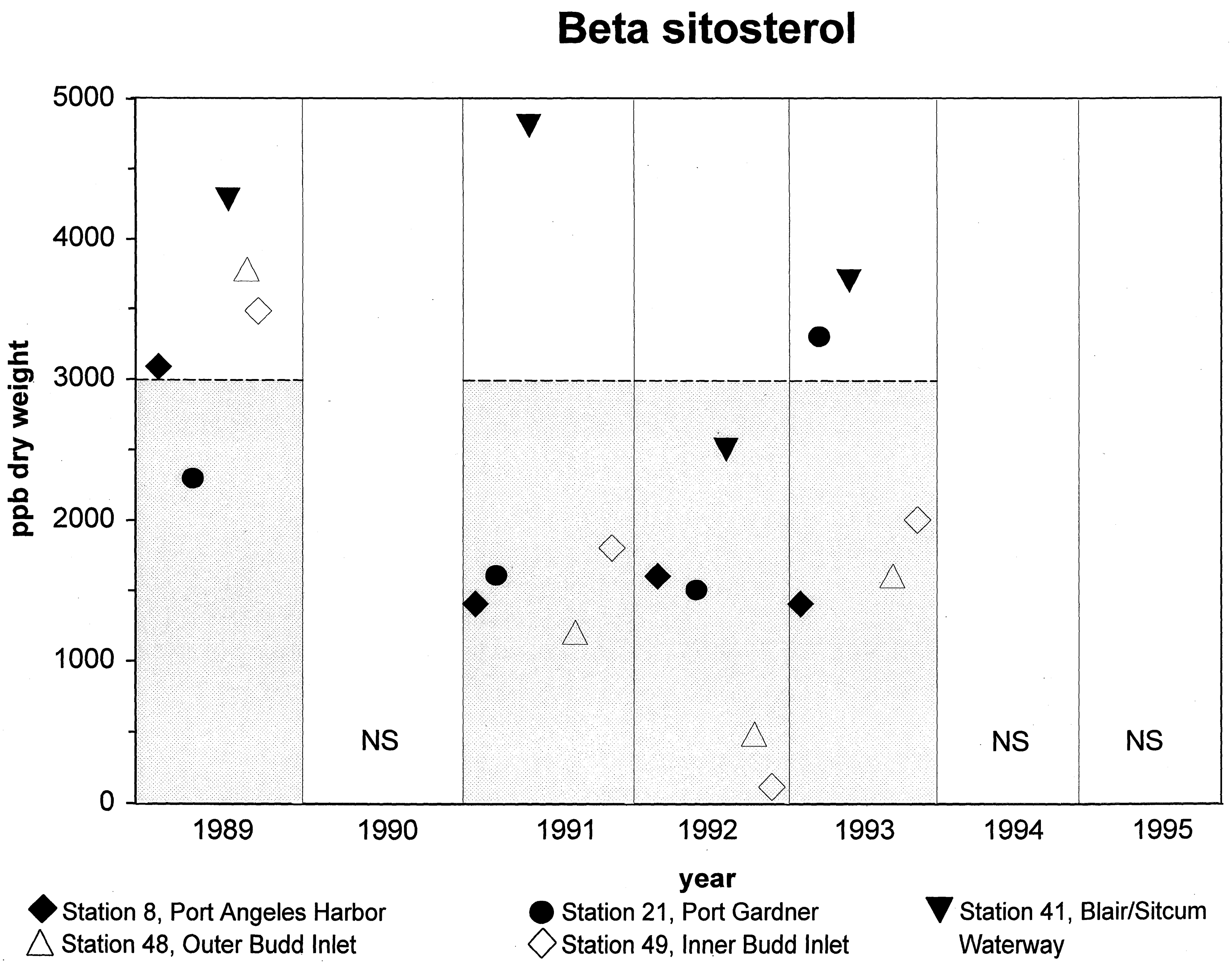


Figure 14. Stations with highest concentrations of beta sitosterol. Shaded areas within dashed lines represent the range of all unshown values. NS = not sampled.

(AET = 420 ppb) in 1989. However, these are the only high concentrations detected for these two compounds during 1989-1993. Other semi-volatile analysis results for organic compounds showed infrequent detection (0.3%-16% detections, Table 7).

Eighteen out of 41 organic compounds analyzed as volatiles (including 1,2-, 1,3-, and 1,4-dichlorobenzene) were never detected in sediments of the MSMP stations (Table 8). Detected VOCs (Appendix D) exhibited low concentrations near analytical detection limits. In addition, detections were inconsistent between years and were mostly qualified because of problems inherent in the analysis of volatile organics. These problems included out of range calibration, positive results below detection limits, blank and field contamination, erratic matrix recoveries, and high variability in surrogate and matrix spike recoveries. Therefore, interpretation of VOC results was limited.

Identification of Contaminated Stations

Comparisons of trace metal concentrations to SQS and organic concentrations to AET values resulted in ten stations having contaminant concentrations above these standards in any one year. Adverse biological effects are always expected to occur above these concentrations. Stations that exceeded SQS or AETs were the following:

Bellingham Bay (Station 4) – dehydroabietic acid
Port Angeles Harbor (Station 8) – abietic, dehydroabietic and isopimaric acids
Port Townsend Bay (Station 12) – bis(2-ethylhexyl)phthalate and dehydroabietic acid
Saratoga Passage (Station 19) – phenol
Port Gardner (Station 21) – mercury and dehydroabietic acid
Sinclair inlet (Station 34) – arsenic, mercury, benzyl alcohol, and PCBs
Dyes Inlet (Station 35) - mercury and 4-methylphenol
Point Pully (Station 38) – cadmium
Commencement Bay (Station 40) – LPAH
Commencement Bay (Station 41) – dehydroabietic and isopimaric acids

In addition, to assess the potential for biological effects in a broader effects range, stations were ranked according to the number and magnitude of contaminants exceeding ER-L guidelines for selected chemicals (see Methods). The above list of stations, therefore, was expanded to include stations with contaminant concentrations above ER-L guidelines. Some frequently detected compounds (perylene, β-sitosterol, 2-butanone, and carbon disulfide) were not used in the identification of contaminated sites because no ER-L or AET was found in the literature. In addition, coprostanol and cholesterol were not used to identify contaminated sites because of their widespread presence in the marine environment, even though they often occur at concentrations above those exhibiting biological effects according to 1988 Puget Sound sensitivity tests (PTI, 1989a). The occurrence and concentration of these sterols, however, were examined for all stations to identify potential inputs from anthropogenic sources.

Fifty-eight stations had one to 24 chemical compounds which were above threshold concentrations with potential for biological effects (Table 9). Stations in Elliott Bay, Dyes Inlet, City Waterway in Commencement Bay, Sinclair Inlet, Eagle Harbor, and Port Angeles showed the largest number of contaminants. Hydrocarbons predominated in Elliott Bay, Commencement Bay and Eagle Harbor sediments, while both metals and hydrocarbons were common in Dyes Inlet. Trace metals predominated in Sinclair Inlet sediments, although several hydrocarbons were detected above threshold concentrations in 1995. Port Angeles sediments exhibited metals, hydrocarbons, and three resin acids above threshold concentrations. The remaining 52 stations had ten or fewer contaminants (predominantly priority pollutant metals). Nickel and arsenic concentrations were above ER-L values for most stations. Stations with five or more contaminants with potential for biological effects are shown in Figure 15.

Comparison of MSMP Chemistry Data to Other Puget Sound Studies

In order to make regional comparisons, the MSMP sediment chemistry (1989-1993) data were compared to other Puget Sound sediment chemistry data which had been collected using comparable methods. Comparisons were made for five metals (arsenic, copper, mercury, lead, and zinc), four hydrocarbons (anthracene, fluoranthene, phenanthrene, and pyrene), total PCBs and DDT. Seven urban bays (Port Angeles, Bellingham Bay, Port Gardner, Elliott Bay, Sinclair Inlet, Commencement Bay, and Budd Inlet), and two reference areas (Samish Bay and Dabob Bay) were selected for comparison. The levels represented by MSMP data were also compared to Puget Sound historical (Romberg *et al.*, 1984) concentrations, and, in one case, to Puget Sound background concentrations (Crecelius *et al.*, 1975).

Romberg *et al.* (1984) reported pre-industrialization levels of contaminants, and Crecelius *et al.* (1975) focused on the natural distribution of metals in Puget Sound. In addition, the following studies were used in the comparisons: a DNR study of 1991 that focused on areas where commercial development may have contributed to sediment contamination (Tetra Tech, 1991); an EPA study conducted in eight bays of Puget Sound during 1983-1984 (Battelle, 1986); a baseline survey of dredged disposal sites (PSDDA) in Bellingham Bay (PTI, 1989b); the Marine Ecosystem Analysis Project (MESA) conducted in 1979 (Malins *et al.*, 1980); and an extensive study (Parametrix) of the ASARCO slag peninsula in Commencement Bay conducted during 1988-1990 (Shimek, 1991).

The range of urban concentrations reported by the studies examined often exceeded MSMP data (Figures 16-26). The high contaminant concentrations detected by these studies reveal the limited coverage of urban areas provided by the MSMP. However, the results of this comparison suggest that contaminants in concentrations high enough to be cause of immediate concern

Table 9. Stations and detected chemical compounds at or above threshold concentrations with potential for biological effects (see text). Concentrations have been rounded to two significant figures, and are presented in mg/kg dry weight for metals and μg/kg dry weight for organics. Where replicate samples were taken, the range of concentrations is shown. Blanks indicate values below threshold concentrations. J = estimate, N = presumptive evidence, NS = not sampled, P = above instrument detection limit, Q = questionable value, R = rejected, U = undetected. Stations are listed in rank order according to the number of contaminants and to their relative concentrations, from high to low.

Station	Number of Compounds	Compound	Concentrations 1989	1990	1991	1992	1993	1994	1995
33 Elliott Bay (SE of Duwamish Head)	24	arsenic		8.3				U	
		copper	36	39	43J		34		
		lead		51					
		mercury					0.22		0.48
		nickel		31				NS	
		acenaphthene	17J	36		26	38	42	27J
		acenaphthylene		49					
		anthracene	90	210		110	160	120	120J
		benzo(a)anthracene		300			670		
		benzo(a)pyrene					1400		
		benzo(g,h,i)perylene					770		
		chrysene		560			920		
		dibenzo(a,h)anthracene		U			350		
		fluoranthene					1000		
		fluorene	28	68	23	61	47	49	40J
		indeno(1,2,3-c,d)pyrene					890		
		naphthalene						170	170J
		phenanthrene		500		350	340	290	
		pyrene					1400		
		total PAHs		4400			10000		
		alpha-chlordane	0.9	U	U	U	U	U	U
		p,p'-DDD	2.6J	U	U		U	U	U
		p,p'-DDE	U	22	U	U		U	U
		total PCBs	40	28	64	27J	28N	27J	55J

Table 9. Continued.

Station	Number of Compounds	Compound	Concentrations 1989	1990	1991	1992	1993	1994	1995
35 Dyes Inlet	24	arsenic	9.4	16-20	11-13	9.5-12	13-14	9P-12P	9.0N-9.5N
		beryllium	U	U	0.28-0.36		0.3-0.4	NS	
		cadmium	1.2J					1P-1.5P	
		copper	66	70-210	72-79	71-76	71-85	60-67	66-68
		lead	69	53-69	66-78	61-70	72-77	50-54	58-60
		mercury	0.51J	0.53J- 0.72J	0.51-0.59	0.42-0.45	0.25-0.49	0.52-0.62	0.51-0.67
		nickel	40	38-42	43-45	39-44	41-47	NS	38-39
		silver	1.1	0.8-1.4	0.7J-1.2J	0.8-1			0.98J-1.1J
		thallium	U	0.4J-0.5U	0.21U-0.28	NS	NS	NS	U
		zinc					130-160		
		4-methylphenol	U	20U-1100J	U	U		NS	NS
		acenaphthylene	56				46-56	6.7J-71	30J-46J
		anthracene	140	130-180	110-200	62-96	120-150	19-160	90J-160
		benzo(a)anthracene	310	250-290	170-350	170-270J	310J-370	61-360	260-370
		benzo(a)pyrene					380-440	13J-440	350-470
		chrysene	410	380-410J	230-390		370J-440	70-440	330-460
		dibenzo(a,h)anthracene			41-72		64-96		
		fluoranthene							450-600
		fluorene			9J-19			8.5J-26J	U
		phenanthrene			120-240				
		pyrene				540J-820J	530-760	730-750	540-750
		total PAHs					3600-4300	720-4400	3300-4400
		p,p'-DDD	U	U	U	U	2.4N-3.8U	U	U
		total PCBs		U	14J-68J		13N-35J	U	11J-41
40 City Waterway (Commencement Bay)	21	arsenic		13				U	
		copper		36	47	35	37	36	
		mercury						0.16	0.10-0.31
		acenaphthene	55J	230	99	37	63	84	42-69
		acenaphthylene	330	290	98	59	170	130	85-110
		anthracene	1100	1800	570	340	510	780	400-720

Table 9. Continued.

Station	Number of Compounds	Compound	Concentrations 1989	1990	1991	1992	1993	1994	1995
		benzo(a)anthracene	1300	1300	570	460	710	790	420-560
		benzo(a)pyrene	1400	1000		490	860	600	470-640
		benzo(g,h,i)perylene	670						
		chrysene	1500	1500	680	550	720	850	520-680
		dibenzo(a,h)anthracene	340	160	170	79	150	74	53-88
		fluoranthene	1700	1700	820	610	1500	1500	880-1100
		fluorene	250	450	190	72	170	190	94-150
		indeno(1,2,3-c,d)pyrene	830						
		2-methylnaphthalene		NS				95	
		naphthalene						270	170-220
		phenanthrene	1500	3400	800	520	1100	1400	720-1000
		pyrene	1900	2400	780	1200	1300	2100	990-1300
		total PAHs	15000	17000	6400	5600	9500	10000	6000-8100
		endrin	U	U	U	U	0.76	NS	U
		total PCBs		U	33	40J			
34 Sinclair Inlet	15	arsenic	12	25	13	13	14	11P	171N
		beryllium	U	U	0.38	U		NS	
		cadmium	1.2J					1.7P	
		copper	130	130	130	120	120	98	100
		lead	94	63	91	73	87	56	65
		mercury	0.86J	0.87J	0.74	0.58	0.43	0.79	0.62
		nickel	42	41	44	41	41	NS	37
		silver	1.9	1.4		1.8	1.1		1.2J
		zinc	170			170			
		anthracene							91
		benzo(a)anthracene							310J
		dibenzo(a,h)anthracene							70J
		total PAH							4400
		benzyl alcohol	U	U	U	U	90	NS	NS
		total PCBs	49	U	51	41J	49	55NJ	300J

Table 9. Continued.

Station	Number of Compounds	Compound	Concentrations 1989	1990	1991	1992	1993	1994	1995
30 Eagle Harbor	14	arsenic						5P-11P	19N
		copper		34			39	34-36	
		mercury	0.19J	0.24J			0.16		0.18
		thallium	U	0.4	0.31	NS	NS	NS	U
		acenaphthene		16	20		20J	132	46J
		acenaphthylene		47					
		anthracene	270	320	140	180	190		230
		benzo(a)anthracene	410	380			400		
		chrysene	730	820		410	700		380
		dibenzo(a,h)anthracene	100	U			110J		
		fluoranthene							770
		fluorene	39	50	43	35	41	120	
		phenanthrene		310				240	310
		total PAHs	4500	4800			4700		
8 Port Angeles	12	arsenic		18			9	18P	
		antimony	U	16Q	U	U	U	NS	U
		copper		82					
		mercury	0.26	0.25J	0.26	0.22	0.25	0.27	0.28
		abietic acid		630		460		NS	NS
		dehydroabietic acid	550J	730	420	460	690	NS	NS
		isopimaric acid	210J	410		220	U	NS	NS
		acenaphthene				U		30	30J
		acenaphthylene		U				87	79
		fluorene	21					34	38J
		naphthalene						370	380
		phenanthrene	300					260	300
21 Port Gardner	10	arsenic		21	16	8.9	11	10P	
		beryllium	U		0.44	U		NS	
		copper		44	57J	41	45	35	

Table 9. Continued.

Station	Number of Compounds	Compound	Concentrations 1989	1990	1991	1992	1993	1994	1995
		mercury	U	U	0.48				
		nickel	33	40	51	40	45	NS	32
		thallium	U	0.4J		NS	NS	NS	U
		dehydroabietic acid	520J	390	NS	NS	NS	NS	NS
		acenaphthene	U					21	17J
		fluorene						25	20J
		total PCBs	30	U		U	U	U	
38 Pt. Pully	9	arsenic	8.9-11	7.5-19	12-15	11-15	13-14	U	
		antimony	R	R				NS	3.0U-3.3J
		beryllium	U	0.5-0.8	0.37-0.55	U	0.4-0.5	NS	0.31P-0.37P
		cadmium				0.41-5.8			U
		copper	46-50	53-55	54-57	48-50	49-51	46-48	43-45
		lead	36-51		36-49	38-120			
		mercury	0.19-0.24	0.16J-0.2J	0.21-0.25	0.17-0.18	0.16-0.17	0.19-0.24	0.17P-0.18P
		nickel	35-40	43-44	41-45	37-39	37-40	NS	32-35
		total PCBs	16-28J	U		U		U	
305R Hood Canal, Outer Lynch Cove	7	arsenic	NS	NS	NS	17	NS	NS	16
		beryllium	NS	NS	NS	U	NS	NS	0.46P
		cadmium	NS	NS	NS	3.2	NS	NS	1.8P
		copper	NS	NS	NS	91	NS	NS	85
		nickel	NS	NS	NS	50	NS	NS	44
		selenium	NS	NS	NS	NS	NS	NS	1J
		silver	NS	NS	NS		NS	NS	1J
4 Bellingham Bay	7	arsenic		19	12			13P	
		beryllium	U	U	0.51	U	U	NS	0.53P
		copper		38	42J	39	37	37	39
		mercury		U	0.16				
		nickel	46	67	71	62	60	NS	57

Table 9. Continued.

Station	Number of Compounds	Compound	Concentrations 1989	1990	1991	1992	1993	1994	1995
		zinc							180
		dehydroabietic acid	190				140J-160J	NS	NS
49 Inner Budd Inlet	7	arsenic	8.2	9	12	13	13	U	9.2N
		beryllium	U	U	0.39	U	U	NS	
		cadmium	1.8J	1.5	1.3	1.6	1.6	2.1P	
		copper	54	54	59	56	60	67	52
		mercury	0.19	0.17J	0.18	0.18	0.2	0.21	0.18
		nickel	30	31			34	NS	
		silver			1.3			U	
203R Bellingham Bay	6	arsenic	NS	NS	15	NS	NS	18P	NS
		beryllium	NS	NS	0.55	NS	NS	NS	NS
		cadmium	NS	NS		NS	NS	1.2P	NS
		chromium	NS	NS	95	NS	NS		NS
		copper	NS	NS	59J	NS	NS	49	NS
		nickel	NS	NS	160	NS	NS	NS	NS
106R Mid Budd Inlet	6	arsenic	NS	12	NS	NS	14	NS	NS
		copper	NS	49	NS	NS	50	NS	NS
		mercury	NS	0.18J	NS	NS	0.17	NS	NS
		nickel	NS	31	NS	NS	36	NS	NS
		fluoranthene	NS		NS	NS	1100	NS	NS
		phenanthrene	NS		NS	NS	440	NS	NS
20 Port Susan	6	arsenic	8.2	13	12	9.3	10	10P	
		antimony	R	R				NS	3.9J
		beryllium	U	U	0.42			NS	
		chromium	100	110	130	110	98	94N	110
		copper	38	46	50J	45	42	40	44
		nickel	110	130	140	130	120	NS	110

Table 9. Continued.

Station	Number of Compounds	Compound	Concentrations 1989	1990	1991	1992	1993	1994	1995
48 Outer Budd Inlet	6	arsenic		16	11	11	11	U	8.8N
		beryllium	U	U	0.36	U	U	NS	
		cadmium	1.2J					1.5P	
		copper	45	42	48	42	45	48	43
		mercury	U	0.15J				0.17	0.14P
		nickel	35		35		33	NS	
5 Samish Bay	6	arsenic		7.9-21	7.5-10	6.6-8.9	7.2-10	4.7P-13P	6.6N-8.2
		beryllium	U	U	0.37-0.4		0.3-0.4	NS	0.32P-0.39P
		copper				32-34			
		mercury	U	U	0.13-0.15				
		nickel	24-37	40-45	43-46	39-42	39-41	NS	37-40
		p,p'-DDE	U	U	2U-3.7	U	U	U	NS
17 South Hood Canal, Great Bend	5	arsenic		29			12	15P	
		beryllium	U	U	0.46	U	0.5	NS	0.61P
		copper	100	110	110	110	120	110	120
		nickel	50	53	53	48	56	NS	47
		silver							1.2J
41 Blair/Sitcum Waterways	5	arsenic		14				U	
		copper						37	
		dehydroabietic acid	NS	NS	250	170	560	NS	NS
		isopimaric acid	NS	NS	170	180	390	NS	NS
		fluorene	U					20J	U
204R East Sound	5	arsenic	NS	NS	16	NS	NS	22P	NS
		cadmium	NS	NS	1.2	NS	NS	1.6P	NS
		copper	NS	NS	37J	NS	NS		NS
		nickel	NS	NS	37	NS	NS	NS	NS
		thallium	NS	NS	0.3	NS	NS	NS	NS

Table 9. Continued.

Station	Number of Compounds	Compound	Concentrations 1989	1990	1991	1992	1993	1994	1995
104R Inner Eld Inlet	5	arsenic	NS		NS	NS	13	NS	NS
		cadmium	NS	1.4	NS	NS	1.4	NS	NS
		copper	NS	47	NS	NS	48	NS	NS
		nickel	NS	34	NS	NS	37	NS	NS
		thallium	NS	0.7	NS	NS	NS	NS	NS
18 Oak Harbor	5	arsenic			11	8.4	17	U	
		chromium						100N	
		copper		45					
		nickel	50	66	53	51	49	NS	50
		thallium	U	U	0.24	NS	NS	NS	U
29 Shilshole	5	arsenic		15				U	23
		beryllium	U	U	0.45	U		NS	
		copper		35	37J	34		38	
		nickel	38	37	36	35	37	NS	35
		p,p'-DDT	U	U	1N	U	U	NS	NS
19 Saratoga Passage	5	arsenic	8.3	13	10	12	12	13P	
		beryllium	U	U	0.41	U	0.4	NS	0.36P
		copper	37	38	42J	42	39	37	34
		nickel	58	62	65	61	66	NS	58
		phenol	520			U	U	NS	NS
12 Port Townsend	5	arsenic		11				12P	
		beryllium	0.42	U	0.38	U		NS	0.39P
		nickel	32	34	34	32	36	NS	
		dehydroabietic acid	NS	NS	150		440	NS	NS
		bis(2-ethylhexyl)phthalate	8300J	U		U		NS	NS

Table 9. Continued.

Station	Number of Compounds	Compound	Concentrations 1989	1990	1991	1992	1993	1994	1995
307R Holmes Harbor	4	arsenic	NS	NS	NS	16	NS	NS	14N
		beryllium	NS	NS	NS	U	NS	NS	0.37P
		copper	NS	NS	NS	52	NS	NS	51
		nickel	NS	NS	NS	63	NS	NS	63
110R Inner Case Inlet	4	arsenic	NS	11	NS	NS	17	NS	NS
		cadmium	NS	1.4	NS	NS	2	NS	NS
		copper	NS	45	NS	NS	45	NS	NS
		nickel	NS	41	NS	NS	40	NS	NS
208R Sequim Bay	4	arsenic	NS	NS	9.8	NS	NS	21P	NS
		cadmium	NS	NS	2.2	NS	NS	2.9P	NS
		copper	NS	NS	40	NS	NS	42	NS
		nickel	NS	NS	37	NS	NS	NS	NS
101R Oakland Bay, North	4	arsenic	NS	15	NS	NS	9.1	NS	NS
		copper	NS	43	NS	NS	45	NS	NS
		nickel	NS	42	NS	NS	44	NS	NS
		thallium	NS	0.6J	NS	NS	NS	NS	NS
303R Quartermaster Harbor	4	arsenic	NS	NS	NS	12	NS	NS	13N
		copper	NS	NS	NS	58	NS	NS	53
		mercury	NS	NS	NS	0.33	NS	NS	0.36
		nickel	NS	NS	NS	32	NS	NS	30
26 Central Basin	4	arsenic		8.6					
		nickel	30-30	33	33	31	33	NS	NS
		anthracene	3J-240			U		NS	NS
		fluorene	9U-22	U		U	U	NS	NS

Table 9. Continued.

Station	Number of Compounds	Compound	Concentrations 1989	1990	1991	1992	1993	1994	1995
24R East Central Basin	4	arsenic		NS	NS		NS	NS	11N
		beryllium	U	NS	NS	U	NS	NS	0.38P
		copper	38	NS	NS	37	NS	NS	
		nickel	41	NS	NS	39	NS	NS	36
304R Hood Canal, Tekiu Point	3	copper	NS	NS	NS	56	NS	NS	50
		beryllium	NS	NS	NS	U	NS	NS	0.43P
		nickel	NS	NS	NS	45	NS	NS	38
102R Inner Totten Inlet	3	arsenic	NS	13	NS	NS	11	NS	NS
		copper	NS	47	NS	NS	42	NS	NS
		nickel	NS	44	NS	NS	42	NS	NS
114R Henderson Bay	3	arsenic	NS	11	NS	NS		NS	NS
		cadmium	NS	1.7	NS	NS	1.6	NS	NS
		thallium	NS	0.4J	NS	NS	NS	NS	NS
70 Oakland Bay, Shelton	3	copper		40	46	39	35		43
		nickel	NS	38	41	37	40	NS	36
		fluorene	NS	20N		U		NS	NS
3 Strait of Georgia, North of Patos Island	3	arsenic						14P	
		beryllium	U					NS	0.38P
		nickel						NS	31
1 Semiahmoo Bay, Blaine	3	arsenic			8.8			12P	
		beryllium	U	U		U	0.4	NS	0.37P
		nickel	32	34	36	35	35J	NS	35

Table 9. Continued.

Station	Number of Compounds	Compound	Concentrations 1989	1990	1991	1992	1993	1994	1995
105R Outer Eld Inlet	3	arsenic	NS	14	NS	NS	11	NS	NS
		copper	NS	37	NS	NS	36	NS	NS
		nickel	NS		NS	NS	31	NS	NS
71 Fidalgo Bay	3	arsenic	NS		8.7		9		
		nickel	NS		32			NS	
		p,p'-DDT	NS	U	1J	U	U	NS	NS
111R Mid Case Inlet	3	arsenic	NS		NS	NS	9	NS	NS
		nickel	NS		NS	NS	30	NS	NS
		thallium	NS	0.4	NS	NS	NS	NS	NS
2R Cherry Pt.	2	arsenic		NS		NS	NS	17P	NS
		nickel		NS	32	NS	NS	NS	NS
14 Hood Canal, Bangor	2	arsenic		12				8.3P	
		nickel	31	31			33	NS	
302R Oak Bay	2	beryllium	NS	NS	NS	U	NS	NS	0.36P
		nickel	NS	NS	NS		NS	NS	30
109R Henderson Inlet	2	arsenic	NS		NS	NS	10	NS	NS
		copper	NS	38	NS	NS	37	NS	NS
201R Roberts Bank	1	arsenic	NS	NS		NS	NS	14P	NS
202R Point Roberts	1	arsenic	NS	NS		NS	NS	14P	NS
207R West Beach	1	arsenic	NS	NS		NS	NS	13P	NS
115R Outer Filucy Bay	1	arsenic	NS	12	NS	NS		NS	NS

Table 9. Concluded.

Station	Number of Compounds	Compound	Concentrations						
			1989	1990	1991	1992	1993	1994	1995
205R NW Blakely Island	1	arsenic	NS	NS		NS	NS	12P	NS
45 Devil's Head	1	arsenic		11				U	
206R Friday Harbor	1	arsenic	NS	NS		NS	NS	11P	NS
11R Discovery Bay	1	arsenic		NS		NS	NS	10P	NS
15 Dabob Bay	1	arsenic						10P	
44 East Anderson Island	1	arsenic		7.4-8.5				U	
209R Skagit Bay	1	nickel	NS	NS	43	NS	NS	NS	NS
9R East of Green Pt.	1	nickel	41	NS	45	NS	NS	NS	NS
10R Dungeness Bay	1	nickel		NS	32	NS	NS	NS	NS
69 Port Madison	1	thallium	U	U	0.25	NS	NS	NS	U

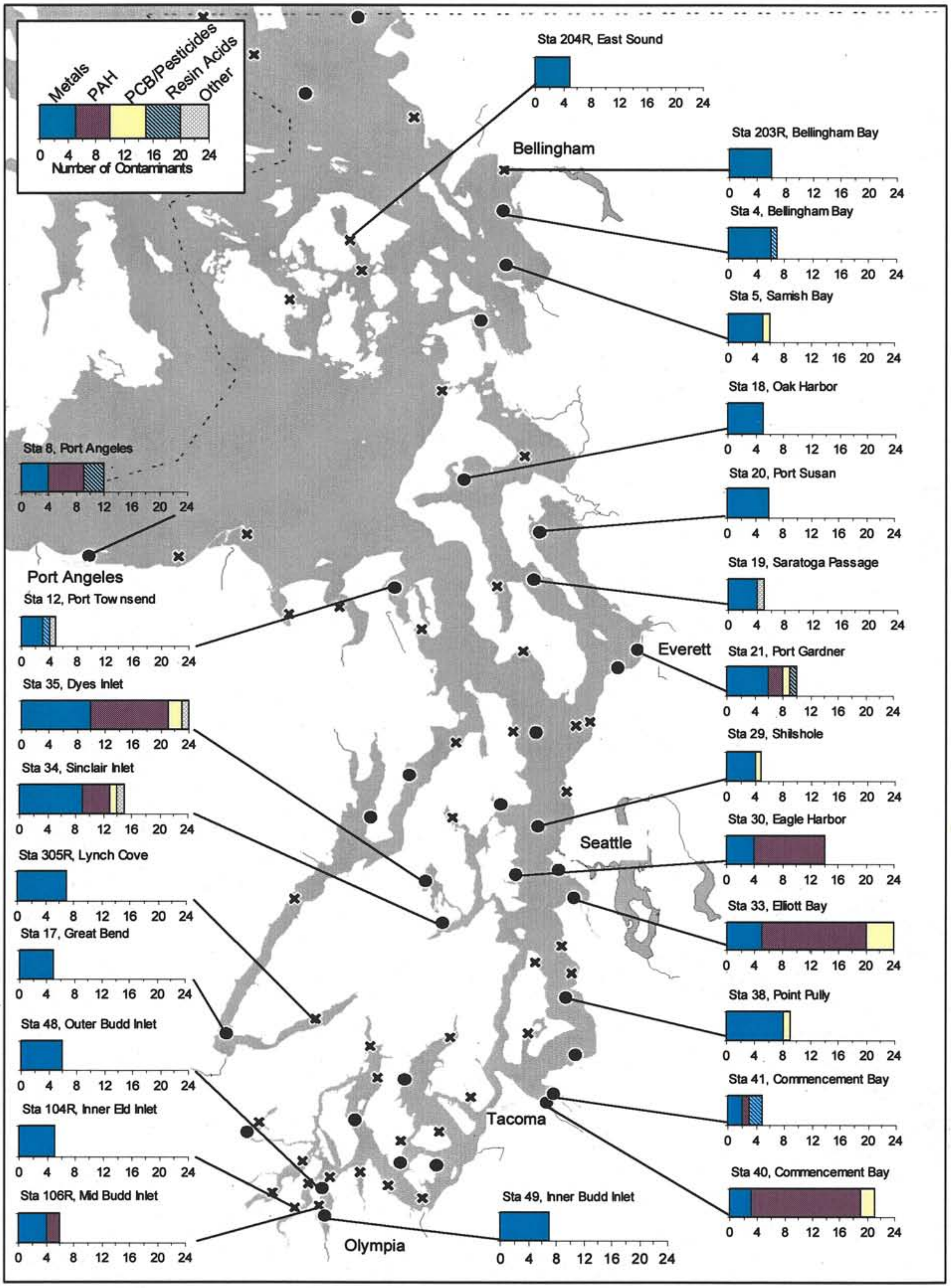


Figure 15. Stations exhibiting contamination with potential for biological effects. Only stations with five or more compounds are shown.

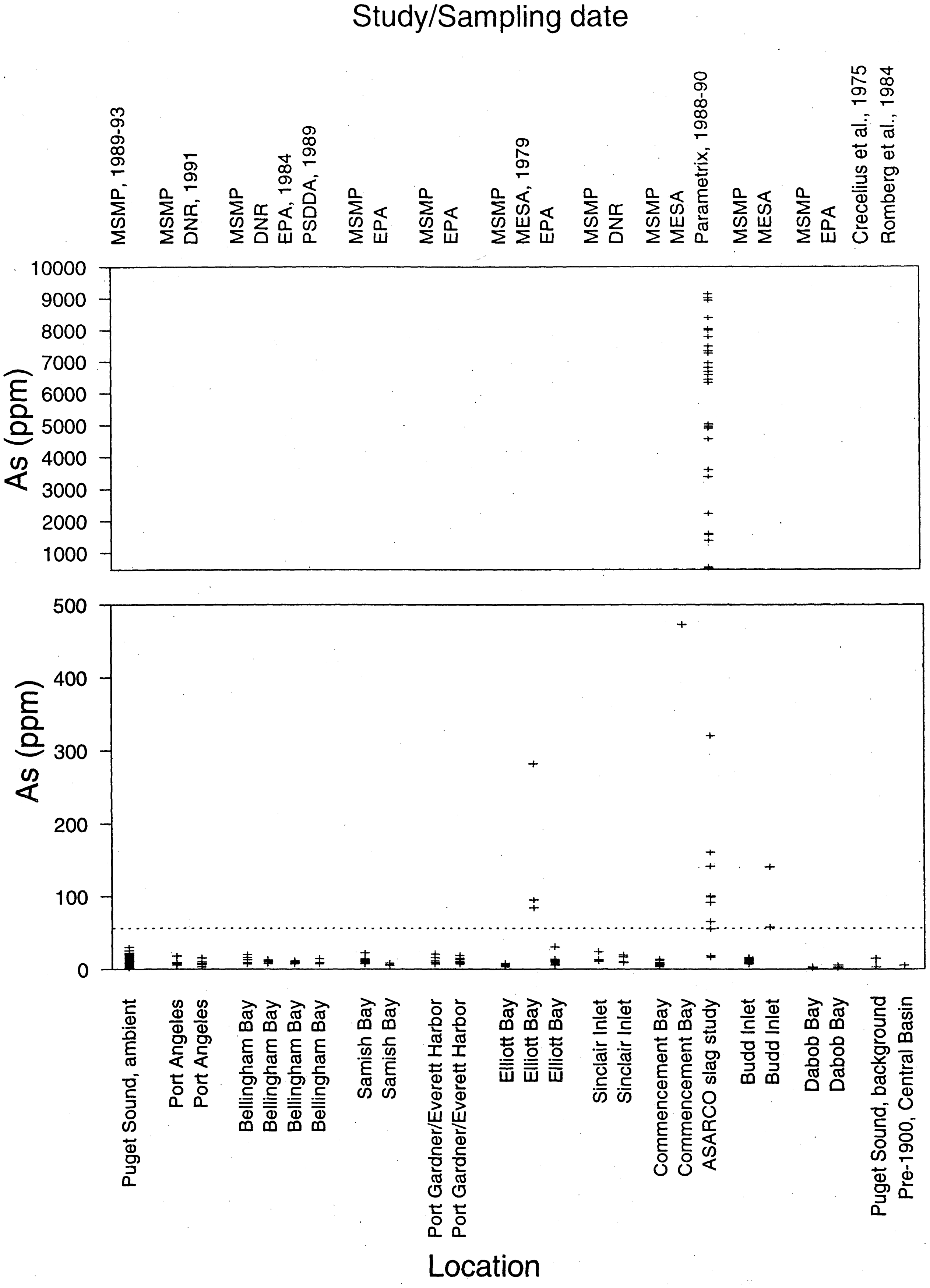


Figure 16. Arsenic in Puget Sound reported by various studies. See text for explanation of studies. Dotted line represents the sediment quality standard.

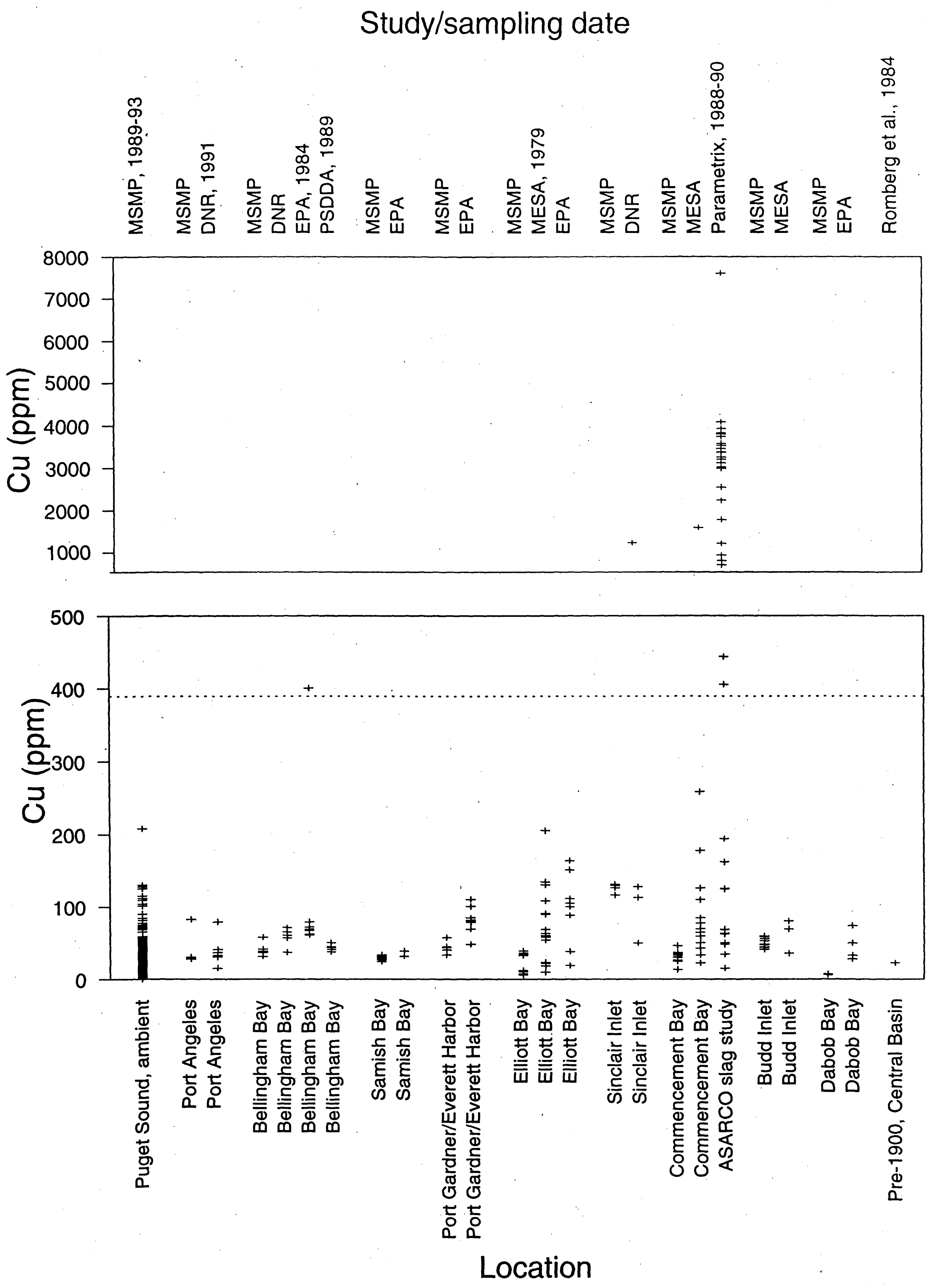


Figure 17. Copper in Puget Sound reported by various studies. See text for explanation of studies. Dotted line represents the sediment quality standard.

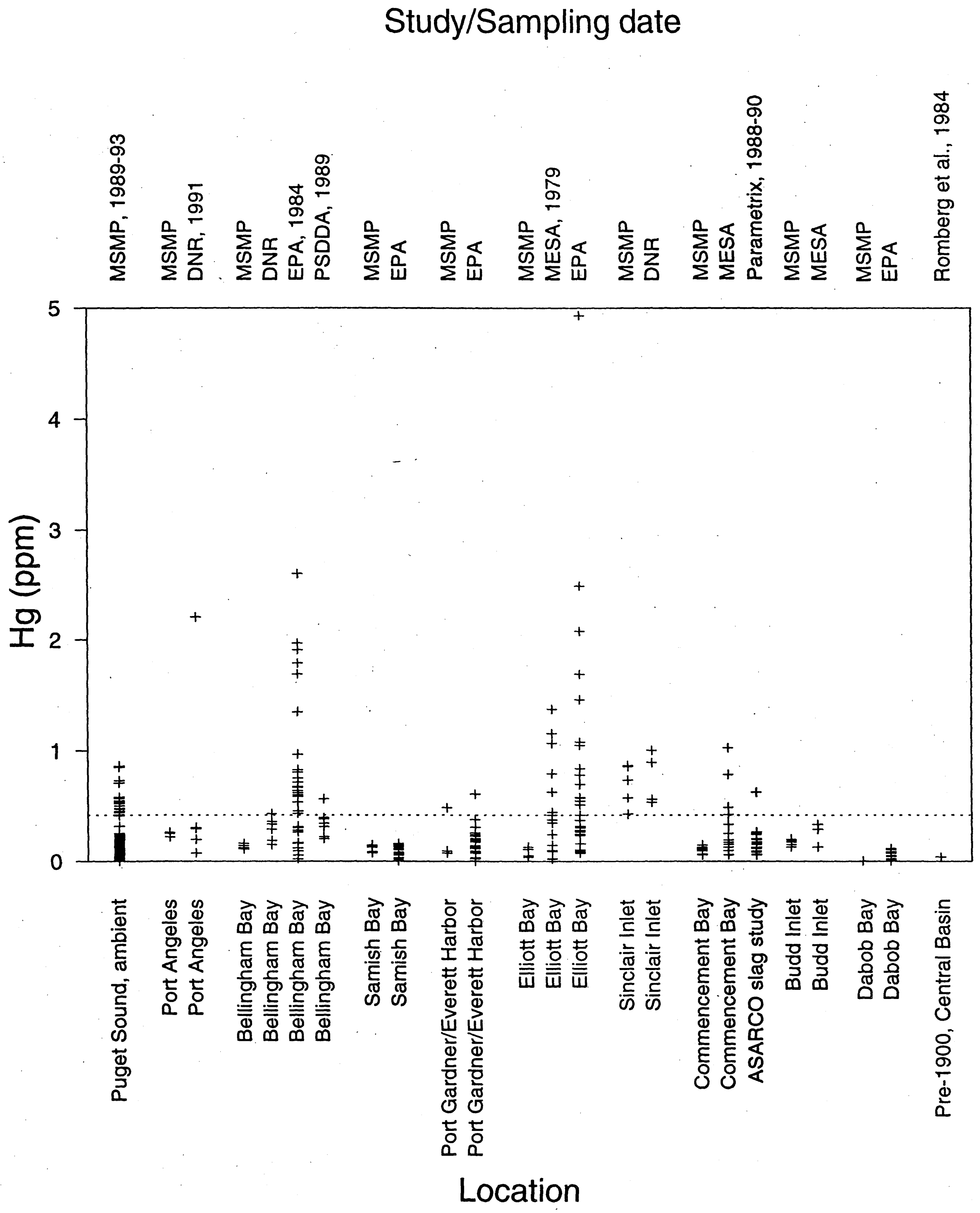


Figure 18. Mercury in Puget Sound reported by various studies. See text for explanation of studies. Dotted line represents the sediment quality standard.

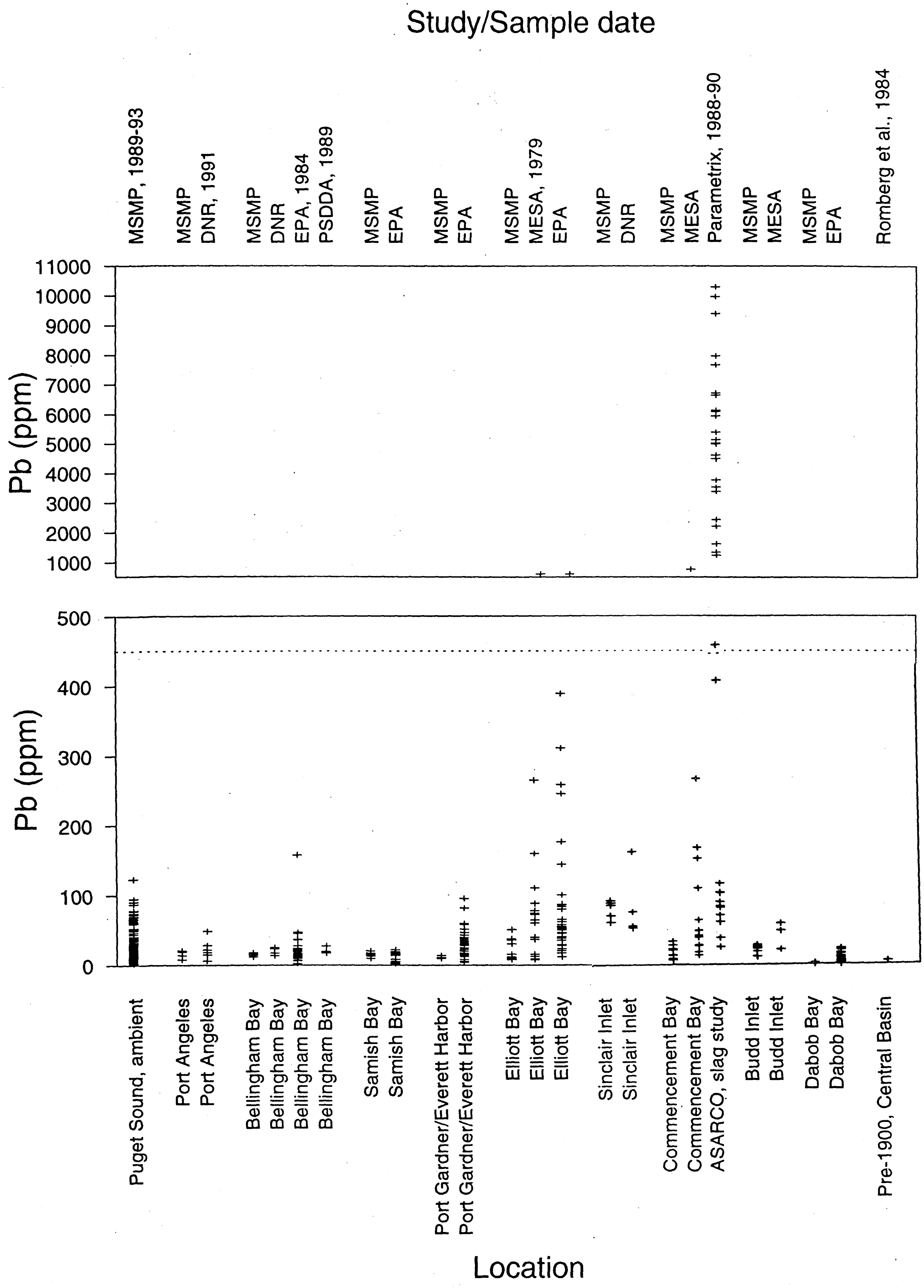


Figure 19. Lead in Puget Sound reported by various studies. See text for explanation of studies. Dotted line represents the sediment quality standard.

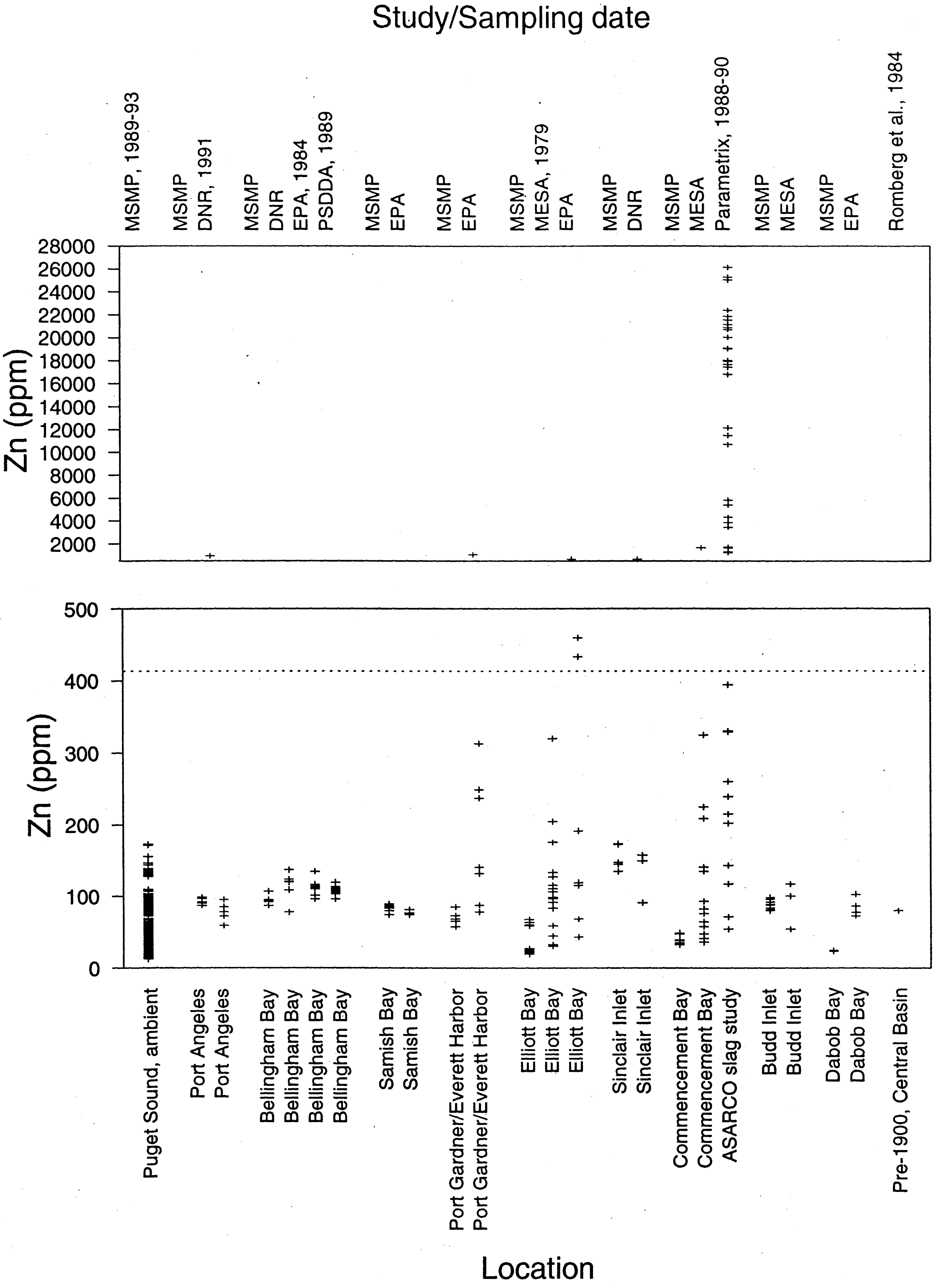


Figure 20. Zinc in Puget Sound reported by various studies. See text for explanation of studies. Dotted line represents the sediment quality standard.

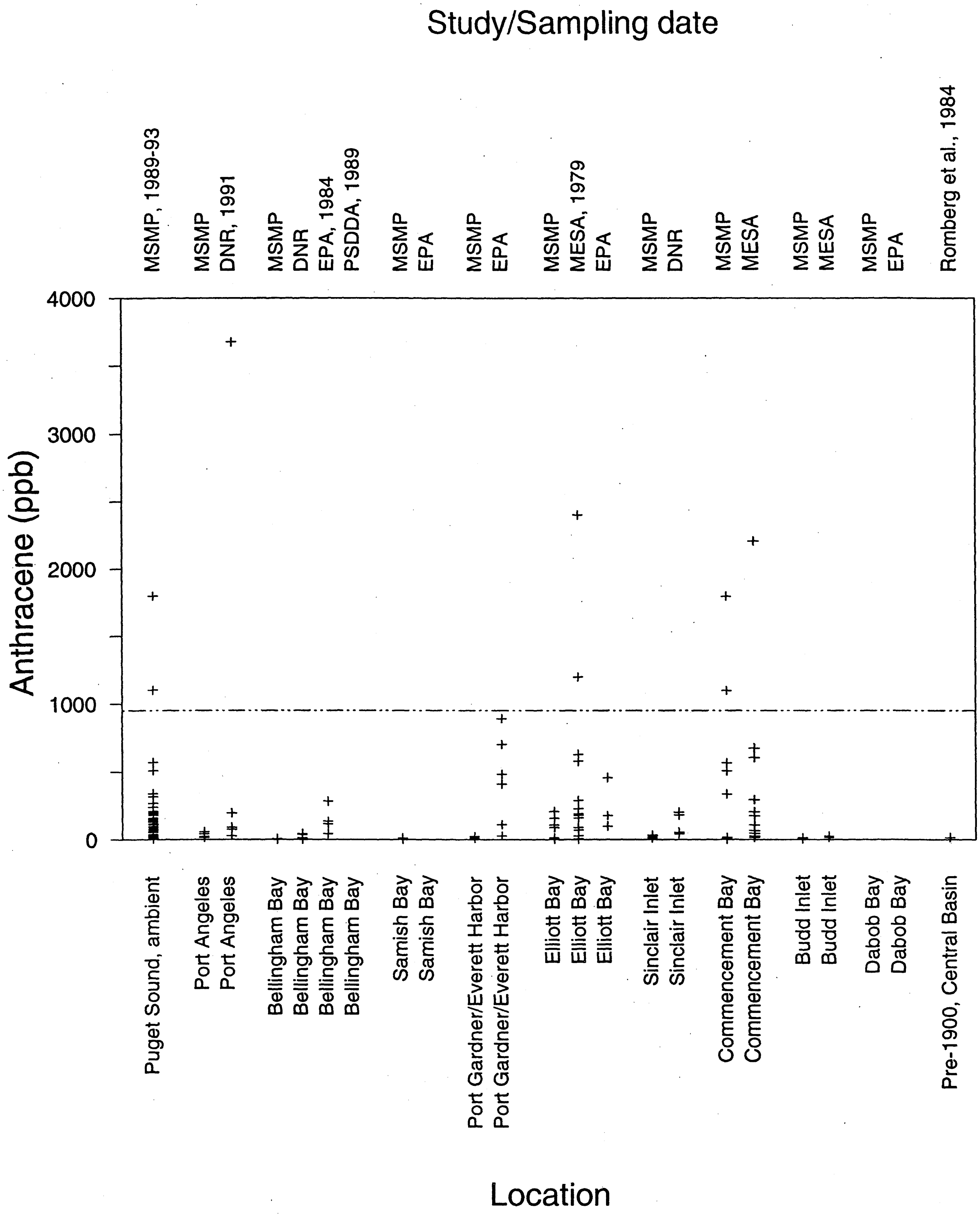


Figure 21. Anthracene in Puget Sound reported by various studies. See text for explanation of studies. Dotted line represents the lowest AET.

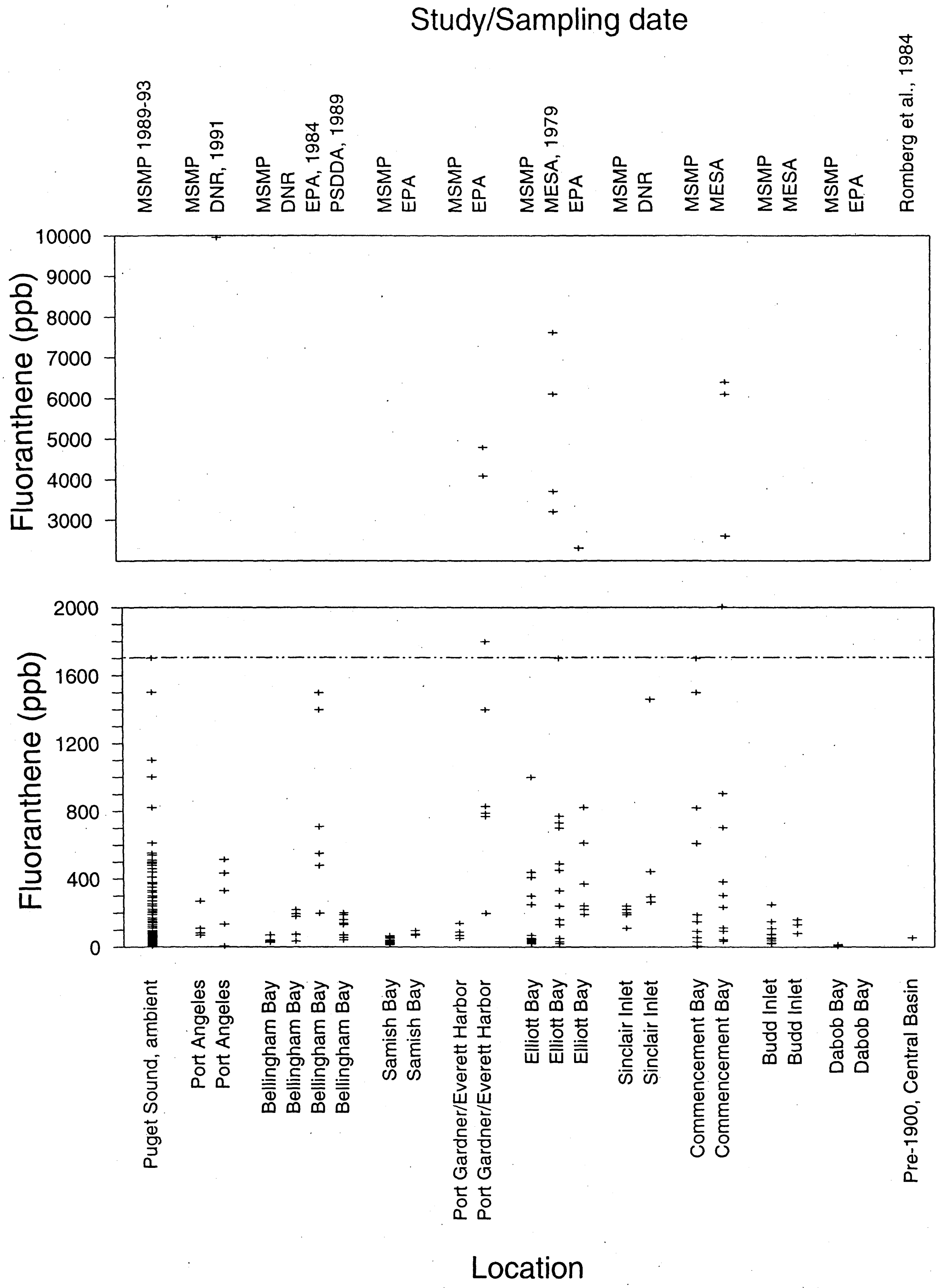


Figure 22. Fluoranthene in Puget Sound reported by various studies. See text for explanation of studies. Dotted line represents the lowest AET.

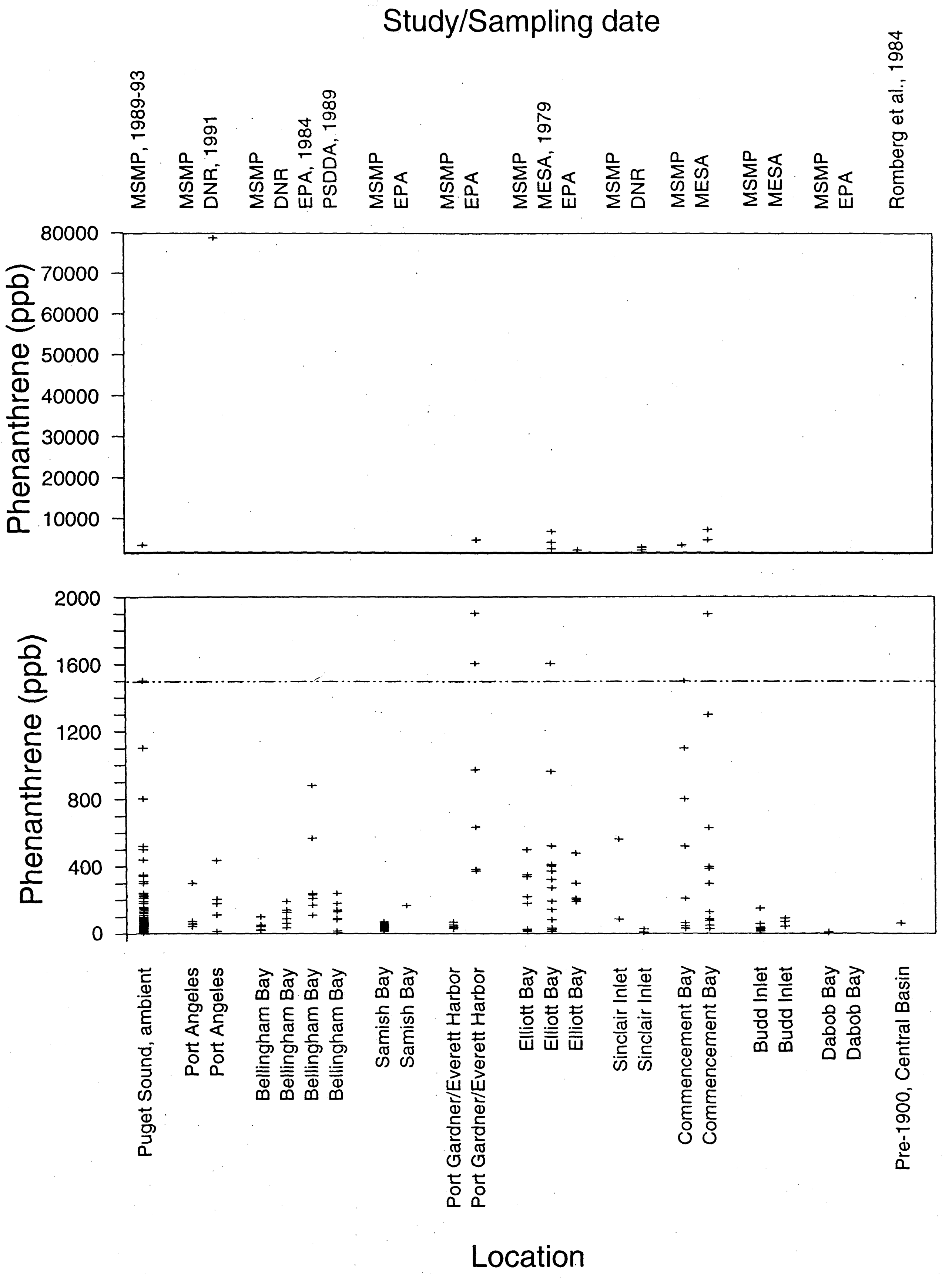


Figure 23. Phenanthrene in Puget Sound reported by various studies. See text for explanation of studies. Dotted line represents the lowest AET.

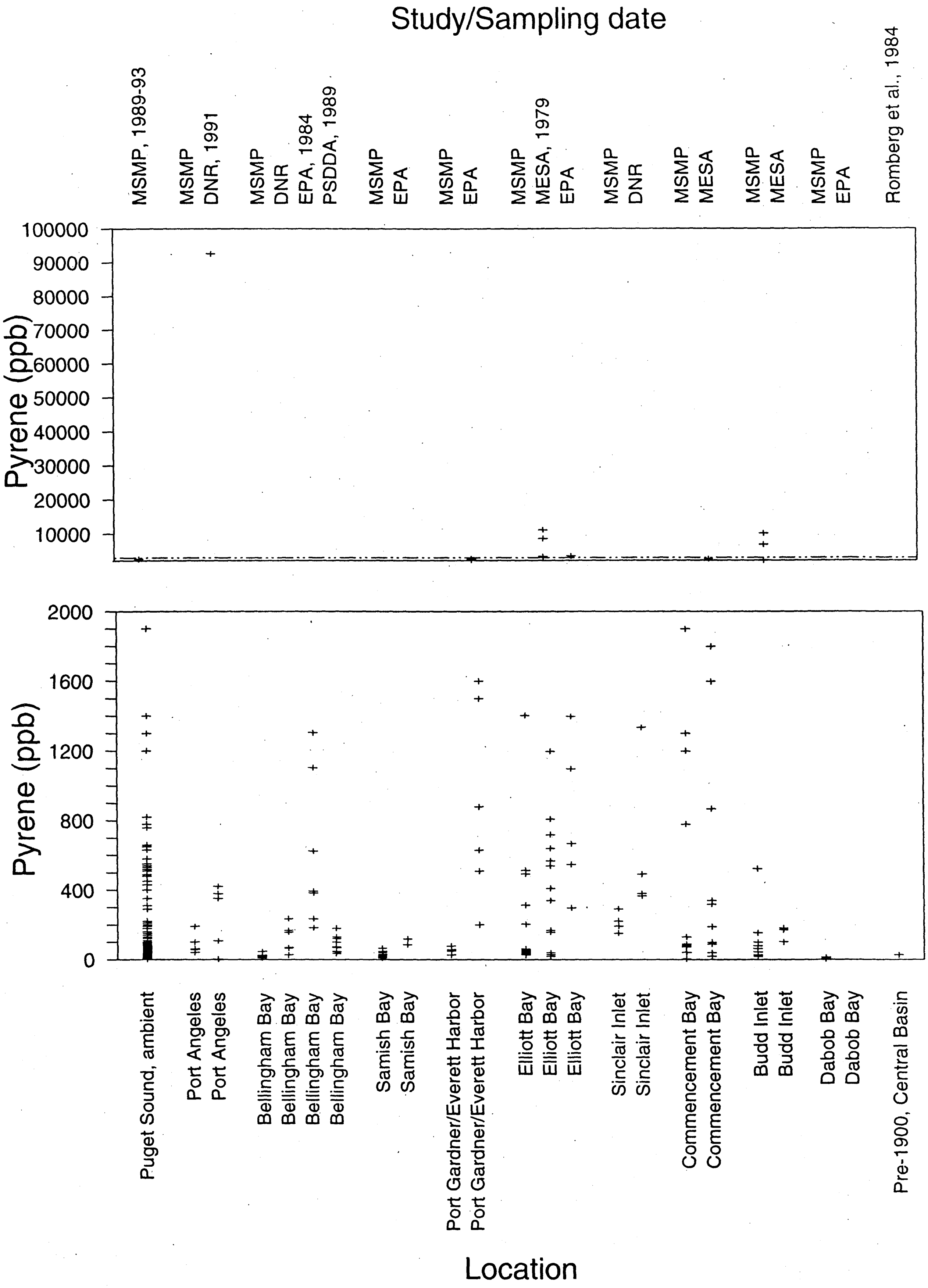


Figure 24. Pyrene in Puget Sound reported by various studies. See text for explanation of studies. Dotted line represents the lowest AET.

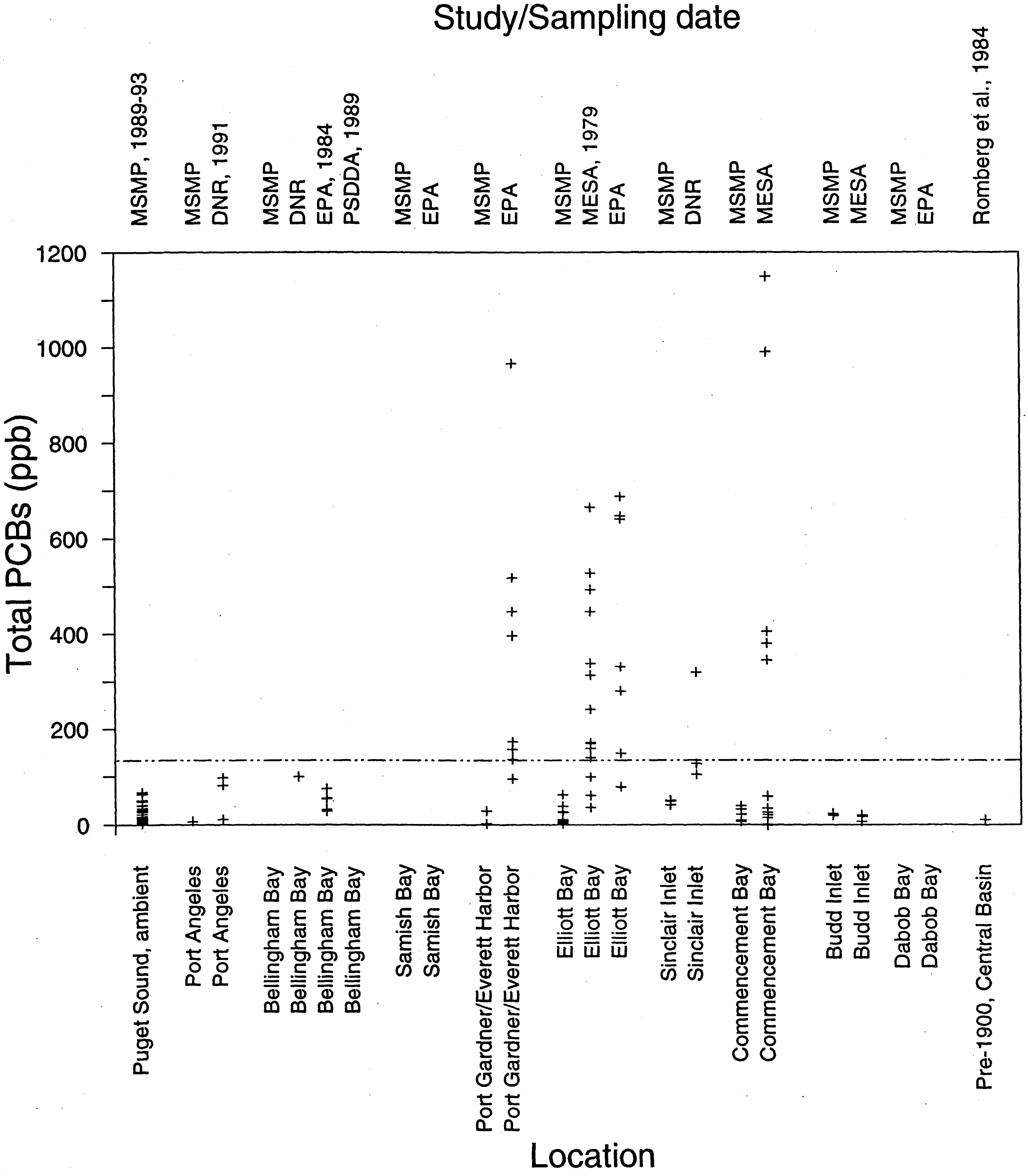


Figure 25. Total PCBs in Puget Sound reported by various studies. See text for explanation of studies. Dotted line represents the lowest AET.

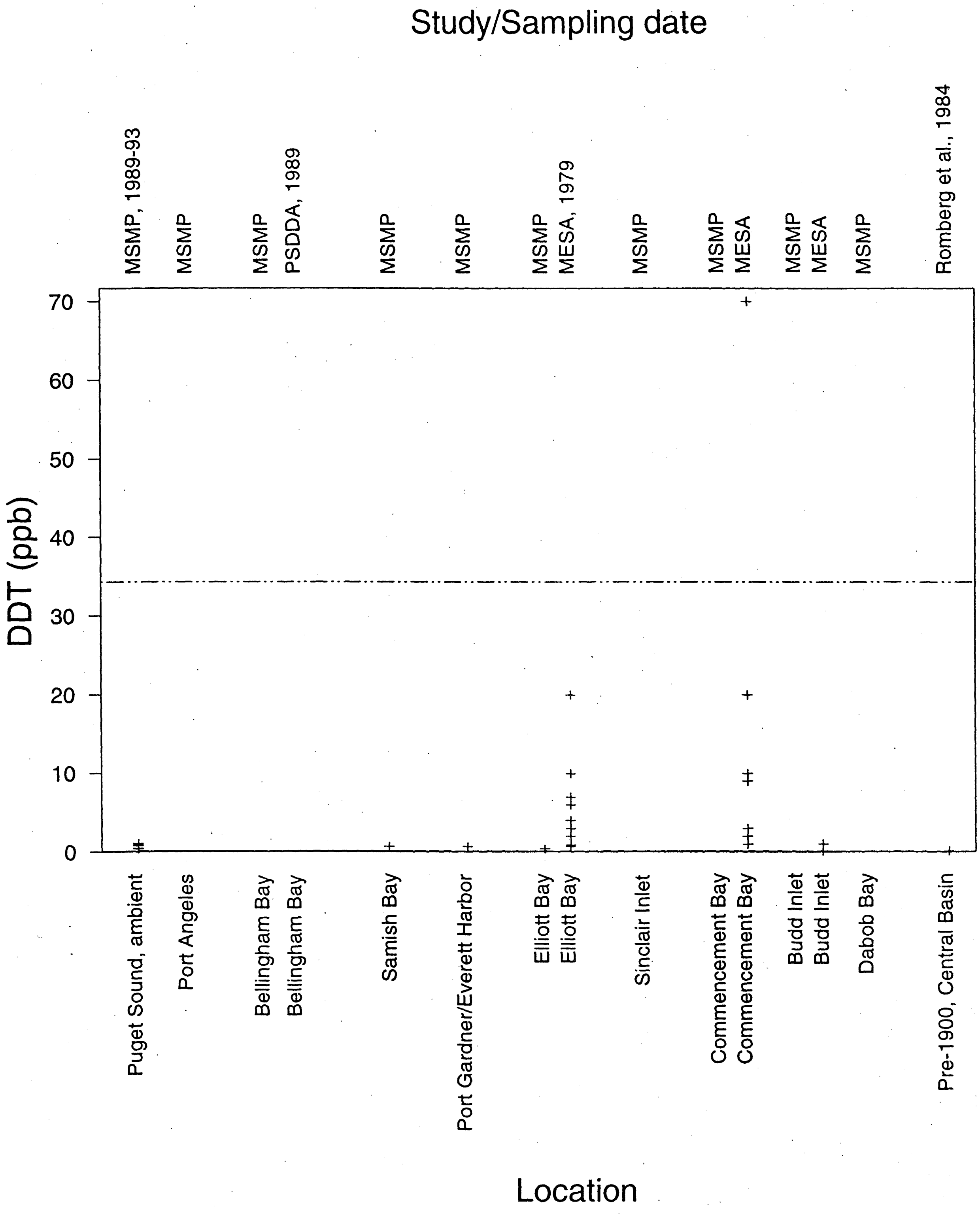


Figure 26. DDT in Puget Sound reported by various studies. See text for explanation of studies. Dotted line represents the lowest AET.

appear to be confined to focus areas near sources of pollution. The studies used in the comparison have focused on specific areas of concern, often encompassing "hot spots" of chemical contamination. MSMP stations in urban bays, however, were located away from the immediate vicinity of known sources of pollution. Only in three instances (anthracene, phenanthrene, and pyrene in Commencement Bay, Figures 21, 23 and 24) were MSMP values within the range of significant contaminant concentrations. Except for Dabob Bay, most of the stations sampled by the MSMP had contaminant concentrations above Puget Sound pre-industrialization levels.

Bioassay

Mean survival of *Rhepoxynius abronius* was significantly ($p<0.05$) lower than control survival in 22 (35%) test sediments collected in 1992, and in 18 (29%) test sediments collected in 1993 (Table 10). In 1991, mean survival in three test sediments was significantly lower than controls ($p<0.01$), but results from only six sediments were tested. These six sediments exhibited elevated amphipod mortality. In 1989, mean survival was significantly lower than controls in four (9%) test sediments.

During the 1990 testing, unusually high mortality was found in numerous samples (Table 10). The amphipods in these tests were exceptionally sensitive to test sediments, as suggested by the low LC_{50} values exhibited in experiments amended with cadmium chloride. 96-hour LC_{50} values ranged from 0.30 to 0.39 mg/l $CdCl_2$, lower than previously observed values in the range of 0.75 to 2.5 mg/l (Striplin *et al.*, 1991). Therefore, results from the 1990 test should not be used for comparison, as amphipod survival may have been affected by physiological or experimental adverse conditions. No statistical tests were conducted on these data.

Stations with significant mortality included both stations with relatively clean sediments (*e.g.*, Station 1, Semiahmoo Bay; Station 11R, Discovery Bay; Station 14, Hood Canal at Bangor; Station 207R, West Beach) and extensively contaminated urban sites (*e.g.*, Station 34, Sinclair Inlet; Station 35, Dyes Inlet). There was no consistency among stations exhibiting mean mortality >24.5% (<15.1 mean survival), threshold above which sediments are clearly toxic according to guidelines of Mearns *et al.* (1986). Only sediments from Port Townsend (Station 12) and Port Susan (Station 20) were found to exhibit mortality above 24.5% in more than one year (1990 data excluded). Furthermore, there was little across-year agreement among the rankings of stations arranged from high to low survival (Kendall's coefficient of concordance, W=0.39 with and without 1990 data).

Because high content of silt and clays in sediments may decrease amphipod survival, bioassay results were overlaid on a model (DeWitt *et al.*, 1988) that accounts for the effects of grain size on *Rhepoxynius abronius* mortality (Figure 27). Using this model, all mortality encountered in the test sediments (with seven possible exceptions) could be explained on the basis of grain size effects, and could not be distinguished from sediment toxicity. When the range of MSMP data for selected contaminants was compared to published amphipod AET levels (Read *et al.*, 1989), contaminant levels in sediments were clearly below values where mortality on the test amphipod would be expected (Figure 28).

Table 10. Survival of *Rhepoxynius abronius* in test sediments from MSMP stations after 10-day acute exposure. Mean number of amphipods surviving ± Standard Deviation (Rank). Asterisks indicate significant lower mean survival than controls. Blanks denote station not sampled in a given year. Stations are listed in rank order, from low to high survival, by the first year in which the sediment was tested.

	Year				
Treatment	1989	1990[1]	1991[2]	1992	1993
35/1, Dyes Inlet	11.2 ± 6.9* (1)	12.6 ± 2.7 (9)	19.0 ± 1.2 (15)	17.0 ± 0.7* (12)	18.2 ± 1.5 (17)
35/4, Dyes Inlet		12.0 ± 1.9 (7)	19.2 ± 1.1 (16)	17.2 ± 1.3 (13)	17.2 ± 2.2* (12)
35/3, Dyes Inlet		13.6 ± 1.7 (13)	18.4 ± 1.7 (11)	17.0 ± 2.0* (12)	18.2 ± 1.1 (17)
35/2, Dyes Inlet		13.8 ± 2.2 (14)	19.4 ± 0.9 (17)	16.0 ± 1.4* (8)	18.0 ± 1.9 (16)
24R, East Central Basin	12.4 ± 7.0 (2)			17.4 ± 1.1* (14)	
20, Port Susan	14.6 ± 6.9 (3)	11.4 ± 1.9 (5)	18.8 ± 1.8 (14)	17.0 ± 1.2* (12)	11.4 ± 2.1* (1)
38/1, Pt. Pully	15.2 ± 4.9 (4)	14.2 ± 2.8 (16)	18.0 ± 0.7 (9)	17.8 ± 1.1 (16)	17.2 ± 1.3 (12)
38/4, Pt. Pully		14.0 ± 2.3 (15)	19.8 ± 0.4 (19)	16.0 ± 1.9* (8)	
38/3, Pt. Pully		14.6 ± 2.9 (18)	19.8 ± 0.4 (19)	17.8 ± 2.3 (16)	18.2 ± 0.8 (17)
38/2, Pt. Pully		15.0 ± 2.3 (19)	19.6 ± 0.5 (18)	16.4 ± 1.1* (10)	16.0 ± 2.2* (8)
2R, Cherry Pt.	16.6 ± 2.3 (5)		15.0 ± 5.4[a] (3)		
30, Eagle Harbor	16.8 ± 4.0 (6)	16.0 ± 1.6 (23)	18.4 ± 1.3 (11)	19.4 ± 0.9 (25)	19.6 ± 0.5 (25)
11R, Discovery Bay	17.2 ± 0.8* (7)		19.2 ± 0.8 (16)		
6, Anacortes (dropped after 1989)	17.4 ± 1.3* (8)				
14, Hood Canal, Bangor	17.4 ± 2.1* (8)	14.0 ± 1.0 (15)	18.8 ± 1.3 (14)	15.6 ± 3.0* (6)	17.4 ± 3.2 (13)
3, Strait of Georgia (N of Patos Is.)	17.6 ± 2.2 (9)	17.0 ± 1.9 (28)	18.4 ± 1.5 (11)	16.4 ± 2.1* (10)	16.4 ± 4.0* (9)
34, Sinclair Inlet	17.8 ± 1.5 (10)	14.6 ± 2.7 (18)	17.0 ± 1.0[a]* (6)	16.8 ± 1.5* (11)	17.4 ± 3.6 (13)
8, Port Angeles	18.0 ± 1.2 (11)	18.2 ± 1.9 (32)	18.0 ± 0.7 (9)	18.4 ± 1.5 (19)	18.2 ± 0.4 (17)
44/1, East Anderson Island	18.0 ± 1.2 (11)	17.0 ± 1.4 (28)	19.2 ± 1.1 (16)	18.6 ± 1.7 (21)	19.0 ± 0.7 (22)
44/4, East Anderson Island		15.8 ± 1.9 (22)	19.8 ± 0.4 (19)	19.0 ± 1.2 (23)	17.6 ± 0.5* (14)
44/3, East Anderson Island		16.6 ± 2.1 (27)	19.4 ± 0.5 (17)	17.2 ± 2.4 (13)	19.2 ± 1.3 (23)
44/2, East Anderson Island		17.2 ± 2.2 (29)	19.8 ± 0.4 (19)	18.4 ± 0.5 (19)	18.2 ± 0.8* (17)
10R, Dungeness Bay	18.4 ± 1.1 (12)		18.8 ± 0.8 (14)		
15, Dabob Bay	18.4 ± 1.3 (12)	16.8 ± 1.6 (27)	19.0 ± 1.2 (15)	19.2 ± 1.3 (24)	19.2 ± 0.8 (23)
26, Central Basin	18.4 ± 1.7 (12)	16.4 ± 1.5 (25)	18.4 ± 0.5 (11)	18.2 ± 1.1 (18)	18.0 ± 2.0 (16)

Table 10. Continued.

	Year				
Treatment	1989	1990^1	1991^2	1992	1993
29, Shilshole	18.4 ± 1.5 (12)	16.2 ± 1.9 (24)	18.4 ± 1.1 (11)	17.8 ± 1.5 (16)	18.6 ± 0.5 (20)
33, Elliott Bay	18.4 ± 0.9 (12)	16.2 ± 1.5 (24)	18.6 ± 0.9 (12)	18.8 ± 0.8 (22)	18.6 ± 1.1 (20)
12, Port Townsend Bay	18.6 ± 1.3 (13)	12.8 ± 2.9 (10)	17.8 ± 2.5 (8)	13.6 ± 1.1* (1)	13.6 ± 2.3* (2)
13R, North Hood Canal	18.6 ± 1.3 (13)		18.2 ± 0.8 (10)		
41, Blair/Sitcum Waterways (Comm. Bay)	18.6 ± 0.9 (13)	16.2 ± 1.8 (24)	18.4 ± 1.1 (11)	16.2 ± 1.3* (9)	19.6 ± 0.5 (25)
21, Port Gardner	18.8 ± 1.3 (14)	16.4 ± 1.5 (25)	15.4 ± 4.3^a (4)	17.8 ± 1.3* (16)	18.8 ± 0.4 (21)
40, City Waterway (Commencement Bay)	18.8 ± 0.8 (14)	17.8 ± 1.8 (30)	19.2 ± 0.8 (16)	17.6 ± 2.4 (15)	18.5 ± 1.3 (19)
45, Devil's Head	18.8 ± 0.8 (14)	15.8 ± 3.3 (22)	19.4 ± 0.9 (17)	18.0 ± 1.4 (17)	17.4 ± 2.1* (13)
4, Bellingham Bay	19.0 ± 1.7 (15)	13.0 ± 2.8 (11)	18.8 ± 0.8 (14)	17.8 ± 1.8 (16)	17.6 ± 1.8 (14)
19, Saratoga Passage	19.0 ± 1.0 (15)	11.2 ± 1.3 (4)	18.0 ± 1.9 (9)	13.6 ± 7.8* (1)	16.8 ± 2.3 (10)
49, Inner Budd Inlet	19.0 ± 1.2 (15)	11.8 ± 4.1 (6)	19.8 ± 0.4 (19)	15.4 ± 3.0* (5)	18.8 ± 1.8 (21)
5/1, Samish Bay	19.2 ± 0.4 (16)	15.2 ± 1.6 (20)	19.0 ± 1.7 (15)	18.5 ± 1.3 (20)	19.4 ± 1.7 (24)
5/4, Samish Bay		14.2 ± 1.8 (16)	19.0 ± 2.2 (15)	18.2 ± 0.4 (18)	17.0 ± 2.0 (11)
5/3, Samish Bay		14.6 ± 2.1 (18)	19.4 ± 0.9 (17)	18.2 ± 2.2 (18)	17.0 ± 2.7 (11)
5/2, Samish Bay		16.0 ± 2.9 (23)	19.6 ± 0.5 (18)	17.4 ± 1.3* (14)	16.0 ± 3.4* (8)
25R, West Central Basin	19.2 ± 1.1 (16)			20.0 ± 0.0 (28)	
36R, Brace Point	19.2 ± 1.1 (16)			19.0 ± 0.7 (23)	
48, Outer Budd Inlet	19.2 ± 1.1 (16)	13.8 ± 1.5 (14)	19.2 ± 0.4 (16)	15.2 ± 2.6* (4)	17.4 ± 1.5* (13)
1, Semihamoo Bay, Blaine	19.4 ± 0.5 (17)	14.4 ± 1.3 (17)	16.8 ± 4.4^a (5)	16.4 ± 1.1* (10)	15.6 ± 2.3* (6)
17, South Hood Canal	19.4 ± 0.9 (17)	13.0 ± 3.1 (11)	18.4 ± 0.9 (11)	15.0 ± 2.3* (3)	16.0 ± 2.5* (8)
23R, East Central Basin (S of Picnic Pt.)	19.4 ± 0.9 (17)			19.8 ± 0.4 (27)	
27R, Richmond Beach	19.4 ± 0.9 (17)			19.0 ± 1.0 (23)	
46R, West Nisqually (Johonson Pt.)	19.4 ± 0.9 (17)	18.0 ± 1.6 (31)			18.0 ± 1.9 (16)
18, Oak Harbor	19.6 ± 0.5 (18)	12.4 ± 2.9 (8)	14.0 ± 2.8^a* (2)	18.0 ± 1.6 (17)	19.0 ± 0.0 (22)
22, Mukilteo	19.6 ± 0.5 (18)	17.0 ± 0.7 (28)	19.0 ± 1.0 (15)	19.4 ± 0.5 (25)	19.4 ± 0.9 (24)
32/1, Magnolia Bluff	19.6 ± 0.9 (18)	16.6 ± 1.8 (27)	17.6 ± 2.1 (7)	18.6 ± 1.5 (21)	19.4 ± 0.5 (24)
32/4, Magnolia Bluff		16.6 ± 2.6 (27)	18.0 ± 1.4 (9)	19.6 ± 0.5 (26)	19.2 ± 1.3 (23)

Table 10. Continued.

Treatment	Year 1989		1990[1]		1991[2]		1992		1993	
32/3, Magnolia Bluff			17.0 ± 3.0	(28)	18.2 ± 1.8	(10)	19.0 ± 1.0	(23)	19.8 ± 0.4	(26)
32/2, Magnolia Bluff			17.2 ± 2.6	(29)	20.0 ± 0.0	(20)	18.2 ± 1.1	(18)	19.6 ± 0.9	(25)
39, Dash Point	19.6 ± 0.5	(18)	18.6 ± 1.5	(34)	18.6 ± 0.9	(12)	19.0 ± 1.2	(23)	19.4 ± 0.5	(24)
43, Carr Inlet	19.6 ± 0.9	(18)	15.4 ± 3.6	(21)	19.0 ± 1.7	(15)	18.8 ± 1.6	(22)	20.6 ± 1.3	(29)
47, Case Inlet	19.6 ± 0.5	(18)	16.4 ± 2.2	(25)	19.4 ± 0.9	(17)	18.4 ± 0.9	(19)	15.0 ± 8.5	(4)
9R, East of Green Pt	20.0 ± 0.0	(20)			19.4 ± 0.9	(17)				
37R, North Vashon Island	20.0 ± 0.0	(20)					18.8 ± 0.4	(22)		
71, Fidalgo Bay			15.4 ± 1.5	(21)	18.4 ± 2.1	(11)	19.0 ± 0.7	(23)	19.2 ± 0.8	(23)
70, Oakland Bay, Shelton			16.4 ± 1.1	(25)	19.0 ± 1.4	(15)	15.8 ± 1.3*	(7)	17.0 ± 2.0*	(11)
69, Port Madison			17.0 ± 1.0	(28)	19.8 ± 0.4	(19)	18.2 ± 1.1	(18)	18.0 ± 0.7	(16)
106R, Mid Budd Inlet			9.8 ± 4.7	(1)					14.6 ± 2.3*	(3)
102R, Inner Totten Inlet			10.0 ± 3.2	(2)					15.4 ± 3.8*	(5)
104R, Inner Eld Inlet			10.0 ± 2.9	(2)					19.2 ± 1.1	(23)
110R, Inner Case Inlet			10.8 ± 2.6	(3)					17.8 ± 1.1*	(15)
109R, Henderson Inlet			12.0 ± 1.9	(7)					15.8 ± 2.7	(7)
105R, Outer Eld Inlet			12.8 ± 1.3	(10)					17.2 ± 1.3*	(12)
114R, Henderson Bay			13.4 ± 2.3	(12)					19.4 ± 0.5	(24)
101R, Oakland Bay, North			14.2 ± 2.2	(16)					18.2 ± 2.8	(17)
115R, Outer Filucy Bay			14.4 ± 1.8	(17)					19.0 ± 1.4	(22)
111R, Mid Case Inlet			15.2 ± 1.3	(20)					18.4 ± 1.1	(18)
112R, Nisqually Delta			17.2 ± 1.8	(29)					19.0 ± 1.4	(22)
113R, Willochet Bay			17.2 ± 1.8	(29)					19.2 ± 0.4	(23)
103R, Mid Totten Inlet			18.2 ± 1.3	(32)					18.2 ± 0.4*	(17)
207R, West Beach, Whidbey Island					13.4 ± 5.3[a]*	(1)				
202R, Point Roberts					17.8 ± 1.9	(8)				
203R, Bellingham Bay					17.8 ± 1.8	(8)				
206R, Friday Harbor					18.4 ± 2.3	(11)				

Table 10. Concluded.

Treatment	Year				
	1989	1990[1]	1991[2]	1992	1993
208R, Sequim Bay			18.6 ± 1.7 (12)		
205R, NW Blakely Island			18.8 ± 1.5 (13)		
201R, Strait of Georgia, Roberts Bank			19.2 ± 0.4 (16)		
204R, East Sound			19.2 ± 0.8 (16)		
209R, Skagit Bay			20.0 ± 0.0 (20)		
304R, Hood Canal, Tekiu Point				14.8 ± 3.7* (2)	
307R, Holmes Harbor				15.4 ± 1.1* (5)	
303R, Quartermaster Harbor				17.6 ± 1.5 (15)	
308R, Liberty Bay				17.6 ± 1.5 (15)	
306R, Seahurst East Bay				17.8 ± 2.2 (16)	
305R, Hood Canal, Outer Lynch Cove				18.6 ± 0.5 (21)	
302R, Oak Harbor				18.8 ± 0.8 (22)	
301R, Useless Bay				19.6 ± 0.5 (26)	
West Beach (Control 1)	19.8 ± 0.4	18.8 ± 1.6	19.8 ± 0.4	19.4 ± 1.2	20.4 ± 0.5
West Beach (Control 2)	20.0 ± 0.0	19.4 ± 0.5	18.6 ± 0.9	18.4 ± 0.8	20.0 ± 0.7
West Beach (Control 3)	19.8 ± 0.4	19.6 ± 0.5	19.8 ± 0.4	19.8 ± 0.4	19.2 ± 1.1
West Beach (Control 4)		18.2 ± 1.6		20.2 ± 0.4	

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[1] Questionable results. No statistical tests conducted in 1990.

[2] Statistical tests conducted only on means marked with the superscript *a*.

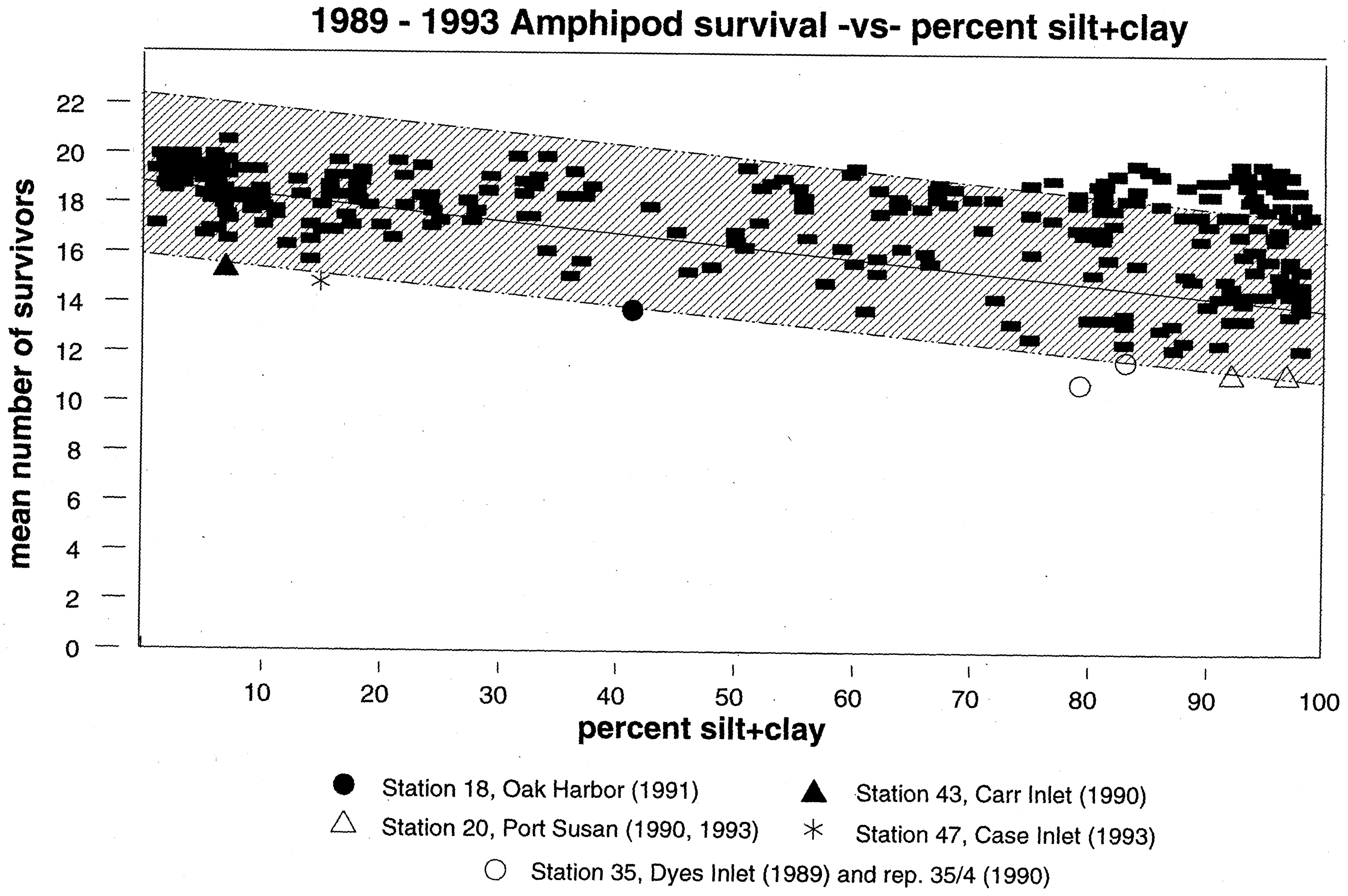

Figure 27. Amphipod survival as a function of percent silt and clay in sediments from MSMP stations. Points are mean survival (N=5) in sediments from each station. Results are overlaid on a model (regression line and 95% prediction limits) that accounts for the effects of grain size on *Rhepoxynius abronius*. Sediments below the lower 95% prediction limit indicate mortality that can be attributed to toxic effects.

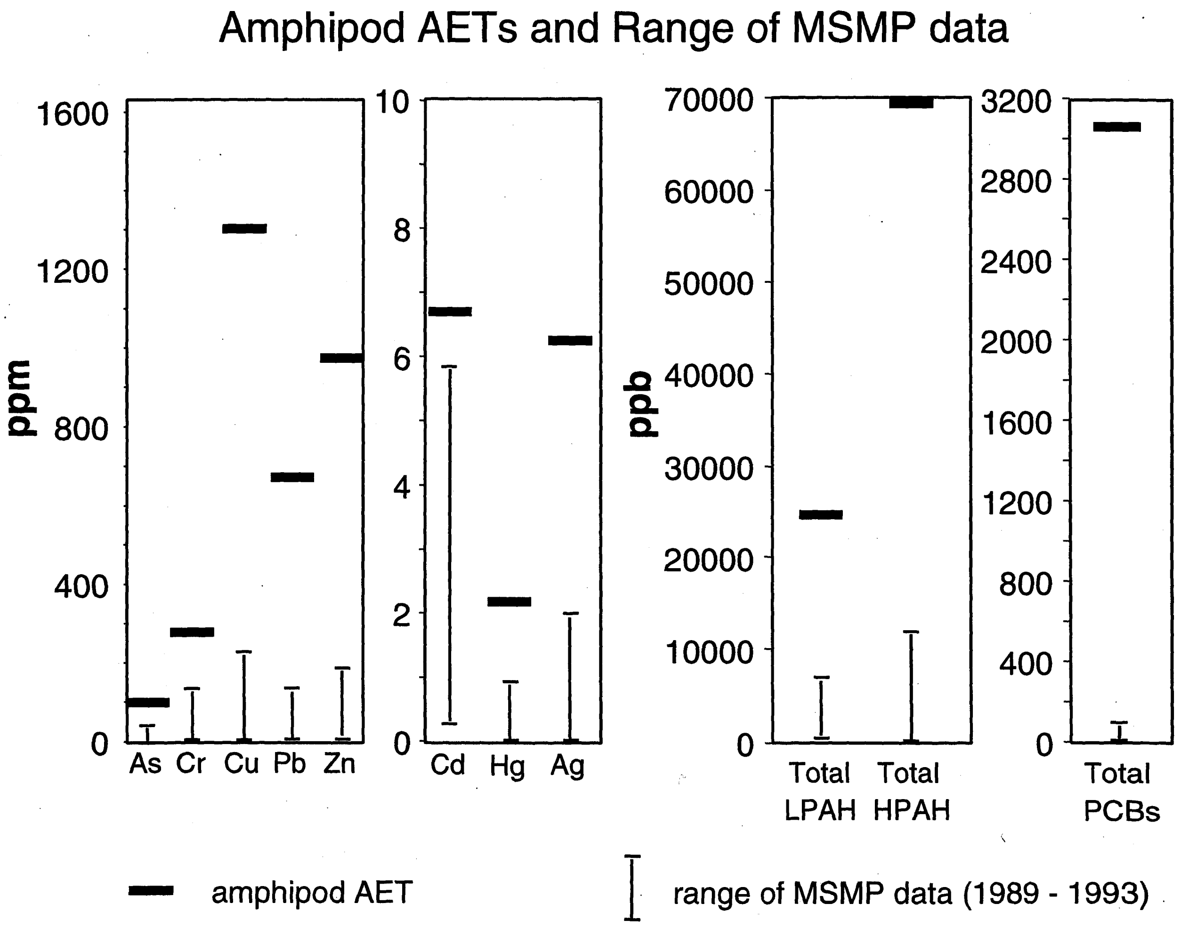

Figure 28. Range of MSMP data compared to published amphipod Apparent Effects Threshold (AET) values.

Discussion

Chemistry

Spatial Trends and Sources

Sediment chemistry results indicated that contamination at stations monitored by the MSMP was generally low near detection limits, except at specific stations closely associated with urban or industrial centers, such as Sinclair Inlet, Dyes Inlet, Eagle Harbor, Elliott Bay, and Commencement Bay. Stations at these urban bays exhibited a variety of contaminants with concentrations above the general range of Puget Sound sediments, although, with some exceptions, below the Washington State Sediment Quality Standards (SQS) or below Apparent Effects Thresholds (AET) expressed as dry weight.

The MSMP was specifically not designed to locate, sample, or evaluate the areas of highest contaminant concentrations in Puget Sound. Most stations were located away from known sources of pollution. Therefore, the range of contaminant concentrations was generally low and cannot be extrapolated to represent conditions in urban bays. This becomes clear as data collected from intensive studies in Puget Sound were compared with data collected by the MSMP (Figures 16-26). These studies have focused on specific areas of concern where chemical contamination is known to be substantial. The high contaminant concentrations detected by these studies contrast with the generally low concentrations found at the MSMP stations and illustrate the spatial heterogeneity of pollutants in Puget Sound sediments.

Notwithstanding the overall low range of contaminant concentrations, some values did exceed sediment quality criteria as defined by SQS or AETs. Comparisons against these criteria allowed the identification of monitoring sites with significant chemical contamination, above levels usually associated with adverse biological effects in Puget Sound. Mercury contamination, for example, was substantial in sediments of Sinclair Inlet and Dyes Inlet (Figure 6), with average concentrations of 0.70 mg/kg and 0.52 mg/kg dry weight, respectively. Sources there are likely from antifouling paints used in the Puget Sound Naval Shipyard and from a military depot. Mercury contamination, however, should not be linked solely with Sinclair and Dyes Inlets. Much higher concentrations of mercury in the range 2-5 mg/kg have been identified in Bellingham Bay and Elliott Bay (Figure 18). A source for the high Bellingham Bay concentrations is waste discharge from a mercury-cell chloralkali plant that has operated there since the 1960s (Crecelius *et al.*, 1975).

It should be emphasized again that the MSMP was not designed to provide bay-wide characterizations. Instead, stations were selected to delineate contamination in background sediments away from known sources of pollution and to monitor these sites over time. The degree of sediment contamination at MSMP monitoring stations depends partially on proximity to potential sources. For example, had a station been located near the historical ASARCO lead-copper smelter in Tacoma, arsenic contamination would have probably been identified as elevated in sediments of Commencement Bay. The smelter discharged significant quantities of arsenic and other heavy metals into Puget Sound during approximately 100 years of operation (Crecelius *et al.*, 1975). Arsenic concentrations near the smelter are three orders of magnitude higher than the average 6.5 mg/kg measured at Station 40 in Commencement Bay (Figure 16).

The distribution of heavy metals in estuaries is controlled, among other factors, by physical and geochemical processes. Thus, average concentrations of some metals in Puget Sound sediments can be traced back to natural and anthropogenic sources based, for example, on knowledge of pathways of transport (Crecelius *et al.*, 1975). The occurrence of measurable concentrations of trace metals and a few other contaminants (above ER-L guidelines, Table 9) in sediments of the deep main basin of Puget Sound, such as those at Point Pully (Station 38) and Central Basin (Station 26), may be explained by water circulation and turbulent mixing. A major likely source of contaminants in deep Puget Sound sediments is the METRO sewage outfall off West Point. Crecelius *et al.* (1975) suggest that strong tidal mixing in the area of discharge dilutes contaminants and prevents the deposition of elevated concentrations in nearby sediments. The low concentrations of heavy metals detected in sediments of Shilshole (Station 29), immediately north of the outfall, support this view. However, bottom waters near West Point have a net flow to the south, which probably explains the higher accumulation of arsenic, copper, lead, and mercury in sediments of Point Pully relative to Shilshole or Central Basin stations (see Table 9). Likewise, the occurrence of mercury at an average concentration of 0.35 mg/kg in Quartermaster Harbor (Station 303R) is consistent with observations of airborne transport over this area of dust particles rich in mercury. Emissions from the ASARCO plant appear to have been the origin of these particles (Crecelius *et al.*, 1975).

The distribution of many metals in Puget Sound sediments is also linked to the input of particulate matter transported by rivers. For example, a high average chromium concentration of 107 mg/kg in sediments of Port Susan (Station 20) points to natural, fluvial sources. Chromium concentrations in sediment samples recently collected in north Puget Sound (Dept. of Ecology, unpublished data) were strongly correlated with aluminum, which is a signal of a natural distribution for this metal in Puget Sound. Similarly, arsenic concentrations at most stations in Puget Sound were in the range of 3-15 mg/kg, which is typical of natural conditions. Arsenic in background sediments of Puget Sound represents one third of the amount delivered by rivers, the balance accounted for by removal to the Strait of Juan de Fuca (Crecelius *et al.*, 1975).

Urbanization (*e.g.*, stormwater runoff, fossil fuel and garbage burning, oil seeps, industry byproducts and processes) is the most likely factor in the intermediate-level occurrences of PAHs and some metals. For example, highest Puget Sound values of antimony are associated with copper smelter wastes (Tetra Tech, 1991). Also, lead and zinc are common mining and industrial contaminants found throughout Puget Sound. The relative enrichment of some Puget Sound areas by these metals over the Puget Sound average may be a result of differential rates of urbanization throughout the region (Tetra Tech, 1990). Some areas may be receiving more runoff than those where contaminants are largely undetected. Therefore, stations exhibiting intermediate levels of contamination above analytical detection limits but below regulatory standards should receive particular attention in future monitoring because they may accumulate toxic chemicals over time.

Sediment Quality Guidelines

The SQS, and the AETs on which they are based, identify areas where the potential for biological effects is greatest. On the other hand, the sediment guidelines of Long and Morgan (1991) and Long *et al.* (1995) define three ranges in chemical concentrations anticipated to be rarely, occasionally, or frequently associated with biological effects. The ER-L sets contaminant thresholds that are occasionally associated with effects. Based on ER-Ls, we identified 58 stations with potential for adverse biological effects (Table 9 and Figure 15). In this report, we use ER-Ls only as an informal screening tool, useful to identify potential problem stations that may or may not show effects on our analyses of benthic community structure.

According to the guidelines, the incidence of biological effects in the ER-L range (above ER-L values but below ER-Ms) for trace metals is generally small, ranging from 11% for arsenic to 47% for zinc. For organic compounds, the incidence is higher, ranging from 18% for acenaphthylene to 75% for total DDT (Long *et al.*, 1995). Forty out of the 58 stations listed in Table 9 exclusively show metal contamination with concentrations generally near ER-L thresholds (compare Tables 9 and 5). Thus, sediments at most of these stations are expected to have a low probability of showing toxic effects. Furthermore, the incidence of effects in the ER-L range for arsenic is very low (11%), and the guidelines for nickel are not particularly accurate, as the incidence of effects associated with nickel (17%) fails to increase with increasing nickel concentrations (Long *et al.*, 1995). These data suggest that minimal effects are probably associated with nickel and with arsenic in the 8-70 mg/kg range. In fact, arsenic concentrations at MSMP stations are within, or slightly above, natural levels of 1-15 mg/kg in Puget Sound (Crecelius *et al.*, 1975). The exception is Sinclair Inlet (Station 34) where an unusually high arsenic concentration of 171 mg/kg dry weight was reported for 1995. Nickel concentrations were unusually high (100-160 mg/kg) only in sediments of Bellingham Bay (Station 203R) and Port Susan (Station 20). In comparison, nickel concentrations in northeastern estuaries as determined by the NOAA Status and Trends Program range from 10.8 to 33.2 mg/kg dry weight (Kennish, 1997, p. 376). Although nickel is commonly discharged in waste water treatment plant effluents, enhanced nickel concentrations in Bellingham Bay and Port Susan are probably associated with natural sources linked to the Nooksack and Stillaguamish Rivers.

In addition to trace metals, 18 stations had organic compounds with concentrations at or above ER-Ls. Seven of these stations (Point Pully, Samish Bay, Shilshole, Saratoga Passage, Central Basin, Oakland Bay, and Fidalgo Bay) showed infrequent organic contamination above guidelines. Pesticides, for example, were mostly undetected or were reported in concentrations at the lower limit of the ER-L range in Samish Bay (Station 5), Shilshole (Station 29), and Fidalgo Bay (Station 71). The remaining 11 stations were distributed in seven areas (ranked according to criteria in Table 9): Elliott Bay (Station 33), Central Puget Sound (Dyes Inlet Station 35, Sinclair Inlet Station 34, Eagle Harbor Station 30), Commencement Bay (Station 40 and Station 41), Strait of Juan de Fuca (Port Angeles Station 8, Port Townsend Station 12), Everett (Station 21), Bellingham Bay (Station 4), and Budd Inlet (Station 106R). These areas are associated with point sources of contamination from municipal and industrial activities occurring near all major population centers in the Puget Sound region (Seattle, Bremerton, Tacoma, Everett, Bellingham, Port Angeles, and Olympia). The identity and relative ranking of these areas in the MSMP should be comparable to areas ranked by Ecology's Sediment Management Unit (SMU) Contaminated Sediment Site List, even though the SMU lists sites where contamination, measured against state sediment quality standards, is substantial. The premise is that contaminants have spread from areas highlighted by the SMU, and that the degree of contamination at MSMP stations is a function of proximity to those areas.

The SMU developed a system to rank sediment sites in Puget Sound where chemical concentrations exceed sediment quality standards (WDOE, 1996). The contaminated sediment site list identifies 49 sites, although it excludes sites already ranked and prioritized by the EPA Superfund Program. The system is based on ecological hazard evaluations, which use waste characteristics, site characteristics, and affected resources as criteria for listing and ranking the sites. Most sites were located along the shores of Elliott Bay and in the vicinity of Harbor Island and the Duwamish River. The remaining of the sites were located, in decreasing number, in Central Puget Sound (Sinclair and Dyes Inlets, Keyport, and Eagle Harbor), Everett, Bellingham Bay, Commencement Bay, and Budd Inlet. The highest ranking site (greater degree of hazard) is in Budd Inlet near Olympia, and most other high ranking sites are in Bellingham Bay or in Elliott Bay. Superfund sites of highest cleanup priority are in Commencement Bay, Eagle Harbor, and Elliott Bay.

The areas listed by the SMU agree well with those identified by the MSMP, except for stations in the Strait of Juan de Fuca region, which have no comparable SMU sites. Elliott Bay and Central Puget Sound had the highest number of sites listed, representing multiple sources of dispersal for a variety of contaminants that contributed to the identification of MSMP contaminated stations. SMU site ranks, however, differed from the MSMP ranking of contaminated stations. This is expected because sites in the SMU list are ranked according to exceedance factors and to ecological criteria. MSMP stations were primarily ranked according to number of contaminants. Also, some contaminants of concern associated with SMU sites were not significantly measured at MSMP stations. For example, dibenzofuran is reported in the SMU list as of ecological hazard in Budd Inlet and Bellingham Bay, and phthalates are listed in Elliott Bay sites. However, only small concentrations of these compounds were detected at monitoring stations near these sites, which suggest that these contaminants are least likely to spread from sources. Alternatively, there are no sediment quality standards for resin acids, and none were used to assess contamination at SMU sites. Resin acids contributed to our ranking of stations in the Strait of Juan de Fuca region (Port Angeles and Port Townsend), in addition to stations in Bellingham Bay, Everett, and Commencement Bay. A pulp-mill in Port Angeles (Rayonier, Inc.) has recently been inspected by EPA, and may turn out to be a major source of resin acids and other wood processing waste.

Temporal Trends

Chemical concentrations found at monitoring stations represent the net value of recent and previously deposited sediments. Differences in chemical values reflected variability in collection, analysis, and natural heterogeneity of the sediments over the seven year period. Laboratory chemical analyses, particularly organic analysis, have been conducted at the most sensitive end of laboratory capabilities. Detection limits often varied by an order of magnitude between years, and sometimes within years. Furthermore, our surface sediment sampling approach measures mixed-age sediments. Since newly arriving particles and contaminants are redistributed in the surface layers by biological and physical mixing, a clear picture of current input is masked (Carpenter *et al.*, 1985). Thus, the identification of temporal contaminant concentration trends is limited with this sampling design over a period of seven years.

Contaminants examined in detail appeared to lack strong temporal trends. The absence of clear trends implies that contaminated stations have not shown any obvious improvements over the seven years examined. Source controls and remedial actions have much improved the level of contamination at some local sites that have been targeted for clean-up. However, it is early to say whether the immediate benefit of these actions will result in significant changes to sediment quality some distance away. With further reduction in inputs, some areas associated with large river sediment loads could show the first signs of improvement. One station where long-term monitoring from this point of view might be useful is Station 40 in Commencement Bay. The large sediment load of the Puyallup River contributes to the dilution of contaminants in this area (Crecelius *et al.*, 1975). Changes to sediment quality at Station 40 between the periods 1989-1990 and 1991-1995 (see Figures 10 and 11) suggest that burial or dilution of hydrocarbon contaminants may have occurred after 1990.

Reference Stations

In general, the stations listed in Table 9 exhibited intermediate levels of contamination above analytical detection limits but below regulatory standards. With some possible exceptions (see below), contaminant concentrations at these stations have the potential for adverse biological effects, and the stations are therefore unsuitable for characterizing reference (unimpacted) conditions. Exclusion of these stations leaves 18 other stations that could be used as reference sites. These potential reference stations are distributed in the following four areas:

Hood Canal – North Hood Canal (Station 13R)
North Puget Sound – Mukilteo (Station 22), East Central Basin (Station 23R), West Central Basin (Station 25R), Useless Bay (Station 301R)
Central Puget Sound – Richmond Beach (Station 27R), Magnolia Bluff (Station 32), Brace Point (Station 36R), North Vashon Island (Station 37R), Dash Point (Station 39), Seahurst Passage (Station 306R), Liberty Bay (Station 308R)
South Puget Sound – Carr Inlet (Station 43), West Nisqually (Station 46R), Case Inlet (Station 47), Mid Totten Inlet (Station 103R), Nisqually Delta (Station 112R), Willochet Bay (Station 113R)

Except for Seahurst Passage (~75 m depth), the stations listed above are characterized by shallow (15-24 m), sandy sediments, and are therefore of limited use for comparisons because silts and clays generally predominate in contaminated sediments. Twelve additional stations could be used as reference. These are stations exhibiting one contaminant above ER-L guidelines (arsenic, nickel or thallium), but at very low concentrations within the range of background, natural levels (see Table 9). These stations have the advantage of being characterized by a broader range of sediment types and depths. Of the 12 stations, three are sands, three are silty sands, five are mixed substrates, and one is mud. Two stations have water depths over 100 m, one station is ~50 m deep, and the remaining nine stations are shallow (18-34 m). The stations are distributed in the following four areas:

Hood Canal and the Strait of Juan de Fuca – Dungeness Bay (Station 10R), Discovery Bay (Station 11R), Dabob Bay (Station 15)
Strait of Georgia and the San Juan Islands – Roberts Bank (Station 201R), Point Roberts (Station 202R), NW Blakely Island (Station 205R), Friday Harbor (Station 206R), West Beach (Station 207R)
Central Puget Sound – Port Madison (Station 69)
South Puget Sound – East Anderson Island (Station 44), Devil's Head (Station 45), Outer Filucy Bay (Station 115R)

Depending on the type of contaminant and the magnitude of contamination above ER-L guidelines, additional reference stations could be considered. For example, Hood Canal at

Bangor (Station 14) exhibits only arsenic and nickel at concentrations near the ER-L. However, locations in regions associated with potential sources of contaminants, whether industrial, municipal or residential, might be sufficient to disqualify the station as reference. This is because the distribution of contaminants in sediments are often patchy, and may exhibit wide local variability. Station 14, for example, is located in the vicinity of a Naval Station. Also, unmeasured contaminants might elicit changes in the biological community, thereby introducing an unsuspected but significant source of error. Based on these criteria, seven stations listed above and located near residential areas from Everett down to Tacoma in North and Central Puget Sound plus Liberty Bay (near Keyport's Superfund site) could be disqualified. Alternatively, if sediments near confined degraded sites were adequately characterized and showed the absence of contaminants, these sediments could constitute excellent reference sites as the physical and ecological conditions of the sites being compared would be similar. Sites at Liberty Bay and Keyport are one such example. In addition, other criteria, such as the occurrence of natural confounding factors that may impact local biota, should be taken into consideration during the evaluation of reference sites. These factors are discussed further below.

Bioassay

Overall, there was little correspondence between chemical concentrations in sediments and the resulting toxicity of these sediments to the amphipod *Rhepoxynius abronius*. Using DeWitt's model to account for the effects of grain size (DeWitt *at al.*, 1988), toxicity could be marginally shown for only 5 stations (Oak Harbor, Port Susan, Carr Inlet, Case Inlet, and Dyes Inlet). Oak Harbor (Station 18) is an urban station where significant contamination has not been detected. Port Susan (Station 20) is a rural embayment where chromium accumulation has been identified, although this metal probably has a fluvial origin from geological sources. Carr Inlet (Station 43) and Case Inlet (Station 47) are rural areas where contamination has not been detected (except for the presence of nickel above ER-L levels, see Table 9). Lastly, Dyes Inlet (Station 35) is an urban station showing extensive contamination, albeit at low to moderate levels.

Except for Port Susan and Dyes Inlet, amphipod mortality did not appear to be related to contamination at monitoring stations in Puget Sound. For Dyes Inlet, there were no consistent results. Only one out of four replicate sediment samples collected at this station in 1989 and one replicate in 1990 (Table 10) showed toxic effects as defined by DeWitt *et al.* (1988). Port Susan results may indicate chromium effects; however, we were unable to identify correlative effects on benthos (see Volume 2 of this report).

DeWitt's model does not rule out mortality effects due to sediment toxicity in samples falling within 95% prediction boundaries. However, the model suggests that amphipod mortality resulting from toxicity cannot be distinguished from sediment particle effects in this region. Thus, toxic effects may be occurring, but since we are not controlling for sediment properties we do not know the actual causative factor. Visual inspection of Figure 27 reveals that there was as much mortality in samples with high percent silt and clay as there was survival. Furthermore, our data do not show a clear relationship between mean amphipod survival and percent silt and clay. DeWitt's model was based on a survival-particle size relationship that explains only 29% of their data. Also, their field and laboratory data indicate that particle size is only one among several other predictors of amphipod survival.

While contaminant concentrations may not have been high enough to elicit unambiguous toxic effects, we found that DeWitt's model did not substantially aid in interpreting toxicity results from the amphipod bioassay. *Rhepoxynius abronius* naturally occurs in fine, well-sorted sands, but has been used to test toxicity of sediments with high silt or clay content. At present, we do not have a clear understanding of the role of sedimentary, environmental or laboratory factors contributing to amphipod mortality in the sediment bioassay. Unless we control for these, we will not be able to separate the effects of toxic pollution from other phenomena.

Other Potential Stressors in Puget Sound

Sulfides were associated with some stations located in terminal inlets of South Puget Sound, semi-enclosed bays, or water bodies that are influenced by freshwater discharge. Restricted water circulation in terminal inlets, particulate organic input, and water column density stratification associated with discharge plumes from major rivers (*e.g.*, the Skagit and the Fraser River), are factors that may partially lead to low dissolved oxygen (DO) episodes and the accumulation of hydrogen sulfide in the sediment. Low DO and hydrogen sulfide are natural occurring factors known to have adverse effects on marine organisms (Diaz and Rosenberg, 1995). Low DO can also result from chemical and biological processes associated with anthropogenic nutrient input. For example, hypoxia or anoxia may arise from seasonal pulses in phytoplankton production stimulated by nutrient enrichment. Both phytoplankton decay and nutrient processes create high oxygen demand. Anthropogenic sources of nutrients such as ammonium, nitrate and phosphate include sewage effluent discharge and leaking septic tanks, and may constitute an important source of pollution in Puget Sound.

Low DO has been historically identified in South Hood Canal (Collias *et al.*, 1974). In addition, Ecology's Marine Waters Monitoring has identified the occurrence of low DO at monitoring stations in Budd Inlet, South Hood Canal, East Sound (Orcas Island), Possession Sound, and Saratoga Passage (Newton *et al.*, 1994). We have detected sulfides or identified the presence of hydrogen sulfide in some stations located in the upper reaches of South Puget Sound inlets, in Hood Canal (Lynch Cove), Saratoga Passage, and the Strait of Georgia. Other locations with low DO and sulfide include Sequim Bay (WDOE, unpublished data; this report). Low DO or sulfide locations also agree relatively well with our classification of stations based on RPD depths (Table 6).

Documenting natural changes to sediment quality is important because natural factors contribute to the structure of biological communities. The identification of alterations to communities of organisms cannot be unambiguously attributed to toxic pollution without an understanding of the relationships between the organism and its natural environment.

Conclusions

- Baseline conditions have been established for sediment chemistry at current monitoring stations. We presently have good knowledge of what type of contamination is more likely to occur at other locations of Puget Sound (*e.g.,* volatile organics or pesticides are less often detected than PAHs). However, we have relatively little information about the overall spatial extent of contamination across Puget Sound.

- The range of contaminant concentrations at current monitoring stations is low. Elevated concentrations of some pollutants (mostly trace metals, PAHs, and resin acids) were more common in urban bays, and at levels below sediment quality standards. A notable exception was mercury concentrations above sediment standards in Sinclair Inlet and Dyes Inlet. However, because the MSMP was not specifically designed to evaluate areas of highest contaminant concentrations in Puget Sound, the MSMP data should not be used to identify "hot spots."

- We have just initiated the collection of long-term monitoring data in Puget Sound. Several more years of monitoring will be necessary before trends can be established. No obvious changes to sediment quality were detected over the seven years examined.

- The potential for sediment toxicity has been only partially assessed. Contaminant concentrations at monitoring stations did not appear to be high enough to elicit consistent toxic effects to the test amphipod *Rhepoxinious abronius*. However, because of uncertainties in the interpretation of results, we could not unambiguously determine which sediments were toxic to test organisms. Further, chronic effects that may have long-lasting consequences for the biological community have not been assessed. For example, contaminants may affect life history traits such as growth and reproduction. These, in turn, may affect recruitment levels that are of critical importance for the establishment of annual patterns in species composition. In addition, low levels of contaminants may have synergistic effects, and thus warrant examination.

- We suggest that natural factors influence sediment quality. Stations in south Puget Sound inlets and other locations with restricted water circulation have the potential for low dissolved oxygen in bottom waters and sulfide accumulation in sediments. More extensive focused projects, however, will be necessary to monitor these conditions and assess effects on biological communities.

Recommendations

- The present approach to sediment monitoring emphasizes trend detection rather than spatial characterization. Stations are located away from major known sources of pollution. It was reasoned that data generated by intensive surveys and other (*e.g.*, regulatory) programs would be made available to the MSMP to aid in the interpretation of results. One goal was preventing overlap and duplication of monitoring efforts. However, the usefulness of other sources of data has been limited. Many intensive studies have focussed on specific areas of concern, such as "Superfund" sites, and have objectives fundamentally different from those of the MSMP.

  In order to clearly identify changes to sediment quality, we recommend a coordinated, comprehensive approach to sediment monitoring. Coordinated meaning that we use data and results from other monitoring programs. Comprehensive meaning that we investigate gradients in urban sediments where toxic compounds may accumulate.

- The 1989-1995 program design consisted of two sets of stations: "core" stations sampled every year, and rotating stations sampled every three years. This design does not allow for inferences to be made about the extent of chemical contamination in bays represented by one sampling location. We recommend that spatial coverage of bays and other specific areas in Puget Sound be increased. Stations could be allocated to regions in a statistically-based manner to assess sediment quality conditions. Different regions could be assessed at different times. This design must also be complementary of the designs established by other PSAMP monitoring components. This will ensure adequate data sharing to support linkages in monitoring efforts. Most core stations should be maintained to evaluate long-term trends. Optimal designs to be evaluated include transect sampling along gradients of pollution, and stratified random sampling (by water depth, sediment type, salinity gradient, and proximity to sources of pollution).

- The MSMP constitutes the only multi-year survey where surface sediment chemistry has been monitored annually throughout Puget Sound. Within the limitations of field and analytical variability, we have established a relatively good baseline at monitoring stations. However, surface chemistry values reflect multi-year deposition of sediment and may not be representative of current inputs. We recommend that the frequency of surface sediment sampling for chemistry be reduced. Several options could be contemplated, including a reduction in the list of target contaminants that have not been significantly detected. One option is to drop target contaminants that have not been significantly detected (for example, VOC, phenols, chlorinated hydrocarbons), and sample for others (priority-pollutant metals, PAH, PCB) on three year intervals. Consideration should be given to adding contaminants of concern that are not included in the current list of target chemicals, such as dioxins and TBT.

- The usefulness of toxicity testing and the type of bioassay employed need revision. The use of additional test organisms should be evaluated because of the sensitivity of *Rhepoxynius abronius* to the fine particle fraction of sediments. Consideration should be given to chronic toxicity tests. Screening tests may be useful even if not included in regulatory standards.

- An important component of sediment quality, presently not monitored, is information on sediment input, deposition, and transport. Many chemicals released to the water column adsorb onto particles that settle to the bottom sediments of rivers, harbors and bays, and therefore heavy burdens tend to remain close to the source. Subsequent dispersal, accretion, and burial of contaminants in estuarine sediments will depend on sediment transport processes and deposition rates. In areas removed from the direct influence of industrial and municipal wastewater effluents, many contaminants entering the estuary are derived from non-point sources. Understanding the impacts of contamination and the increasing anthropogenic input due to population growth cannot occur if we do not have reliable estimates of source loading, pathways, and fate of pollutants in the marine environment.

  In order to evaluate contaminant inputs to Puget Sound, the MSMP supports compilation and improved accessibility of data on source loading and sediment transport. We recommend the use of sediment traps and geochemistry methods (*e.g.*, coring, radiochemical dating) to measure sediment deposition rates and temporal trends at selected stations. Lastly, we recommend and support research on the interactions of particle-adsorbed contaminants in seawater, and on their cycling and fate within marine sediments.

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