Metals Concentrations in Commencement Bay Waterways During 1997 – 1998

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by
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Abstract

Zinc, copper, arsenic, cadmium, lead, mercury, chromium, and nickel were analyzed in surface and deep water samples from three waterways in Commencement Bay and in the main bay during 1997-98. Clean sampling techniques and low-level methods of analysis were used.

The data were analyzed for differences in metals concentrations between waterways and with depth, and compared to water quality criteria, historical data, and Puget Sound background. The fraction of dissolved metals was calculated and compared to EPA conversion factors used for setting metals limits in NPDES permits.

Results showed all metals concentrations were well within criteria for protection of aquatic life. Cleanups have resulted in substantial water quality improvements in Blair and Hylebos Waterways, where arsenic and zinc concentrations are an order of magnitude lower than in the 1980s.

Acknowledgements

The advice and assistance given on this project by Bill Kammin of Manchester Laboratory and Eric Crecelius of Battelle Laboratory was extremely helpful. The good work of Manchester Laboratory staff, especially Jim Ross, Randy Knox, and Sally Cull, is very much appreciated. This report benefited from review comments by Dale Norton, Dave Smith, and Ken Dzinbal. Dale Norton originally saw the need for and proposed this study.

Summary

The Washington State Department of Ecology measured metals concentrations in the waterways of Tacoma's Commencement Bay and in the main bay on three occasions during 1997-98. The waterways were Thea Foss, Blair, and Hylebos. Zinc, copper, arsenic, cadmium, lead, mercury, chromium, and nickel were the metals of interest.

Historically, this area was highly contaminated with arsenic and other metals because of widespread use of ASARCO slag and discharges from a variety of industrial facilities. Log sort yards that used slag to stabilize driving surfaces were sources of large amounts of arsenic, zinc, copper, and lead to Blair and Hylebos Waterways. Cleanups and source controls are now in place for all known metals sources to these two waterways.

The objectives of Ecology's 1997-98 sampling program were to: 1) conduct the first low-level metals analysis of the waterways; 2) assess compliance with water quality criteria; 3) document changes in water quality that have followed cleanups; and 4) obtain data needed for NPDES permits.

Water samples were collected in November, March, and August, periods selected to cover a range of runoff conditions. Three stations were occupied in each waterway – mouth, middle, and head – and one station in the center of the main bay. Surface water samples (0.5 meters) were taken at all sites and deep water (8 meters) was sampled in the middle of the waterways and in the bay. Sample collection and handling followed the guidance in EPA (1995a) *Method 1669: Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels.* To achieve low detection limits for zinc, copper, arsenic, cadmium, lead, chromium, and nickel, the samples were preconcentrated (co-precipitation with Fe/Pd or APDC) and analyzed by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Mercury was analyzed by cold-vapor techniques.

Statistical tests showed that concentrations of dissolved zinc, dissolved copper, and unfiltered arsenic were significantly higher ($p<.05$) in Hylebos Waterway than in Thea Foss or Blair Waterways. Arsenic increased going from Thea Foss to Blair to Hylebos Waterway, with median values of 1.0, 1.3 and 2.1 ug/L, respectively (parts per billion). The highest levels of dissolved lead, to 0.16 ug/L, occurred in Thea Foss Waterway. No significant between-waterway differences were found for cadmium, mercury, chromium, or nickel. Limited samples from the main bay indicated mercury is elevated relative to the waterways.

Surface water concentrations of dissolved zinc, copper, lead, and nickel, and total recoverable mercury were significantly higher than in deep water. Metals not enriched at the surface were arsenic (except for Hylebos Waterway), cadmium, and chromium. The only seasonal pattern consistently observed was for zinc and arsenic, which decreased in all areas going from November to March to August. This occurred in both surface and deep water samples.

All metals concentrations were well within state and the EPA water quality criteria for marine life, in most cases by a factor of five or better. The higher of the dissolved copper concentrations in Thea Foss and Hylebos Waterways reached 50% - 70% of the chronic criterion. Comparison with the historical data available on Blair and Hylebos Waterways shows that cleanups have resulted in an order of magnitude decrease in arsenic and zinc contamination. Similar improvements have likely occurred for copper and lead.

Results of the present study indicate that the metals data reported on Blair and Hylebos Waterways by NPDES dischargers are generally inaccurate, substantially overstating concentrations of zinc, lead, and nickel. Ecology's data further show that use of EPA water quality criteria conversion factors for setting NPDES permit limits for lead will overestimate dissolved concentrations in the receiving waters by factors of 2 to 5.

Relative to deep inflowing seawater to Puget Sound, zinc, copper, and mercury are elevated by approximately a factor of 5 in Commencement Bay and in the waterways, including deep water in the main bay. Metals only slightly above background (less than approximately a factor of 2) are lead in Thea Foss and Hylebos Waterways, arsenic in Hylebos Waterway, and nickel in Commencement Bay and Hylebos Waterway. Cadmium does not appear elevated in any area, nor chromium, based on limited samples.

Historical data show arsenic concentrations in the surface water of Commencement Bay once averaged 2.0 – 2.5 ug/L, concentrations not seen elsewhere in Puget Sound at that time. Current arsenic levels in the main bay have decreased by almost half. Results from Ecology's 1997-98 survey indicate that elevations in arsenic are now primarily restricted to Hylebos Waterway and that these are moderate.

Introduction

The Washington State Department of Ecology (Ecology) Environmental Assessment Program measured metals concentrations in the waterways of Tacoma's Commencement Bay on three occasions between November 1997 and August 1998. The waterways were Thea Foss (formerly City Waterway), Blair, and Hylebos. Zinc, copper, arsenic, cadmium, lead, mercury, chromium, and nickel were the metals of interest.

Historically, this area was highly contaminated with arsenic and other metals because of widespread use of ASARCO slag and discharges from a variety of industrial facilities (Tetra Tech. 1985). Log sort yards that used slag to stabilize driving surfaces were sources of large amounts of arsenic, zinc, copper, and lead to Blair and Hylebos Waterways (Norton and Johnson, 1985).

In 1983, seven of Commencement Bay's nine waterways were listed as Superfund sites. The U.S. Environmental Protection Agency (EPA) and Ecology initiated extensive source identification and cleanup efforts beginning in 1989 (Smith et al., in prep). Although post-cleanup monitoring has been conducted on runoff and effluents going into the waterways, few data were available on metals concentrations in the receiving waters.

The objectives of Ecology's 1997-98 sampling program were to:

1. Use new EPA clean sampling and analytical techniques to conduct the first low-level metals analysis of the waterways.

2. Assess compliance with state and EPA water quality criteria for metals.

3. Document changes in water quality that have followed metals cleanups.

4. Obtain data needed for setting metals limits in NPDES permits.

Study Overview

Water samples were collected on November 21, March 18, and August 13 at the ten stations shown in Figure 1. Sampling periods were selected to cover a range of runoff conditions (Table 1). All sampling was done during ebb and extreme tides were avoided.

Three stations were occupied in each waterway – mouth, middle, and head – and one station in the center of the main bay. Surface water samples (0.5 meters) were taken at all sites. Deeper water (8 meters) was also sampled in the middle of each waterway and at center bay. At lower low water, depths at these four stations are approximately: 7 meters (Thea Foss); 9 meters (Hylebos); 11 meters (Blair); and 100 meters (main bay).

Sample collection and handling followed the guidance in EPA (1995a) *Method 1669: Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels.* Water samples were taken with an all-plastic pumping system consisting of a peristaltic pump, teflon tubing, and in-line 0.45 micron filters, prepared and acid-cleaned for low-level metals analysis by the Battelle Marine Sciences Laboratory (Battelle) in Sequim, WA. Sample containers for metals were 500 mL teflon bottles, cleaned for low-level metals analysis by the Ecology Manchester Environmental Laboratory (Manchester) .

Sampling proceeded from the mouth to head of each waterway, with a dilute acid wash of the tubing between waterways. Samples were stored on ice and preserved at the laboratory with high-purity nitric acid.

Filtered and whole water samples were analyzed for zinc, copper, arsenic, cadmium, lead, chromium, and nickel. Mercury was analyzed on unfiltered samples only. Chromium and nickel analyses were limited to the outer bay and Hylebos Waterway. Conventional water quality variables included temperature, salinity, total suspended solids (TSS), and turbidity. Field quality assurance samples consisted of bottle blanks, filter blanks, and replicates.

Zinc, copper, arsenic, lead, cadmium, chromium, and nickel were analyzed using co-precipitation and Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Mercury was determined by Cold-Vapor Atomic Adsorption (CVAA) or Cold-Vapor Atomic Flourescence (CVAF). The samples were analyzed by the Battelle and Manchester laboratories.

In this report, the results on 0.45 micron filtered water samples are referred to as "dissolved" metals. Most of the metals data on Commencement Bay waterways are based on a total recoverable analysis. Co-precipitation was used for the present study to achieve low detection limits in a seawater matrix. Although co-precipitation produces equivalent results to total recoverable, the data are more accurately termed "unfiltered" when applied to whole water samples (Kammin, 1988). Unfiltered is the term used throughout this report.

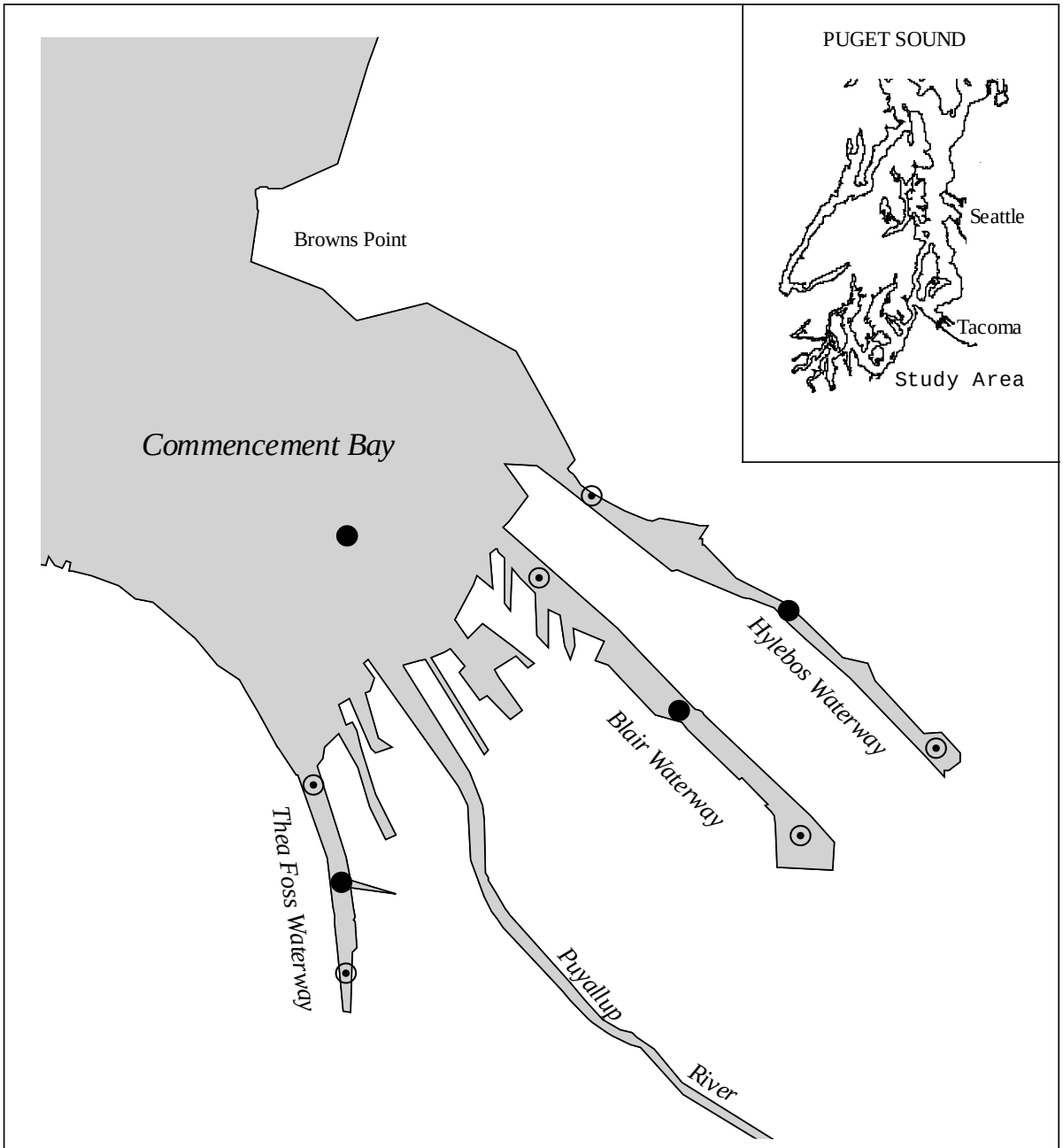

Figure 1. Ecology Water Sampling Stations in Commencement Bay, 1997-98

Table 1. Runoff and Tidal Conditions for Metals Sampling Periods in Commencement Bay

	Sampling Date		
	November 21, 1997	March 18, 1998	August 13, 1998
Precipitation (inches)	0.0 - 11/21	0.0 - 3/18	0.0 - 8/13
(NOAA station Tacoma 1)	0.30 - 11/20	0.0 - 3/17	0.0 - 8/12
	0.34 - 11/19	0.0 - 3/16	0.0 - 8/11
	0.01 - 11/18	0.0 - 3/15	0.0 - 8/10
	0.41 - 11/17	0.03 - 3/14	0.0 - 8/09
	0.01 - 11/16	0.0 - 3/13	0.0 - 8/08
	0.0 - 11/15	trace - 3/12	0.0 - 8/07
Flow (cfs)			
Puyallup River @ Puyallup (USGS station 12101500)	2,710	3,090	2,130
Tide Stage (feet above LLW)			
High water	12.1 ft. @ 1052	10.8 ft. @ 0739	9.6 ft. @ 0953
Low water	5.6 ft. @ 1721	1.5 ft. @ 1228	3.0 ft. @ 1540
Time of sample collection	0855 - 1405	0930 - 1320	1105 - 1435

Methods

Field

Sample collection and handling followed EPA Method 1669. The pumping system employed a Masterflex variable speed peristaltic pump head and drive (Cole Parmer, Models 7518-20 and 7570-10, respectively). A short length of C-Flex tubing was used in the pump head; the remainder of the sampling tubing was teflon. Filters were in-line, Gelman Aqua Prep 250 Capsule 0.45 micron (PN86982A). Sample containers were 500 mL teflon bottles.

The tubing and filters were acid-cleaned at Battelle and sealed in plastic bags, as described in Method 1669. The teflon bottles were acid-cleaned at Manchester using methods in Kammin et al. (1995), filled with de-ionized, and place in zip-lock bags. For the deep water samples, the tubing was weighted with an acid-cleaned teflon sample bottle filled with clean silica sand. Non-talc gloves were worn by sampling personnel.

Sampling proceeded along an assumed gradient from lower-to-higher metals concentrations, beginning at the main bay station and ending at the head of Hylebos Waterway. New filters were used for each sample. Dedicated tubing was used for surface and bottom water.

Sampling stations were located by DGPS and visual fixes. Station coordinates are given in Appendix A. The sampling vessel was a 21-foot outboard powered fiberglass skiff.

After completing the sampling in Thea Foss Waterway and again after Blair Waterway, the tubing was rinsed with one liter of deionized water acidified with high-purity nitric acid, followed by pumping approximately one liter of de-ionized water through the tubing. Bottle (transfer) blanks and filter blanks were prepared at the head of Thea Foss Waterway, after cleaning the pumping system. For the transfer blank, deionized water was transferred from one sample bottle to another and the bottle re-sealed. Surface water sampling at the middle Hylebos Waterway station was done in replicate by collecting two separate sets of samples approximately five minutes apart.

Sample containers for conventional water quality variables were polyethylene. Temperature was measured in the field with a long-line thermometer. All samples were placed in plastic bags and stored on blue ice for transport to the laboratory. Chain-of-custody was maintained.

Laboratory

Metals samples were acidified in the laboratory to pH <2 using high-purity nitric acid in a Class 100 clean room. The November and March samples were analyzed by Battelle; the August samples by Manchester. All conventional water quality analyses were done at Manchester.

Zinc, copper, arsenic, lead, cadmium, chromium, and nickel were preconcentrated (co-precipitation with Fe/Pd or APDC) and analyzed by ICP-MS. Battelle followed EPA Method 1640; Manchester used EPA Method 200.8. Mercury was analyzed by CVAF, EPA Method 1631 (Battelle) or CVAA, EPA Method 245.7 (Manchester). Analysis for conventional parameters was by routine methods described in Manchester Laboratory (1994).

Data Quality

The metals data were reviewed by Bill Kammin and Randy Knox of Manchester Laboratory and included an assessment of sample holding times, instrument calibration, method blanks, spiked sample analysis, precision data, and standard reference materials (SRMs). Appendix B contains the results for method blanks, matrix spikes, laboratory replicates, and SRMs.

All samples were analyzed within holding times. The data review identified calibration shortcomings that resulted in re-analysis for cadmium, lead, and nickel in the November samples.

Method blanks were below the concentrations in field samples, except for chromium in the August sample set. The chromium blanks for these samples consistently ran at 0.13 – 0.15 ug/L indicating the August data may be biased high for chromium.

Good accuracy was generally achieved in the analysis of SRMs (Table 2). The results on CASS 3 (coastal seawater) were high for lead and chromium for both laboratories. This can largely be accounted for by the method blanks. Nickel and arsenic recoveries for the August sample set were slightly below the ranges certified in CASS 3 and SLEW 1 (estuarine water).

Three sets of field blanks were analyzed (Table 3). Metals concentrations in filter blanks were consistently at or below the transfer blank, indicating there was no contamination from the filtration procedure. The levels of metals in the blanks (Manchester deionized water) were generally low compared to field samples.

The total variability in the data reported here (analytical + field) can be assessed from the results on replicate field samples (Table 4). Agreement between replicates was 15% or better in most cases. There is potentially greater variability associated with the data on dissolved lead, where the replicates differed by 32 – 55%. The results for replicate samples were averaged for use in this report.

The metals data in this report are not blank corrected.

Table 2. Analysis of Standard Reference Materials (ug/L; parts per billion)

SRM	Laboratory	Result	Cu	Cd	Pb	Zn	Cr	Ni	As	Hg
1643d	Battelle	mean (n=3)	20.2	6.5	18.3	73.9	14.9	58.2	56.9	- -
"		s.d.	0.64	0.029	0.12	0.81	3.4	2.2	na	- -
"		**certified value**	**20.5**	**6.47**	**18.2**	**72.5**	**18.5**	**58.1**	**56.0**	**- -**
"		**range**	**+/-3.8**	**+/-0.37**	**+/-0.64**	**+/-0.65**	**+/-0.20**	**+/-2.7**	**+/-0.73**	**- -**
CASS 3	Battelle	mean (n=3-4)	0.56	0.036	0.035	1.7	0.14	0.38	0.95	- -
"		s.d.	0.05	0.002	0.037	0.9	0.08	0.05	0.48	- -
"	Manchester	mean (n=4)	0.47	0.025	0.029	1.7	0.24	0.26	0.79	- -
"		s.d.	0.04	0.001	0.021	0.53	0.021	0.051	0.03	- -
"		**certified value**	**0.517**	**0.03**	**0.012**	**1.24**	**0.092**	**0.386**	**1.09**	**- -**
"		**range**	**+/-0.062**	**+/-0.005**	**+/-0.004**	**+/-0.25**	**+/-0.006**	**+/-0.062**	**+/-0.07**	**- -**
SLEW 1	Manchester	mean (n=2)	1.3	0.016	0.036	1.1	0.36	0.40	0.56	- -
"		s.d.	0.19	0	0.008	0.23	0.06	0.028	0.049	- -
"		**certified value**	**1.76**	**0.018**	**0.028**	**0.86**	**0.139**	**0.743**	**0.765**	**- -**
"		**range**	**+/-0.09**	**+/-0.003**	**+/-0.007**	**+/-0.15**	**+/-0.016**	**+/-0.078**	**+/-0.093**	**- -**
1641c	Battelle	mean (n=2)	- -	- -	- -	- -	- -	- -	- -	1515
"		s.d.	- -	- -	- -	- -	- -	- -	- -	49
"		**certified value**	**- -**	**- -**	**- -**	**- -**	**- -**	**- -**	**- -**	**1470**
"		**range**	**- -**	**- -**	**- -**	**- -**	**- -**	**- -**	**- -**	**+/-40**
1631c	Manchester	result	- -	- -	- -	- -	- -	- -	- -	0.0291
"		**certified value**	**- -**	**- -**	**- -**	**- -**	**- -**	**- -**	**- -**	**0.0294**

s.d = standard deviation
na = not analyzed

Table 3. Metals Concentrations in Field Blanks (ug/L; parts per billion)

Location	Date	Zn	Cu	As	Pb	Cd	Cr	Ni	Hg
Filter Blank	21/11/97	0.92	0.20	- -	0.009	0.003	< 0.03	0.092	0.0003
"	18/03/98	1.1	<0.06	- -	<0.006	<0.006	0.011	0.053	0.0005
"	13/08/98	0.44	0.12	< 0.025	0.036	0.0054	0.17	0.045	< 0.002
Transfer Blank	21/11/97	4.1	0.20	< 0.15	0.008	0.002	< 0.03	0.17	0.0003
"	18/03/98	1.1	< 0.06	< 0.014	< 0.006	< 0.006	0.02	0.17	0.0005
"	13/08/98	0.85	0.044	< 0.025	0.013	0.0022	0.23	0.083	< 0.002

Table 4. Variability Between Replicate Samples Collected in Hylebos Waterway

	November 11, 1997			March 18, 1998			August 13, 1998		
	#1	#2	RPD	#1	#2	RPD	#1	#2	RPD
Salinity (ppt)	20	20	0%	21	20	5%	20	20	0%
TSS (mg/L)	6	6	0%	2	3	40%	7	6	15%
Turbidity (NTU)	5.3	5.7	7%	2.4	2.3	4%	2.3	2.2	4%
Dissolved (ug/L)									
Zinc	14.8	16.0	8%	16.1	14.4	11%	7.7	6.8	12%
Copper	1.8	2.1	11%	2.2	2.1	6%	1.8	1.6	12%
Arsenic	na	na	- -	na	na	- -	1.2	1.1	9%
Lead	0.026	0.046	55%	0.007	0.010	39%	0.037	0.051	32%
Cadmium	0.070	0.072	2%	0.14	0.078	58%	0.034	0.033	3%
Chromium	0.15	0.15	0%	0.13	0.13	0%	0.20	0.33	49%
Nickel	0.79	0.81	2%	0.72	0.74	3%	0.20	0.23	14%
Unfiltered (ug/L)									
Zinc	19.1	17.2	10%	14.4	14.3	1%	7.8	8.0	3%
Copper	2.9	2.8	5%	2.2	2.2	0%	2.4	2.3	4%
Arsenic	3.8	4.0	6%	2.9	2.8	4%	1.5	1.5	0%
Lead	0.51	0.53	4%	0.15	0.15	0%	0.12	0.12	0%
Cadmium	0.088	0.082	7%	0.082	0.083	1%	0.039	0.043	10%
Chromium	0.50	0.50	0%	0.22	0.20	8%	0.29	0.26	11%
Nickel	1.2	1.2	0%	0.79	0.76	4%	0.27	0.26	4%
Total Recoverable (ug/L)									
Mercury	0.0050	0.0046	8%	0.0044	0.0036	19%	0.0044	0.0039	12%

RPD = Relative Percent Difference (range as percent of mean)
na = not analyzed

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Results and Discussion

[The complete data on samples collected for this project are in Appendix C.]

General Water Quality Conditions

Table 5 summarizes the temperature, salinity, TSS, and turbidity data. Water quality was more variable at the surface (0.5 meters) than at depth (8 meters).

The salinity of deep water samples remained within a narrow range of 27 – 30 ‰ throughout the study area, while surface waters were at 10 – 20 ‰. TSS were typically less than 10 mg/L and turbidity less than 10 NTU. During the initial sampling of the outer bay in November, the presence of the Puyallup River plume resulted in high TSS (34 mg/L) and turbidity (37 NTU) in the surface water samples.

Metals Concentrations

Surface Water

Table 6 summarizes data on metals concentrations in surface water. The findings are also illustrated with box plots[1] in Figures 2 and 3. Lead and mercury were below detection limits in some samples. In these cases, half the detection limit was used for statistical calculations and in figures.

The data discussed here are based either on the dissolved or whole water samples, depending on the form of the metal specified in the water quality standards (WAC 173-201). For zinc, copper, lead, cadmium, chromium, and nickel this is dissolved; for mercury it is total recoverable.

Although the arsenic criteria were recently changed to dissolved, most of the analyses were conducted on unfiltered samples. There is little difference between dissolved and unfiltered arsenic in Commencement Bay. Fifteen paired determinations of arsenic in dissolved and unfiltered samples showed $\geq$95 percent is dissolved (Appendix C). Table 6 contains the more complete data on unfiltered arsenic.

The metal occurring at the highest concentrations in Commencement Bay is zinc, followed by copper and arsenic. Other metals decrease in the order: nickel > chromium > cadmium > lead > mercury.

Concentrations remained within a relatively narrow range over the course of the study. Mercury showed the most variability, ranging from <0.002 – 0.007 ug/L within the

[1] In box plots, the median value is the horizontal line within the box, and the ends of the box mark the interquartile range, 50% of the values. The whiskers extend to include values that fall within a factor of 1.5 of the interquartile range. Outliers are plotted as asterisks, or, for far outside values, as empty circles.

Table 5 . General Water Quality Conditions

Parameter	Location	Median	Minimum	Maximum
Temperature (^{o}C)	Commencement Bay - Surface	9.5	9.0	16.0
	Commencement Bay - Deep	11.1	8.9	12.6
	Thea Foss Waterway - Surface	10.5	10.0	16.4
	Thea Foss Waterway - Deep	11.5	9.4	12.7
	Blair Waterway - Surface	10.6	9.2	17.9
	Blair Waterway - Deep	11.4	8.9	12.7
	Hylebos Waterway - Surface	11.7	9.9	17.6
	Hylebos Waterway - Deep	11.0	8.9	11.2
Salinity (ppt)	Commencement Bay - Surface	20	14	21
	Commencement Bay - Deep	28	28	30
	Thea Foss Waterway - Surface	21	10	24
	Thea Foss Waterway - Deep	28	28	28
	Blair Waterway - Surface	22	19	27
	Blair Waterway - Deep	28	27	29
	Hylebos Waterway - Surface	20	10	28
	Hylebos Waterway - Deep	28	27	28
TSS (mg/L)	Commencement Bay - Surface	7	4	34
	Commencement Bay - Deep	5	3	6
	Thea Foss Waterway - Surface	4	2	13
	Thea Foss Waterway - Deep	6	4	6
	Blair Waterway - Surface	3	2	12
	Blair Waterway - Deep	3	3	7
	Hylebos Waterway - Surface	6	2	10
	Hylebos Waterway - Deep	5	3	6
Turbidity (NTU)	Commencement Bay - Surface	5.6	1.7	37
	Commencement Bay - Deep	0.7	0.6	1.4
	Thea Foss Waterway - Surface	2.1	0.7	12
	Thea Foss Waterway - Deep	1.4	0.7	1.5
	Blair Waterway - Surface	3.4	1.3	5.4
	Blair Waterway - Deep	1.2	1.1	1.9
	Hylebos Waterway - Surface	2.6	1.3	10
	Hylebos Waterway - Deep	1.5	0.8	2.0

Table 6. Summary Statistics on Metals Concentrations in Surface (0.5 m) Water Samples
[ug/L; parts per billion]

Metal	Location	n =	Median	Percentiles 25th	Percentiles 75th	Maximum
ZINC	Commencement Bay	3	2.0	1.8	2.1	2.1
(dissolved)	Thea Foss Waterway	9	4.9	3.7	6.6	20.1
	Blair Waterway	9	3.7	3.0	5.0	5.6
	Hylebos Waterway	9	11.6	7.3	13.7	15.4
COPPER	Commencement Bay	3	0.61	0.60	0.84	0.90
(dissolved)	Thea Foss Waterway	9	1.2	0.81	1.6	2.0
	Blair Waterway	9	0.81	0.73	0.84	1.1
	Hylebos Waterway	9	1.6	1.5	1.9	2.2
ARSENIC	Commencement Bay	3	1.1	0.88	1.8	1.9
(unfiltered)	Thea Foss Waterway	9	1.0	0.66	1.4	1.6
	Blair Waterway	9	1.3	0.81	1.7	2.0
	Hylebos Waterway	9	2.1	1.5	2.9	3.9
CADMIUM	Commencement Bay	3	0.044	0.038	0.056	0.059
(dissolved)	Thea Foss Waterway	9	0.061	0.029	0.066	0.071
	Blair Waterway	9	0.061	0.040	0.064	0.066
	Hylebos Waterway	9	0.069	0.038	0.071	0.11
LEAD	Commencement Bay	3	0.018	0.015	0.024	0.025
(dissolved)	Thea Foss Waterway	9	0.034	0.026	0.072	0.16
	Blair Waterway	9	0.020	0.016	0.023	0.026
	Hylebos Waterway	9	0.036	0.021	0.040	0.044
MERCURY	Commencement Bay	3	0.0056	0.0033	0.0064	0.0067
(tot. recoverable)	Thea Foss Waterway	9	0.0027	0.0023	0.0035	0.0058
	Blair Waterway	9	0.0023	0.0016	0.0024	0.0051
	Hylebos Waterway	9	0.0026	0.0021	0.0042	0.0074
CHROMIUM	Commencement Bay	3	0.20	0.16	0.20	0.21
(dissolved)	Hylebos Waterway	9	0.14	0.13	0.21	0.27
NICKEL	Commencement Bay	3	0.43	0.33	0.47	0.48
(dissolved)	Hylebos Waterway	9	0.55	0.22	0.80	0.82

Note: Statistics were calculated using 1/2 the detection limit for non-detected values.

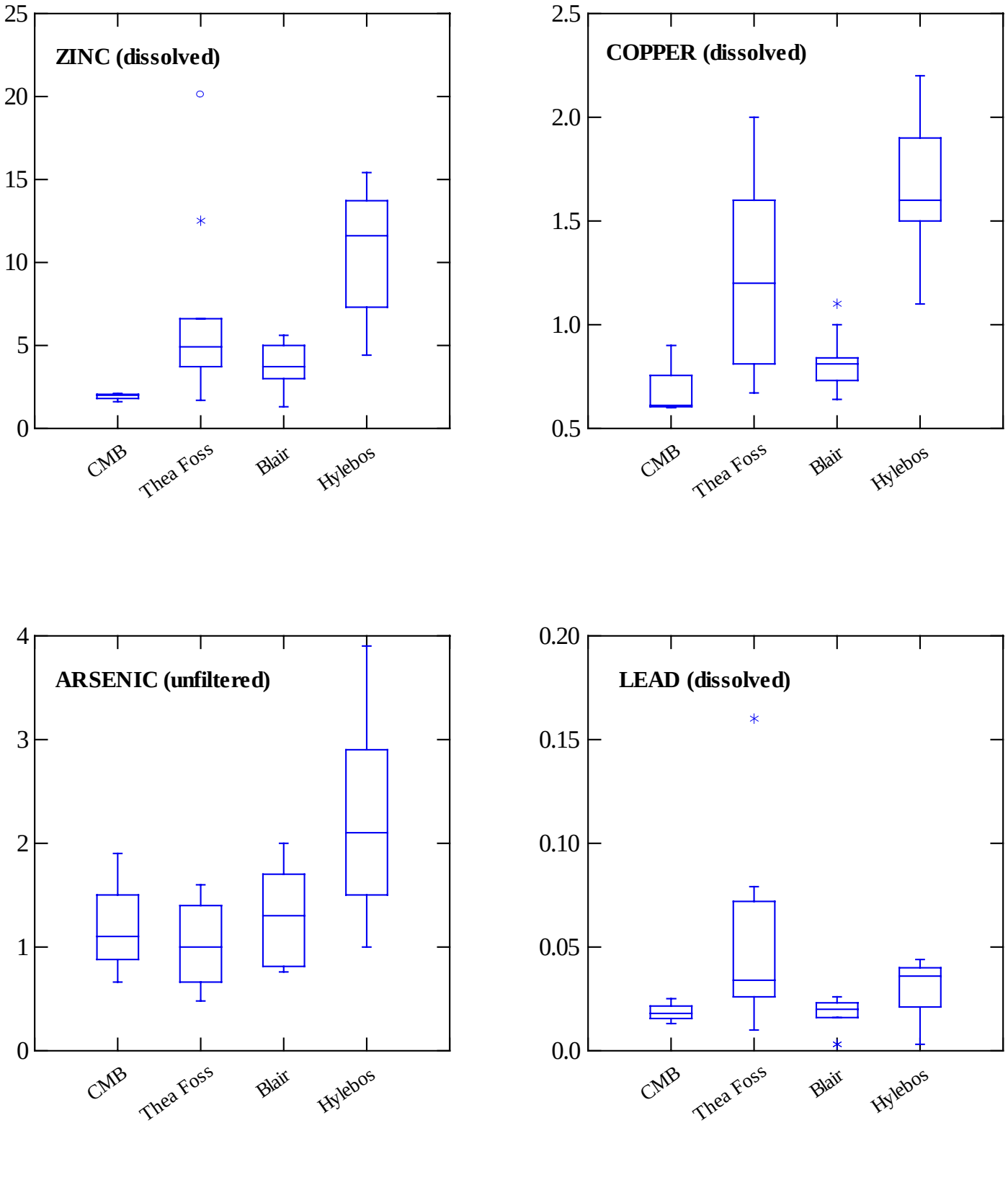

Figure 2. Zn, Cu, As, and Pb Concentrations in Surface Water Samples (ug/L; ppb)

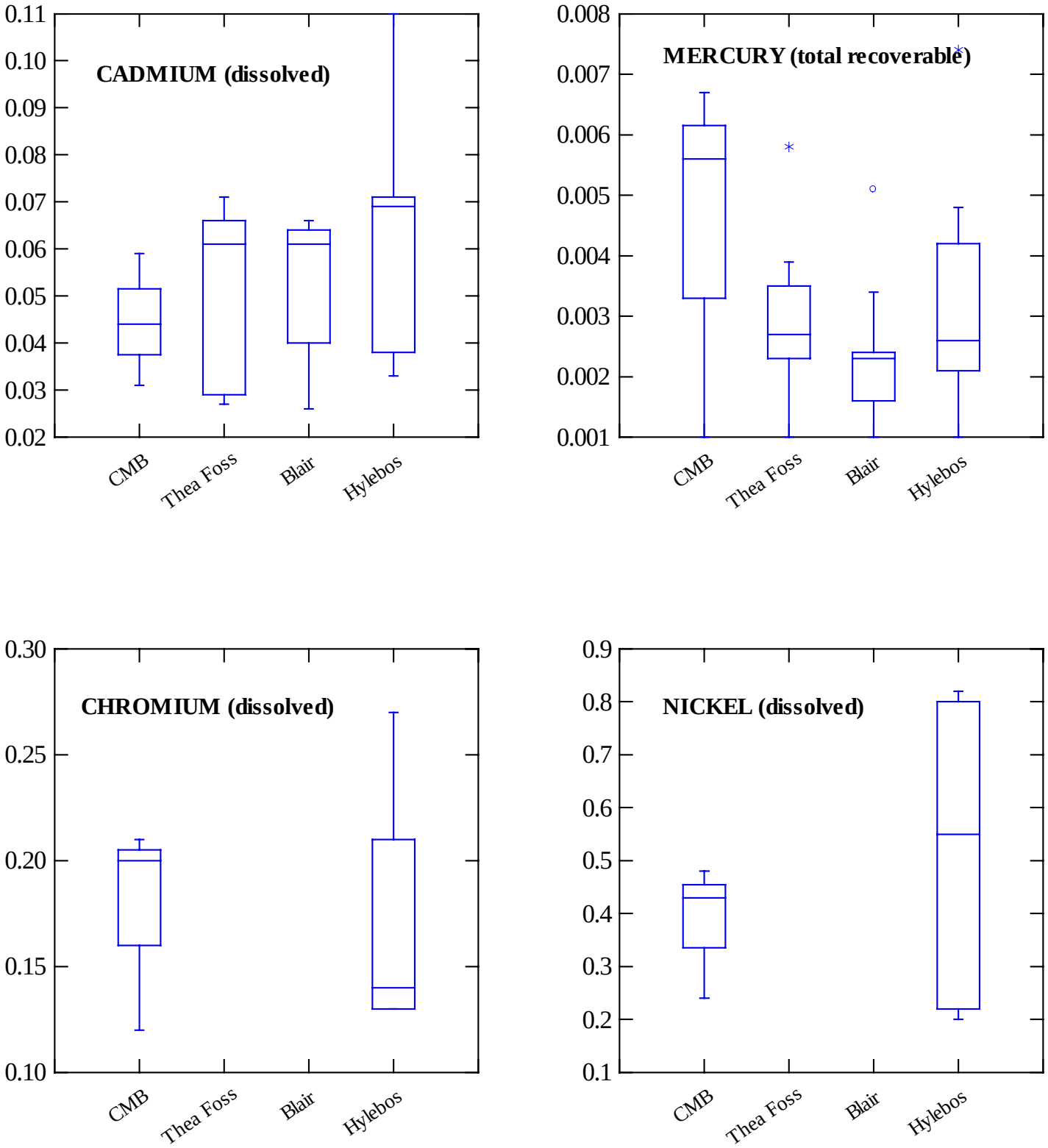

Figure 3. Cd, Hg, Cr, and Ni Concentrations in Surface Water Samples (ug/L; ppb)

waterways (parts per billion). One or two of the values recorded in Thea Foss Waterway for dissolved zinc, 12.5 and 20.1 ug/L, and dissolved lead, 0.16 ug/L, were high relative to other samples from this area.

Only three surface water samples were analyzed from the main bay. The concentrations of zinc, copper, arsenic, cadmium, and lead were low compared to the waterways. The limited data obtained on chromium and nickel suggest similar concentrations in the bay and in Hylebos Waterway.

Mercury concentrations were higher at the main bay station than in any of the three waterways, with a median of 0.0056 ug/L vs. medians of 0.0023 – 0.0027 ug/L (Figure 3). No good explanation could be found for the difference. The Puyallup River does not appear to be the source since mercury concentrations are normally less than 0.004 ug/L (Appendix D). Crecelius (1998) has reported similar mercury concentrations in Commencement Bay surface water (see Other Recent Data).

Sufficient samples were collected from the waterways for statistical tests. Results showed significant differences in surface water concentrations of zinc, copper, arsenic, and lead (Kruskall-Wallis, $p<0.05$). This can be seen in Figure 2. Zinc and copper were higher in Hylebos Waterway than either Thea Foss or Blair Waterways. Arsenic increased going from Thea Foss to Blair to Hylebos Waterway, with median values of 1.0, 1.3 and 2.1 ug/L, respectively. The highest levels of lead occurred in Thea Foss Waterway.

No significant between-waterway differences were found for cadmium, mercury, chromium, or nickel. Except for arsenic, Blair consistently showed the lowest surface water concentrations of metals among the three waterways.

Deep Water

Metals analysis of deep water was limited to three samples each from the main bay and center waterway stations. Table 7 summarizes the results for dissolved zinc, copper, lead, cadmium, chromium and nickel, unfiltered arsenic, and total recoverable mercury.

Samples from Hylebos Waterway tended to have the highest metals concentrations in deep water. Lead was an exception, where, as in surface water, Thea Foss Waterway was highest. The only metal that was consistently elevated in Hylebos deep water was dissolved zinc, which ranged from 2.8 – 8.3 ug/L compared to 0.56 – 2.6 ug/L at other stations.

Metals concentrations in deep water were generally lower than at the surface. Figures 4 and 5 compare the pooled data for the study area. Surface water concentrations were significantly higher for zinc, copper, and nickel ($p<.05$) and for lead ($p<0.1$) (Wilcoxon Signed Ranks). A single high value for mercury, 0.0098 ug/L, was recorded in a deep water sample from Blair Waterway, which otherwise had uniformly low levels of mercury (Figure 5). When this outlier is removed, the data show significantly higher mercury concentrations in surface vs. deep water ($p<.05$).

Table 7. Summary Statistics on Metals Concentrations in Deep (8m) Water Samples
[ug/L; parts per billion]

Metal	Location	n =	Median	Percentiles 25th	Percentiles 75th	Maximum
ZINC	Commencement Bay	3	1.5	1.0	1.9	2.0
(dissolved)	Thea Foss Waterway	3	1.8	1.3	2.4	2.6
	Blair Waterway	3	1.8	1.4	1.8	1.9
	Hylebos Waterway	3	3.6	3.2	7.4	8.3
COPPER	Commencement Bay	3	0.42	0.38	0.46	0.46
(dissolved)	Thea Foss Waterway	3	0.42	0.36	0.48	0.50
	Blair Waterway	3	0.49	0.46	0.58	0.60
	Hylebos Waterway	3	0.63	0.53	0.63	0.63
ARSENIC	Commencement Bay	3	1.2	1.1	1.5	1.5
(unfiltered)	Thea Foss Waterway	3	1.1	1.0	1.5	1.6
	Blair Waterway	3	1.2	1.1	1.5	1.6
	Hylebos Waterway	3	1.4	1.3	2.7	3.1
CADMIUM	Commencement Bay	3	0.064	0.052	0.071	0.072
(dissolved)	Thea Foss Waterway	3	0.064	0.052	0.066	0.067
	Blair Waterway	3	0.060	0.051	0.064	0.066
	Hylebos Waterway	3	0.064	0.052	0.075	0.078
LEAD	Commencement Bay	3	0.022	0.016	0.023	0.023
(dissolved)	Thea Foss Waterway	3	0.028	0.022	0.056	0.064
	Blair Waterway	3	0.009	0.008	0.021	0.024
	Hylebos Waterway	3	0.033	0.019	0.039	0.040
MERCURY	Commencement Bay	3	0.0011	0.0010	0.0057	0.0069
(tot. recoverable)	Thea Foss Waterway	3	0.0010	0.0009	0.0044	0.0052
	Blair Waterway	3	0.0013	0.0012	0.0081	0.0098
	Hylebos Waterway	3	0.0026	0.0021	0.0042	0.0074
CHROMIUM	Commencement Bay	3	0.20	0.17	0.22	0.22
(dissolved)	Hylebos Waterway	3	0.12	0.09	0.22	0.25
NICKEL	Commencement Bay	3	0.42	0.30	0.44	0.44
(dissolved)	Hylebos Waterway	3	0.44	0.32	0.47	0.48

Note: Statistics were calculated using 1/2 the detection limit for non-detected values.

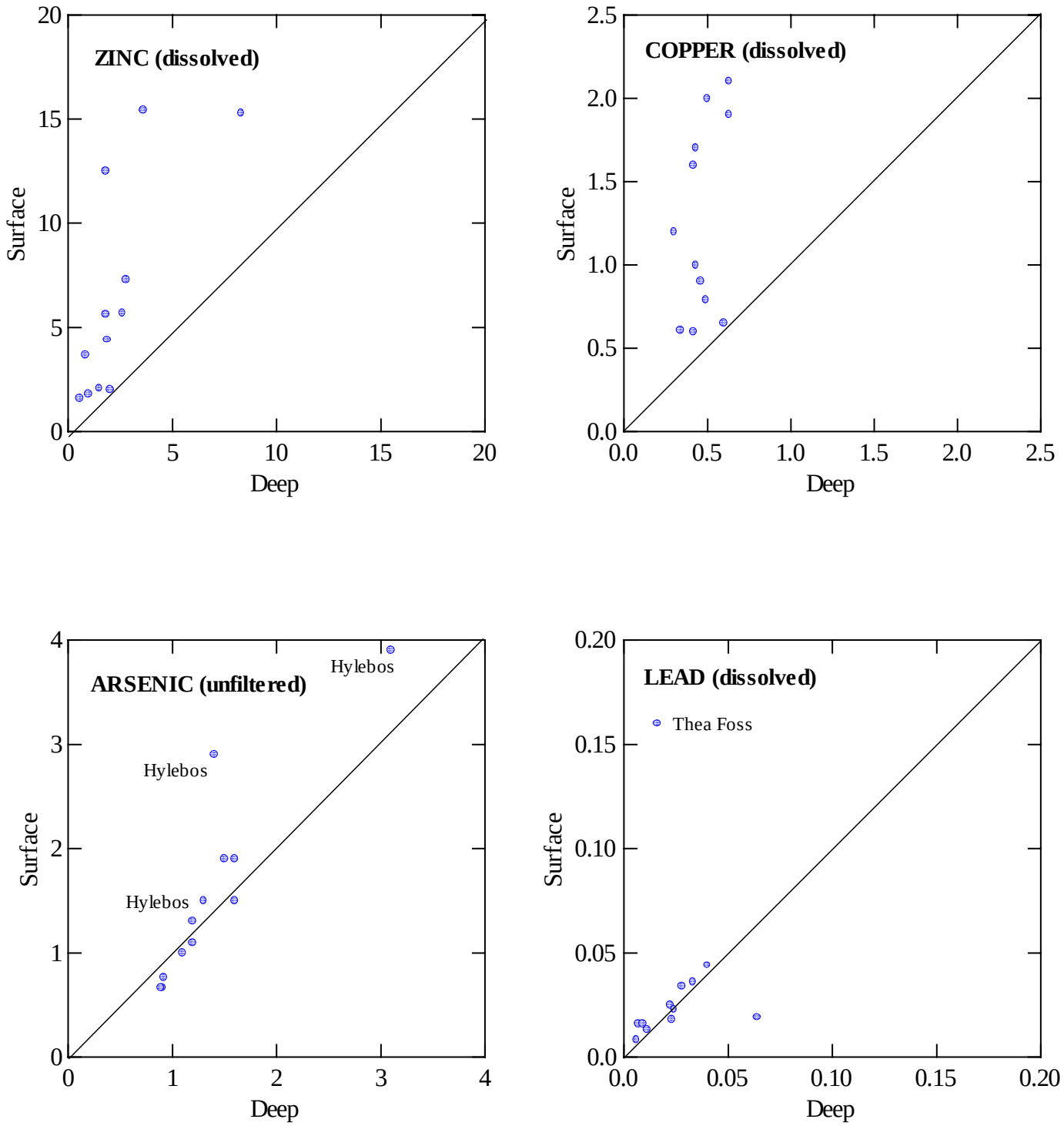

Figure 4. Surface vs. Deep Water Concentrations of Zn, Cu, As, and Pb (ug/L; ppb)

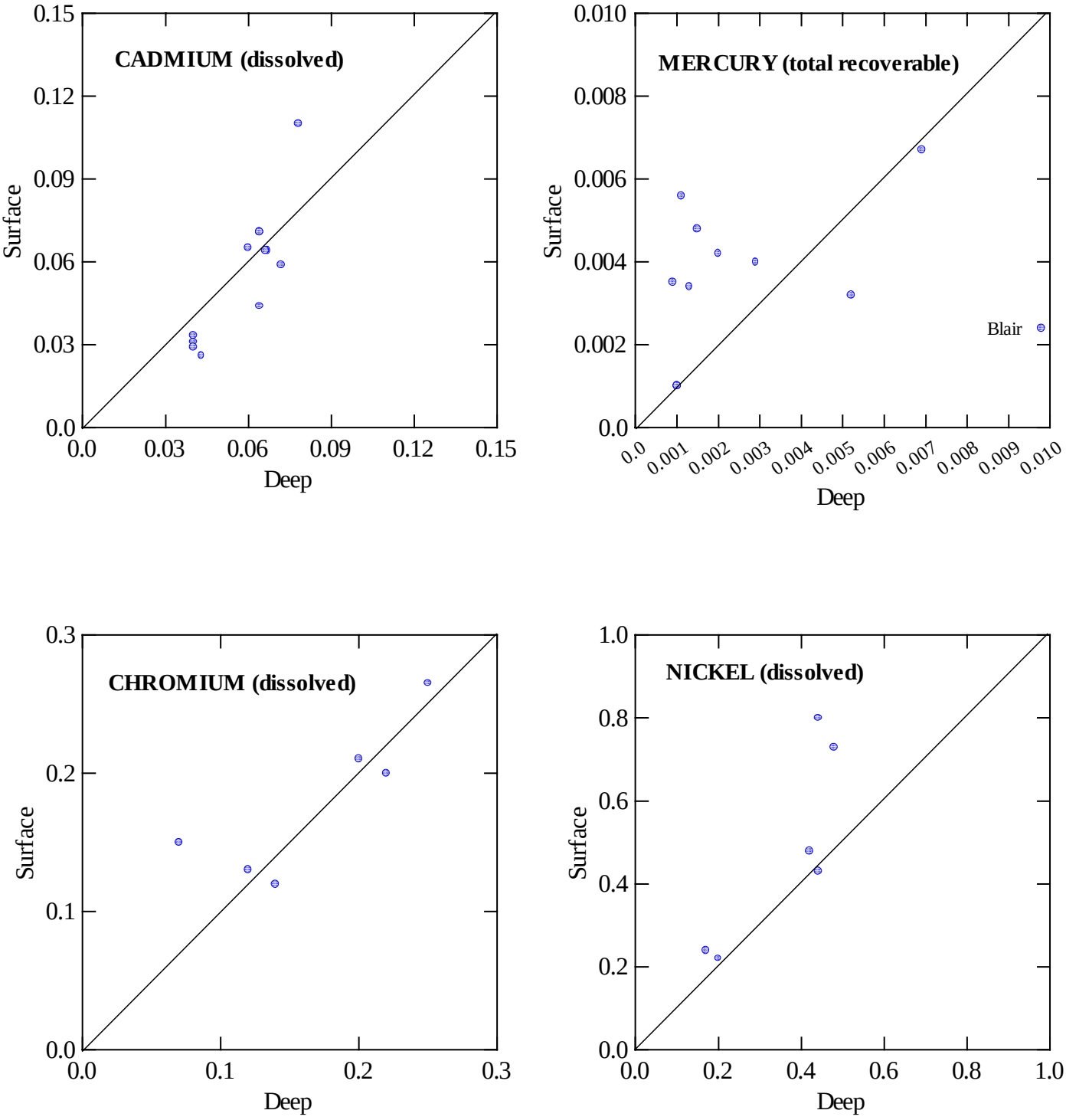

Figure 5. Surface vs. Deep Water Concentrations of Cd, Hg, Cr, and Ni (ug/L: ppb)

Metals not significantly enriched in surface water overall were arsenic, cadmium, and chromium. This general conclusion probably does not hold for the Hylebos, where arsenic concentrations were higher at the surface for each of the three sampling periods (Figure 4).

Seasonal Differences

Sampling frequency did not allow strong conclusions to be made about seasonal changes in metals concentrations. The only pattern observed consistently was for zinc and arsenic.

At all ten sampling stations, zinc and arsenic were at their highest concentrations in November. Concentrations decreased at all sites in March, followed by minimum concentrations in August. This occurred in both surface and deep water. The somewhat low recovery of arsenic in the SRMs analyzed with the August sample set (see Data Quality) does not entirely account for the reductions seen in the field samples.

In surface water samples from Thea Foss Waterway and inner Blair Waterway, zinc and arsenic were correlated with salinity (r^2 = 0.64 - 0.99), suggesting a relationship with runoff. There was an inconsistent relationship with salinity in Hylebos surface water and no clear relation to TSS or turbidity.

The zinc and arsenic decrease in deep water occurred without a corresponding change in salinity of more than 1 or 2 ‰. TSS and turbidity also did not track the changes in deep water, the lowest values for these parameters being in March.

Other Recent Metals Data

Commencement Bay

Crecelius (1998) analyzed metals in surface (1 meter) samples collected from a grid of ten stations in the center of Commencement Bay on July 11, 1997. This effort was part of a larger study to determine metals background in receiving waters near refineries, conducted for the Western States Petroleum Association. Sampling and analytical methods were identical to those of the present study. The complete data for Commencement Bay are in Appendix E.

Ecology's 1997-98 surface water data for the main bay are compared to Crecelius' results in Table 8. Except for zinc, there is excellent agreement between the two sets of data. The lower zinc concentrations reported by Crecelius are largely due to these data being blank-corrected by 0.66 ug/L (Appendix E).

Similar concentrations of zinc, copper, arsenic, cadmium, lead, and nickel were reported for Commencement Bay water samples collected in the mid-1980s (Paulson et al., 1991a,b; Stinson and Norton, 1987). Mercury and chromium were not analyzed in these studies.

Table 8. Comparison of Recent Data on Metals in Commencement Bay Surface Water
(median values in ug/L; parts per billion)

Metals	Dissolved		Unfiltered/Tot. Recoverable	
	present study (n=3)	Crecelius (1998) (n=10)	present study (n=3)	Crecelius (1998) (n=10)
ZINC	2.0	0.57	2.4	1.0
COPPER	0.61	0.56	0.92	0.94
ARSENIC	0.68*	0.92	1.1	1.0
CADMIUM	0.044	0.058	0.047	0.061
LEAD	0.018	0.010	0.058	0.066
MERCURY	- -	0.0002	0.0056	0.0079
CHROMIUM	0.20	0.10	0.30	0.20
NICKEL	0.43	0.39	0.43	0.48

*n=1

Waterways

Recent metals data on Commencement Bay waterways are limited to total recoverable. Zinc and lead have been analyzed in Blair Waterway by Reichhold Chemicals Inc., and copper, arsenic, lead, and nickel in Hylebos Waterway by Occidental Chemical Corp. Elf Atochem analyzed metals in water samples collected from the Hylebos in 1993, but detection levels were too high to produce useful data (Boateng & Associates, 1993).

This information, summarized in Table 9 along with Ecology's 1997-98 data, was obtained in connection with NPDES permits for these facilities. The Reichhold data are from 1997-98, as contained in their Discharge Monitoring Reports. The Occidental data are in their permit; the most recent 1995-96 data were used.

Inspection of Table 9 shows that, with the exception of Occidental's data on copper in Hylebos Waterway, the NPDES data are inaccurate, overstating concentrations of zinc, lead, and nickel by one-to-two orders of magnitude.

Water Quality Criteria

Table 10 compares the metals concentrations measured in surface and deep water samples to state and EPA water quality criteria for marine life (WAC 173-201A; 11/18/97 update). All concentrations were well within the acute criteria and few metals approached the chronic criteria. The maximum concentrations measured for dissolved cadmium, lead, chromium, and nickel were between 10 and 150 times lower than the chronic criteria. Copper, mercury, zinc, and arsenic were 10 times less than chronic levels.

Figure 6 compares the copper, mercury, zinc, and arsenic concentrations to the chronic criteria. The higher of the dissolved copper concentrations in Thea Foss and Hylebos Waterways were within 50% - 70% of the chronic criterion. Total recoverable mercury reached about 30% of the chronic criterion in the bay and in each waterway. Dissolved zinc was at or below approximately 20 % of the chronic criterion in all areas. All concentrations of arsenic were less than 10% of the dissolved criterion.

EPA has set water quality criteria for arsenic, mercury, and nickel to protect human health from consumption of aquatic organisms that accumulate these metals (National Toxics Rule, 40 CFR Part 131). The criteria are: arsenic - 0.14 ug/L, mercury - 0.15 ug/L, and nickel - 4,600 ug/L. Mercury and nickel concentrations in Commencement Bay are far below the EPA human health criteria.

Although the criterion for arsenic is exceeded in all parts of Commencement Bay, this value is substantially below the natural background in seawater. There is significant uncertainty regarding the accuracy of the current arsenic criteria for human health. Even EPA is reluctant to impose the arsenic criteria (62 FR 42179, August 5, 1997) promulgated through the National Toxic Rule. Ecology is currently considering revising the arsenic standard (Butkus, 1998).

Table 9. NPDES Data[1] Compared to Present Study Results[2] for Blair and Hylebos Waterways
[ug/L; parts per billion]

Metal	Investigator	n =	Median	Percentiles 25th	Percentiles 75th	Maximum
		Blair Waterway				
ZINC	Reichhold: mid-depth	3	44	32	51	57
	Ecology: surface	5	5.6	5.2	6.5	8.4
	Ecology: deep	3	2.7	2.1	4.5	6.3
LEAD	Reichhold: mid-depth	3	4.5	3.7	4.8	5
	Ecology: surface	5	0.22	0.08	0.32	0.41
	Ecology: deep	3	0.059	0.059	0.061	0.062
		Hylebos Waterway				
COPPER	Occidental: saltwater intake	18	2	1	2	5
	Ecology: surface	6	2.6	2.2	3.2	3.5
	Ecology: deep	3	0.75	0.74	0.86	0.98
LEAD	Occidental: saltwater intake	18	2	2	3	5
	Ecology: surface	6	0.19	0.14	0.45	0.86
	Ecology: deep	3	0.16	0.13	0.19	0.23
NICKEL	Occidental: saltwater intake	18	2	1	3	8
	Ecology: surface	6	0.52	0.26	0.9	1.2
	Ecology: deep	3	0.48	0.36	0.54	0.6

[1]Total recoverable metals

[2]Unfiltered metals

Table 10. Water Quality Criteria for Protection of Marine Life (ug/L; parts per billion)

Metal	Acute[1]	Chronic[2]	Concentrations in Commencement Bay and Waterways during 1997 - 98
Zinc (dissolved)	90	81	0.86 - 20.1
Copper (dissolved)	4.8	3.1	0.34 - 2.2
Arsenic (dissolved)	69	36	0.48 - 4.0 (unfiltered)
Lead (dissolved)	210	8.1	<0.006 - 0.16
Cadmium (dissolved)	42	9.3	0.026 - 0.11
Mercury (dissolved)	1.8	- -	- -
Mercury (total recoverable)	- -	0.025	<0.002 - 0.0098
Chromium (dissolved)	1100	50	0.07 - 0.33
Nickel (dissolved)	74	8.2	0.17 - 0.82

Source: WAC 173-201A (11/18/97 update)

[1]One-hour average, not to be exceeded more than once every three years on average

[2]Four-day average, not to be exceeded more than once every three years on average

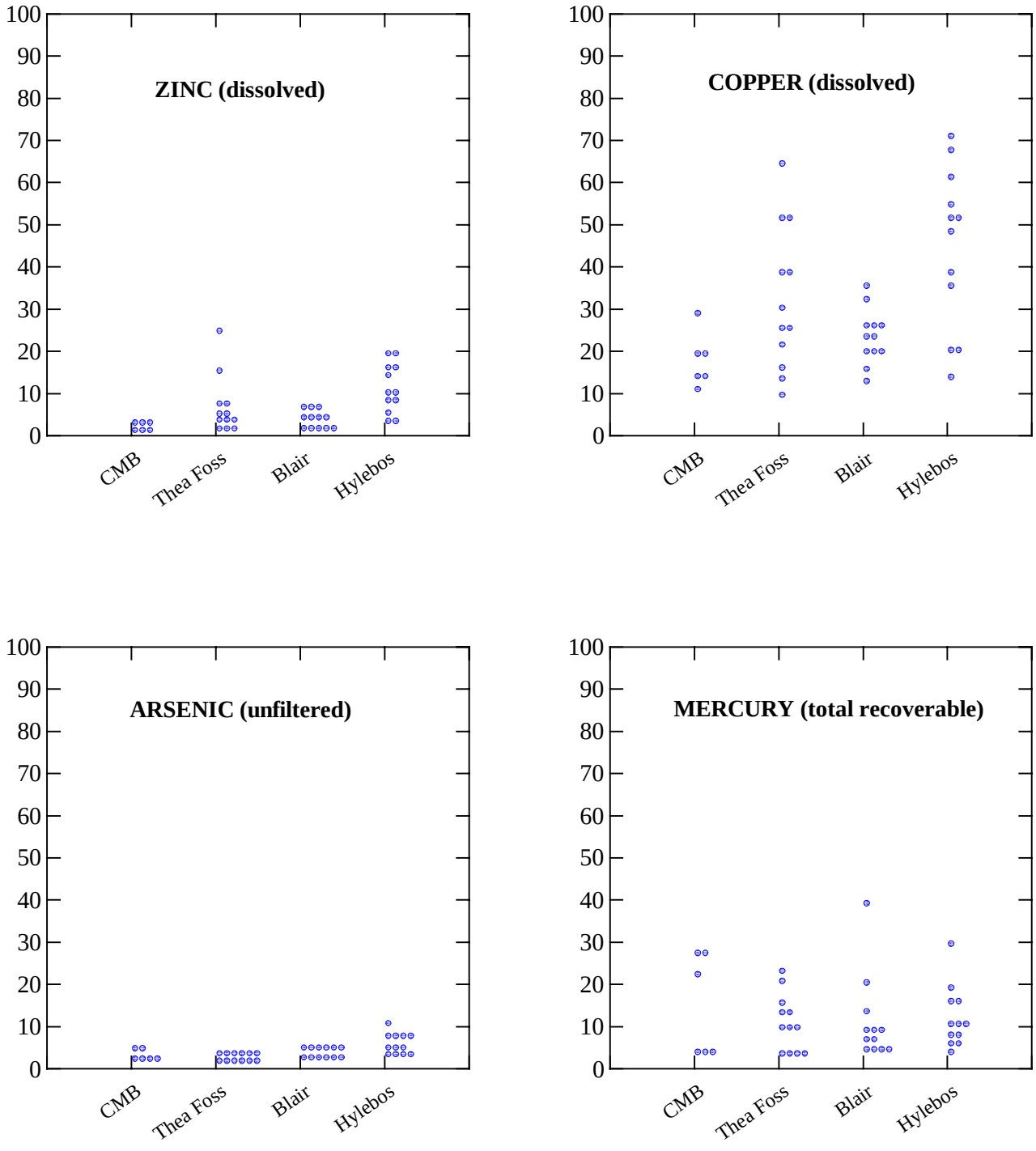

Figure 6. Zn, Cu, As, and Hg Concentrations as Percent of Chronic Water Quality Criteria

Dissolved Metals Fraction

By regulation, NPDES permit limits for metals must be based on total recoverable. A metals "translator" is therefore required to determine what fraction of metal in an effluent will be dissolved in the receiving water. The translator can be: 1) assumed to be equal to the EPA water quality criteria conversion factors for total recoverable to dissolved metals; 2) developed from partition coefficients related to TSS or other parameters; or 3) measured directly in the receiving waters as the ratio of dissolved to total recoverable metal (EPA, 1996).

Table 11 shows metals translators derived from the pooled surface water and pooled deep water data collected in the present study and the Crecelius (1998) surface water data for the main bay. The EPA criteria conversion factors are also listed for comparison (EPA, 1995b). For the Ecology data set, three outliers with zinc or cadmium ratios >>1 were deleted. Three non-detects each for dissolved lead (Ecology data) and dissolved mercury (Crecelius data) were set at half the detection limit, as recommended by Ecology's TMDL Workgroup (1996).

Except for zinc, as previously mentioned, the dissolved metals fractions measured in these two studies are similar. Metals that are primarily in a dissolved state are zinc, copper, arsenic, cadmium, chromium, and nickel. Lead and mercury are more strongly associated with particulates.

The 95th percentile value is recommended for deriving permit limits based on metals ratios in the receiving water (TMDL Workgroup, 1996). As shown in Table 11, for most metals, the 95th percentile of the field-derived ratios for Commencement Bay are almost identical to the EPA conversion factors. However, for lead and, to a lesser extent, mercury, use of conversion factors in setting permit limits will overestimate the dissolved fraction in the receiving waters. The EPA conversion for lead is high by factors of 2 to 5.

Historical Data

Relatively few of the historical studies on Commencement Bay waterways included water column samples for metals. EPA (1980), Dames & Moore (1981), and Norton & Johnson (1985) conducted three surveys in the early 1980s that focused on metals in Blair and Hylebos Waterways. Total recoverable metals were analyzed.

Multiple sources of arsenic, zinc, copper, and lead were in existence at that time. EPA (1980) for example, reported 7,500 – 12,000 ug/L of arsenic in Pennwalt (now Elf Atochem) storm drains to Hylebos Waterway and 219 ug/L of lead in Hooker (now Occidental Chemical) effluent. The source of the arsenic at Pennwalt was buried sludges from manufacture of arsenical pesticides.

In a year-long Ecology study, Norton & Johnson (1985) measured metals in runoff from twelve log sort yards in Commencement Bay. Ten of the yards had high concentrations from ASARCO slag used as ballast to stabilize soils in areas of heavy vehicle traffic. Nine

Table 11. Dissolved Metals Fractions in Commencement Bay

Metal	Location	n =	Median	95th Percentile	EPA Conversion Factor
ZINC	Surface Water [1]	10	0.72	0.92	0.946
	Surface Water[2]	22	0.89	1.0	
	Deep Water[2]	9	0.67	0.96	
COPPER	Surface Water [1]	10	0.68	0.84	0.83
	Surface Water[2]	22	0.69	0.86	
	Deep Water[2]	12	0.73	0.88	
ARSENIC	Surface Water [1]	10	0.92	0.94	1.00
	Surface Water[2]	11	0.96	1.0	
	Deep Water[2]	4	0.93	0.99	
CADMIUM	Surface Water [1]	10	0.94	1.0	0.994
	Surface Water[2]	22	0.85	1.0	
	Deep Water[2]	12	0.93	1.0	
LEAD	Surface Water [1]	10	0.13	0.20	0.951
	Surface Water[2]	22	0.14	0.37	
	Deep Water[2]	12	0.17	0.48	
MERCURY	Surface Water [1]	10	0.31	0.70	0.85
	Surface Water[2]	0	na	na	
	Deep Water[2]	0	na	na	
CHROMIUM	Surface Water [1]	10	0.51	0.74	0.993
	Surface Water[2]	7	0.64	0.91	
	Deep Water[2]	6	0.73	0.88	
NICKEL	Surface Water [1]	10	0.82	1.0	0.99
	Surface Water[2]	7	0.81	1.0	
	Deep Water[2]	6	0.88	0.99	

[1]Crecelius (1998) - main bay

[2]present study - main bay and waterways
na = dissolved mercury not analyzed

of these were located on Blair and Hylebos Waterways. These two waterways received yard runoff with combined annual loads estimated at 8.2 tons of arsenic, 3.7 tons of zinc, 1.7 tons of copper, and 0.9 tons of lead (Tetra Tech, 1985).

Cleanups and source controls are now in place for all known metals sources to Blair and Hylebos Waterways (Smith, 1998; Smith et al., in prep.). Additional metals sources included rock wool manufacture (from slag), metals scrap yards, landfills (with slag), marinas, and ship builders.

The data in EPA (1980), Dames & Moore (1981), and Norton & Johnson (1985) show that log sort yard runoff and other discharges were resulting in high levels of arsenic, zinc, copper, and lead in Blair and Hylebos Waterways. Their waterway data on arsenic and zinc are summarized in Tables 12 and 13. Arsenic concentrations in center channel were reported to reach 50 ug/L or more. Nearshore samples collected adjacent to sort yards had up to 180 ug/L arsenic. Similar elevations were seen for zinc, with concentrations up to 155 ug/L near the yards.

The Ecology data give a snapshot of conditions during May 1984. Figures 7 and 8 plot center channel concentrations of arsenic and zinc. Also shown are arsenic and zinc concentrations in runoff from several of the yards and in two tributaries, Hylebos and Wapato Creeks, sampled at the same time. Upstream disposal of slag was also a metals source to the creeks (Johnson & Norton, 1985). Inserts to these figures include the range of arsenic and zinc concentration measured in whole water samples collected during the present study.

Arsenic and zinc can be seen to have been substantially elevated in both waterways in the vicinity of log sort yards. Concentrations decreased with distance from sources, approaching levels currently seen in the outer bay.

Arsenic levels in Blair and Hylebos Waterways are now an order of magnitude lower than in 1984. Present-day concentrations of zinc in Blair Waterway are also an order of magnitude below historic levels. Less of a zinc decrease seems to have occurred in the Hylebos, where concentrations up to 18 ug/L (unfiltered) were measured in 1997-98, about half of the higher concentrations recorded in the 1980s.

The complete waterway data from the Ecology 1984 survey are included as Appendix F. Although similar water quality improvements likely occurred for copper and lead, the accuracy of this era's data on copper and lead in seawater is uncertain (Kammin, 1998; Patterson & Settle, 1976).

Metals Background in Puget Sound

Data on metals concentrations in incoming seawater to Puget Sound were reviewed to assess which metals are elevated in Commencement Bay and by how much. Table 14 summarizes the best information currently available on background levels of zinc, copper, arsenic, cadmium, lead, mercury, chromium, and nickel.

Table 12 . Arsenic Concentrations in Blair and Hylebos Surface Water during the 1980s
[total recoverable metal in ug/L; parts per billion)

Approximate Location (proceeding upstream)	Center Channel Transect			Nearshore
	Dames&Moore Dec-80	EPA Jun-80	Ecology May-84	Ecology May-84
Blair Waterway				
Entrance	<20	**6**	**3**	- -
Off Pier No. 4	- -	**9**	**8**	- -
11th Avenue	- -	**9**	- -	- -
Midway 11th & Lincoln	- -	- -	**34**	- -
Lincoln Ave	- -	**9**	**59**	**120**
Murray Pacific Yard, downstream end	- -	- -	- -	**88**
Murray Pacific Yard, middle	- -	- -	**8**	**40**
Murray Pacific Yard, upstream end		- -	- -	**13**
Turning Basin Entrance	- -	- -	**1**	- -
Center Turning Basin	- -	**12**	**13**	- -
NE Corner Turning Basin	- -	- -	**16**	- -
Wapato Creek	<20	**3**	**36**	- -
Hylebos Waterway				
Entrance	<20	**9**	**8**	- -
Midway 11th & Lincoln	- -	- -	**18**	- -
11th Street	**50**	**15**	- -	- -
Lincoln Ave	- -	- -	**15**	**80**
Murray Pacific Yard, downstream end	- -	- -	- -	**38**
Murray Pacific Yard, upstream end	- -	- -	- -	**68**
Lower Turning Basin	**30**	- -	**18**	- -
Between Turning Basins	- -	- -	**18**	- -
Upper Turning Basin	**50**	**30**	**13**	- -
Off Hylebos Creek	- -	- -	**37**	- -
Wasser/Winters Yard, south end	- -	- -	- -	**56**
Wasser/Winters Yard, north end	- -	- -	- -	**48**
Hylebos Creek	- -	**51**	**28**	- -
Field Blank	none analyzed	<2	<1	<1

Table 13. Zinc Concentrations in Blair and Hylebos Surface Water during the 1980s
[total recoverable metal in ug/L; parts per billion)

Approximate Location (proceeding upstream)	Center Channel Transect			Nearshore
	Dames&Moore Dec-80	EPA Jun-80	Ecology May-84	Ecology May-84
Blair Waterway				
Entrance	**14**	**40**	**8**	- -
Off Pier No. 4	- -	**20**	**12**	- -
11th Avenue	- -	**25**	- -	- -
Midway 11th & Lincoln	- -	- -	**33**	- -
Lincoln Ave	- -	**25**	**87**	**72**
Murray Pacific Yard, downstream end	- -	- -	- -	**35**
Murray Pacific Yard, middle	- -	- -	- -	**15**
Murray Pacific Yard, upstream end		- -	**14**	**10**
Turning Basin Entrance	- -	- -	**1**	- -
Center Turning Basin	- -	**30**	**17**	- -
NE Corner Turning Basin	- -	- -	**23**	- -
Wapato Creek	**15**	**30**	**36**	- -
Hylebos Waterway				
Entrance	**15**	**30**	**1**	- -
Midway 11th & Lincoln	- -	- -	**10**	- -
11th Street	**23**	**40**	- -	- -
Lincoln Ave	- -	- -	**7**	**155**
Murray Pacific Yard, downstream end	- -	- -	- -	**36**
Murray Pacific Yard, upstream end	- -	- -	- -	**32**
Lower Turning Basin	**31**	- -	**19**	- -
Between Turning Basins	- -	- -	**27**	- -
Upper Turning Basin, Center	**33**	**30**	**24**	- -
Off Hylebos Creek	- -	- -	**36**	- -
Wasser/Winters Yard, south end	- -	- -	- -	**56**
Wasser/Winters Yard, north end	- -	- -	- -	**48**
Hylebos Creek	- -	**45**	**35**	- -
Field Blank	none analyzed	**20**	<1	<1

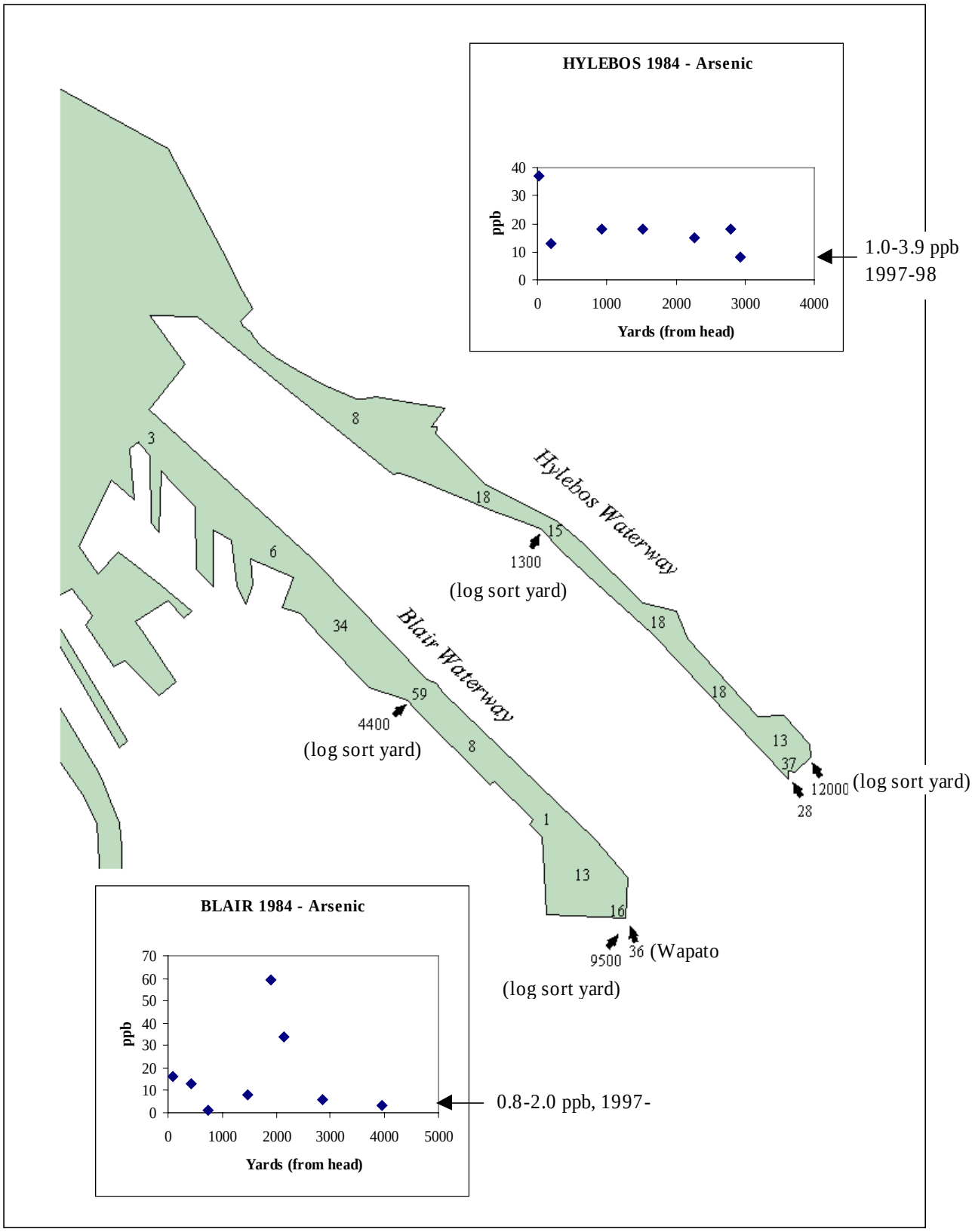

Figure 7. Arsenic Concentrations in Blair and Hylebos Waterways during May 1984 with the Range of Concentrations Measured in 1997-98 Indicated on Graph Inserts (ug/L; ppb)

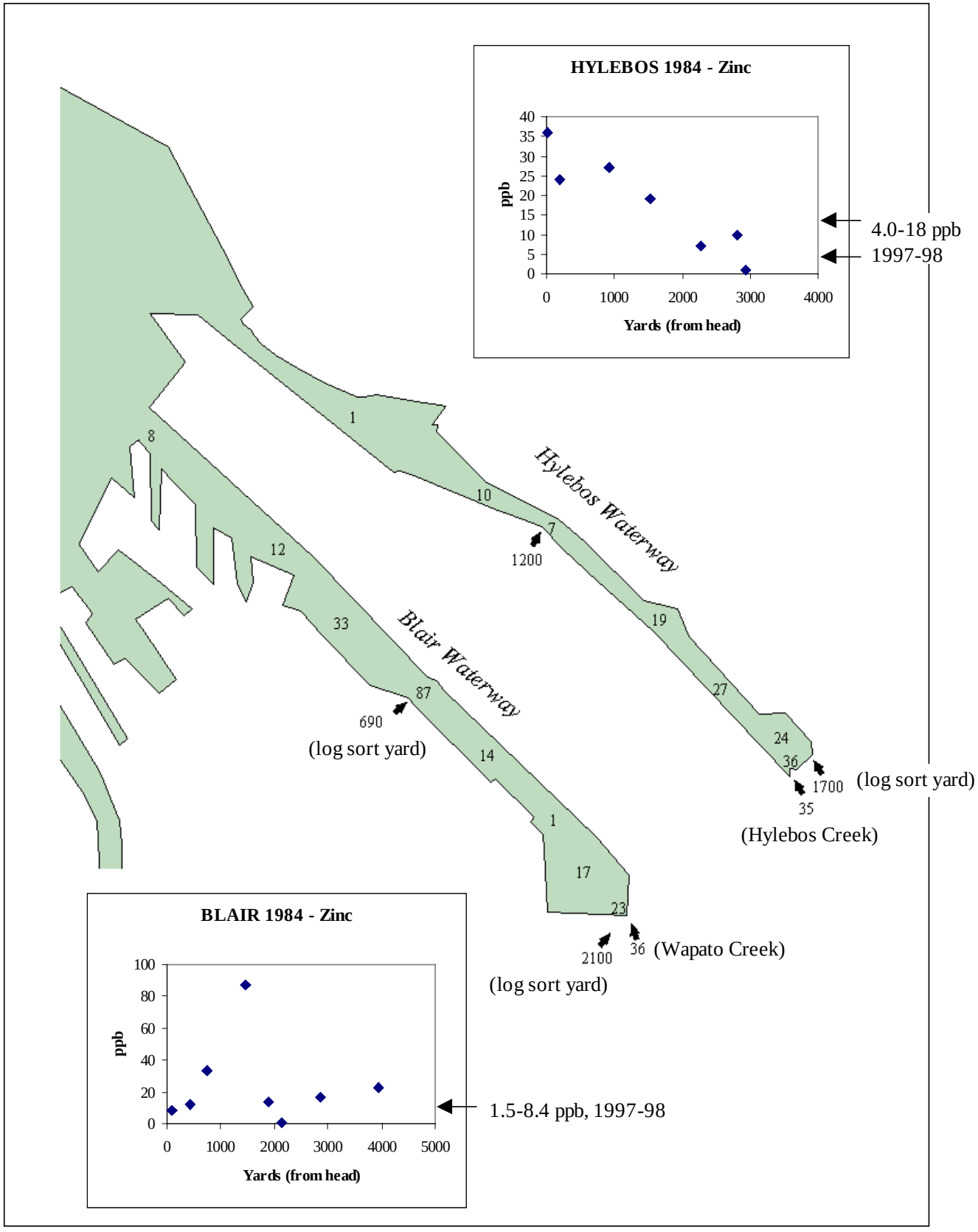

Figure 8. Zinc Concentrations in Blair and Hylebos Waterways during May 1984 with the Range of Concentrations Measured in 1997-98 Indicated on Graph Inserts (ug/L; ppb)

Table 14. Background Metals Concentrations for Puget Sound Compared to Commencement Bay
[average concentrations in ug/L; parts per billion)

Location	Depth (meters)	n =	Dissolved						Total Recoverable		Reference
			Zn	Cu	Cd	Pb	Cr	Ni	As	Hg	
Background											
Eastern Juan de Fuca Strait	140-270	4	0.19	0.14	0.089	0.015	- -	0.27	- -	- -	Paulson et al. (1988, 1991a,b)
Central Juan de Fuca Strait	180	10	0.53	0.14	0.086	0.025	0.30	0.29	1.7	0.0003	Romberg et al. (1984)
Central Juan de Fuca Strait	100	6	- -	- -	- -	- -	- -	- -	- -	0.0002	Bloom & Crecelius (1983)
Admiralty Inlet	"bottom"	25	- -	- -	- -	- -	- -	- -	1.6	- -	Carpenter et al. (1978)
Commencement Bay - Deep	8								Unfiltered/Tot. Rec.		
Commencement Bay		3	1.5	0.42	0.064	0.022	0.20	0.42	1.2	0.0011	present study (medians)
Thea Foss Waterway		3	1.8	0.42	0.064	0.028	- -	- -	1.1	0.0010	"
Blair Waterway		3	1.8	0.49	0.060	0.009	- -	- -	1.2	0.0013	"
Hylebos Wateway		3	3.6	0.63	0.064	0.033	0.12	0.44	1.4	0.0026	"
Commencement Bay - Surface	0.5										
Commencement Bay		3	2.0	0.61	0.044	0.018	0.20	0.43	1.1	0.0056	present study (medians)
Thea Foss Waterway		9	4.9	1.2	0.061	0.034	- -	- -	1.0	0.0027	"
Blair Waterway		9	3.7	0.81	0.061	0.020	- -	- -	1.3	0.0024	"
Hylebos Wateway		9	11.6	1.6	0.069	0.036	0.14	0.55	2.1	0.0026	"

These results are for bottom water samples collected at depths of 100 meters or more in the Strait of Juan de Fuca and the Admiralty Inlet entrance to north Puget Sound. The analyses were conducted by the Battelle Sequim Laboratory, NOAA Pacific Marine Environmental Laboratory, and University of Washington, Department of Oceanography (arsenic). Clean sampling techniques and low-level analytical methods were used.

Based on these data, the average concentrations of dissolved metals in clean seawater flowing into Puget Sound are approximately as follows: zinc - 0.36 ug/L, copper - 0.14 ug/L, cadmium - 0.088 ug/L, lead - 0.020 ug/L, chromium - 0.30 ug/L, and nickel - 0.28 ug/L. For total recoverable arsenic and mercury, average background concentrations are about 1.6 ug/L and 0.0002 ug/L, respectively. The arsenic data from these studies may be biased slightly high (Eric Crecelius, personal communication).

Figures 9 and 10 illustrate, in general terms, how metals concentrations in Commencement Bay compare to background, based on ratios with median values from the present study. Ratios less than 1.0 for cadmium may reflect dilution within Puget Sound.

Metals elevated over background by a factor of approximately 5 or more – including deep water samples from the main bay – are zinc, copper, and mercury. Metals only slightly above background (less than a factor of 2) are lead in Thea Foss and Hylebos Waterways, arsenic in Hylebos Waterway, and nickel in Commencement Bay and Hylebos Waterway. Cadmium does not appear elevated in any area, nor chromium, based on limited samples.

Crecelius (1998) concluded that the metals generally found to be elevated in Puget Sound urban bays are zinc, copper, lead, mercury, nickel, and chromium, while cadmium and arsenic are not enriched. Historical data show arsenic concentrations in surface water in the main part of Commencement Bay were once at 2.0 – 2.5 ug/L, concentrations not seen elsewhere in Puget Sound at that time (Carpenter et al., 1978). Current arsenic levels in the main bay have decreased by almost half. Results from Ecology's 1997-98 survey indicate that elevations in arsenic are now primarily restricted to Hylebos Waterway and that these are moderate.

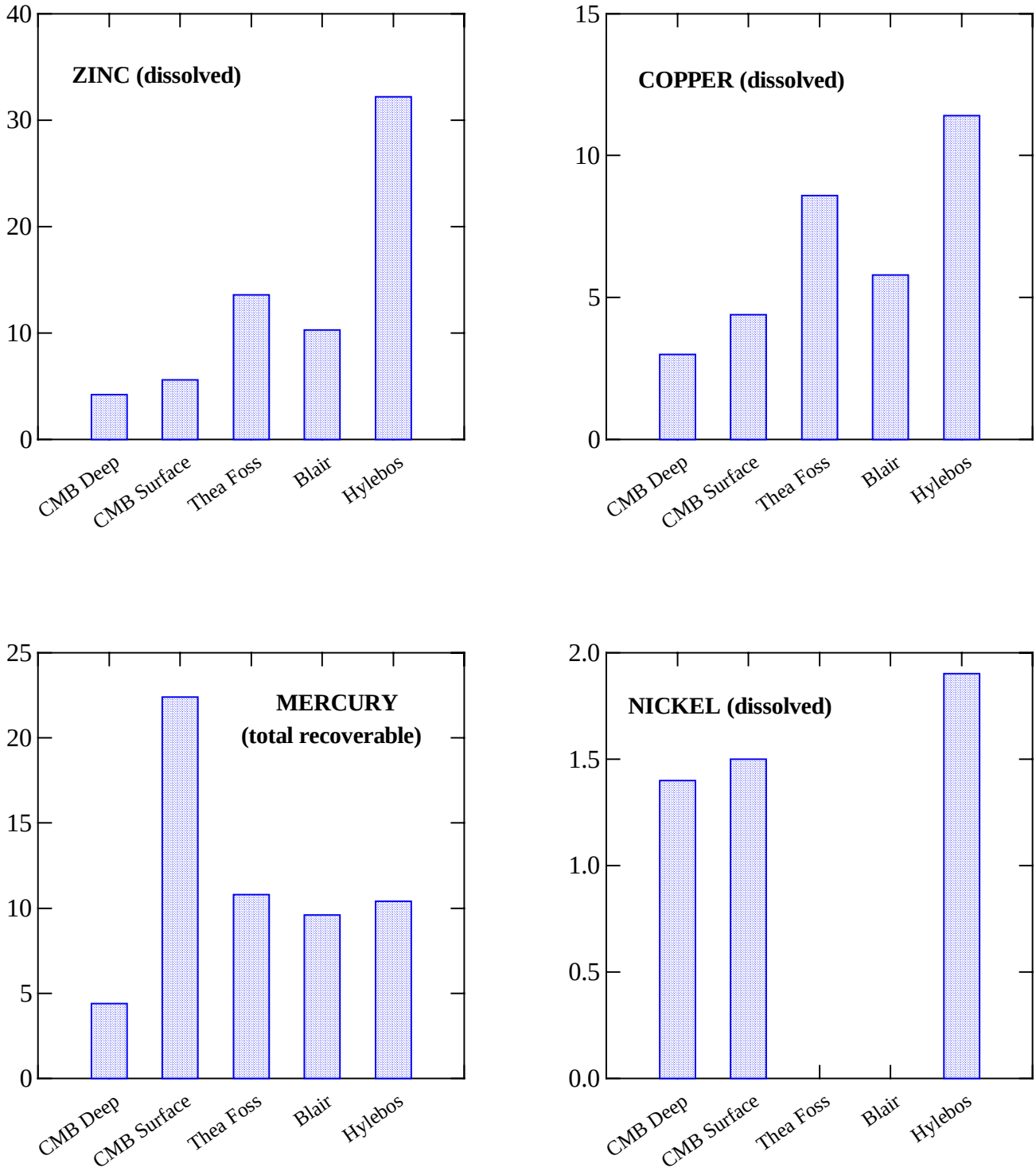

Figure 9. Elevations over Background for Zn, Cu, Hg, and Ni in Commencement Bay

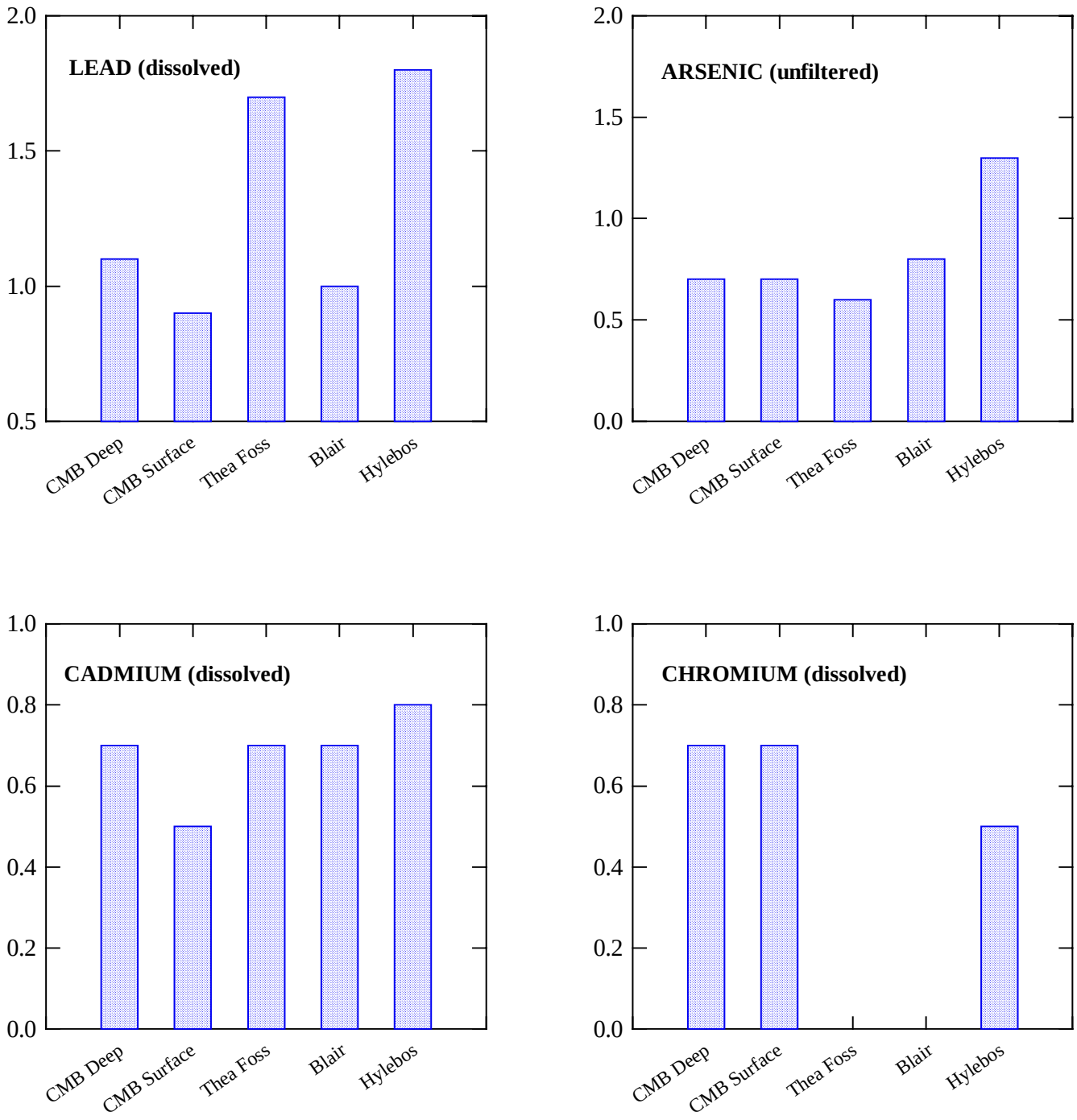

Figure 10. Elevations over Background for Pb, As, Cd, and Cr in Commencement Bay

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Appendix A

Appendix A. Sampling Stations for Ecology 1997-98 Commencement Bay Metals Study

Location	Description	Latitude (47^{o})	Longitude (122^{o})
Commencement Bay	Middle of bay, 1.3 miles off Sitcum Waterway	17.00"	26.00"
Thea Foss Waterway @ mouth	Approximately 200 yards inside entrance	15.57"	26.18"
Thea Foss Waterway @ middle	Off entrance to Wheeler-Osgood Waterway	15.12"	25.88"
Thea Foss Waterway @ head	Midway 96" storm drains and Pick's Cove	14.58"	25.85
Blair Waterway @ mouth	Approximately 200 yards inside entrance, off Pier No. 2	16.63"	24.68"
Blair Waterway @ middle	Approximately 100 yards downstream of Lincoln Avenue storm drain	15.88"	23.38"
Blair Waterway @ head	Center of turning basin	15.33"	22.75"
Hylebos Waterway @ mouth	Approximately 200 yards inside entrance, off downstream (NW) end of Occidental* facility	16.91"	24.32"
Hylebos Waterway @ middle	Midway between Lincoln Avenue storm drain and Elf Atochem facility	16.34"	22.75"
Hylebos Waterway @ head	Cener of upper turning basin	15.77"	21.72"

*now Pioneer

Appendix B

Appendix B. QA Data for Ecology 1997-98 Commencement Bay Metals Samples (ug/L; ppb)

QA Sample		Cu	Cd	Pb	Zn	Cr	Ni	As	Hg
		November 21, 1997 Sample Set - Battelle Laboratory							
Standard Reference Material									
1643d	Result	20.6	6.46	18.4	73.0	18.6	59.5	56.9	na
	Certified	20.5	6.47	18.2	72.5	18.5	58.1	56.0	
	Range	+/3.8	+/-0.37	+/-0.64	+/-0.65	+/-0.20	+/-2.7	+/-0.73	
	Percent Difference	2%	0%	1%	1%	1%	2%	2%	
1641c	Result	na	na	na	na	na	na	na	1480
	Certified								1470
	Range								+/-40
	Percent Difference								1%
CASS 3	Result	0.617	0.0379	0.0815	1.50	0.204	0.300	0.94	na
		0.591	0.0359				0.396		
	Certified	0.517	0.03	0.012	1.24	0.092	0.386	1.09	
	Range	+/-0.062	+/-0.005	+/-0.004	+/-0.25	+/-0.006	+/-0.062	+/-0.07	
	Percent Difference	91%	26%	54%	21%	122%	3%	14%	
		14%	20%				1%		
Method Blanks		0.0589	0.00032	0.0095	0.537	<0.03	0.0671	<0.15	0.00019
		0.0590	0.00158				0.0651		
Replicate Analyses									
	Sample No. 8252	2.25	0.0639	0.0316	11.6	0.13	0.549	na	na
		2.21	0.0625	na	na	na	0.545	na	na
	Percent Difference	2%	2%				1%		
	Sample No. 8256	2.92	0.0878	0.511	19.8	0.503	1.20	3.75	0.005
		na	na	0.508	18.4	0.500	na	3.90	na
	Percent Difference			1%	7%	1%		4%	
Matrix Spikes									
	Amount Spiked	ns	ns	ns	ns	ns	ns	ns	0.0132
	Sample No. 8235								0.00267
	Result								0.0159
	Amount Recovered								0.0132
	Percent Recovery								100%
	Amount Spiked	ns	ns	ns	ns	ns	ns	ns	0.0124
	Sample No. 8235 duplicate								0.00267
	Result								0.0148
	Amount Recovered								0.0121
	Percent Recovery								98%
	RPD								2%

Appendix B. Commencement Bay QA Data (continued)

QA Sample	Cu	Cd	Pb	Zn	Cr	Ni	As	Hg
Amount Spiked	ns	ns	ns	ns	ns	ns	1.80	ns
Sample No. 8251							1.30	
Result							3.06	
Amount Recovered							1.76	
Percent Recovery							98%	
Amount Spiked	ns	ns	ns	ns	ns	ns	1.80	ns
Sample No. 8251 duplicate							1.30	
Result							2.84	
Amount Recovered							1.54	
Percent Recovery							86%	
RPD							1%	
Amount Spiked	5.00	5.00	ns	ns	ns	5.00	ns	ns
Sample No. 8252	2.33	0.0632				0.547		
Result	6.61	3.69				4.01		
Amount Recovered	4.38	3.63				3.46		
Percent Recovery	88%	73%				69%		
Amount Spiked	5.00	5.00	ns	ns	ns	5.00	ns	ns
Sample No. 8252 duplicate	2.23	0.0632				0.547		
Result	6.39	3.44				3.74		
Amount Recovered	4.16	3.38				3.19		
Percent Recovery	83%	68%				64%		
RPD	5%	7%				8%		
Amount Spiked	10.0	10.0	10.0	10.0	10.0	10.0	10.0	ns
Sample No. 8256	3.38	0.0871	0.510	19.1	0.502	1.48	3.82	
Result	12.7	10.1	9.42	27.2	10.5	10.6	13.5	
Amount Recovered	9.3	10.1	8.91	8.09	10.0	9.08	9.67	
Percent Recovery	93%	101%	89%	81%	100%	91%	97%	
Amount Spiked	10.0	10.0	10.0	10.0	10.0	10.0	10.0	ns
Sample No. 8256 duplicate	3.38	0.0871	0.51	19.1	0.502	1.48	3.82	
Result	13.0	10.2	9.39	32.5	10.6	10.9	13.4	
Amount Recovered	9.62	10.1	8.88	13.4	10.1	9.37	9.57	
Percent Recovery	96%	101%	89%	134%	101%	94%	96%	
RPD	3%	1%	0%	50%	1%	3%	1%	
Amount Spiked	1.00	1.00	1.00	1.00	1.00	1.00	1.00	ns
Sample No. 8258	3.21	0.0896	0.531	17.2	0.500	1.5	4.04	
Result	4.17	1.17	1.45	18.7	1.54	2.71	4.98	
Amount Recovered	0.968	1.08	0.917	1.45	1.04	1.21	0.936	
Percent Recovery	97%	108%	92%	SL	104%	121%	94%	

Appendix B. Commencement Bay QA Data (continued)

QA Sample		Cu	Cd	Pb	Zn	Cr	Ni	As	Hg
	Amount Spiked	10.0	10.0	10.0	10.0	10.0	10.0	10.0	ns
	Sample No. 8258 duplicate	3.21	0.0896	0.531	17.2	0.500	1.5	4.04	
	Result	12.3	9.74	9.47	27.9	10.7	9.79	13.4	
	Amount Recovered	9.10	9.65	8.94	10.7	10.2	8.29	9.35	
	Percent Recovery	91%	97%	89%	107%	102%	83%	93%	
		March 18, 1998 Sample Set - Battelle Laboratory							
Standard Reference Material									
1643d	Result	20.6	6.46	18.2	74.5	14.1	59.5	na	na
		19.5	6.51	18.4	74.3	12.0	55.7		
	Certified	6.47	20.5	18.2	72.5	18.5	58.1		
	Range	+/-0.37	+/-3.8	+/-0.64	+/-0.65	+/-0.20	+/-2.7		
	Percent Difference	0%	1%	0%	3%	24%	2%		
		1%	5%	1%	2%	35%	4%		
1641c	Result	na	na	na	na	na	na	na	1550
	Certified								1470
	Range								+/40
	Percent Difference								5%
CASS 3	Result	0.535	0.0329	0.0135	1.92	0.113	0.391	1.01	na
		0.509	0.0359	0.0110	1.68	0.116	0.418	0.913	
	Certified	0.517	0.03	0.012	1.24	0.092	0.386	1.09	
	Range	+/-0.062	+/-0.005	+/-0.004	+/-0.25	+/-0.006	+/-0.062	+/-0.07	
	Percent Difference	3%	10%	12%	55%	23%	1%	7%	
		2%	20%	9%	36%	26%	8%	16%	
Method Blanks		0.0788	<0.006	<0.006	0.428	0.0401	0.0857	<0.15	0.00005
		<0.06	0.00646	<0.006	0.532	0.0421	<0.02	<0.15	na
Replicate Analyses									
	Sample No. 8107	2.15	0.0827	0.151	14.3	0.201	0.757	2.75	0.00359
		na	na	na	na	na	na	2.87	na
	Percent Difference							4%	
Matrix Spikes									
	Amount Spiked	ns	ns	ns	ns	ns	ns	ns	0.0141
	Sample No. 8235								0.00665
	Result								0.0205
	Amount Recovered								0.0139
	Percent Recovery								98%

Appendix B. Commencement Bay QA Data (continued)

QA Sample		Cu	Cd	Pb	Zn	Cr	Ni	As	Hg
	Amount Spiked	ns	ns	ns	ns	ns	ns	ns	0.0131
	Sample No. 8235 duplicate								0.00665
	Result								0.0208
	Amount Recovered								0.0142
	Percent Recovery								108%
	RPD								9%
	Amount Spiked	5.00	5.00	5.00	5.00	5.00	5.00	2.25	ns
	Sample No. 8083	0.460	0.0679	0.0393	1.49	0.166	0.464	1.21	
	Result	4.48	4.64	4.74	5.41	4.23	4.45	3.39	
	Amount Recovered	4.02	4.57	4.70	3.93	4.06	3.98	2.18	
	Percent Recovery	80%	91%	94%	79%	81%	80%	97%	
	Amount Spiked	5.00	5.00	5.00	5.00	5.00	5.00	1.13	ns
	Sample No. 8083 duplicate	0.460	0.0697	0.0339	1.49	0.166	0.464	1.21	
	Result	4.57	4.54	4.96	5.54	4.34	4.53	2.40	
	Amount Recovered	4.11	4.47	4.92	4.06	4.17	4.06	1.19	
	Percent Recovery	82%	89%	98%	81%	83%	81%	105%	
	RPD	2%	2%	5%	3%	3%	2%	8%	na
	<u>August 13, 1998 Sample Set - Manchester Laboratory</u>								
Standard Reference Material									
CASS 3	Result	0.47	0.025	0.016	1.1	0.26	0.24	0.80	na
		0.44	0.023	0.019	2.3	0.24	0.22	0.75	
		0.45	0.024	0.020	2.0	0.24	0.23	0.78	
		0.53	0.026	0.060	1.5	0.21	0.33	0.82	
	Certified	0.517	0.03	0.012	1.24	0.092	0.386	1.09	
	Range	+/-0.062	+/-0.005	+/-0.004	+/-0.25	+/-0.006	+/-0.062	+/-0.07	
	Percent Recovered	91%	83%	133%	89%	283%	62%	73%	
		85%	77%	158%	185%	261%	57%	69%	
		87%	80%	167%	161%	261%	60%	72%	
		103%	87%	500%	121%	228%	85%	75%	
SLEW 1	Result	1.42	0.016	0.030	0.92	0.32	0.42	0.59	na
		1.15	0.016	0.042	1.25	0.40	0.38	0.52	
	Certified	1.76	0.018	0.028	0.86	0.139	0.743	0.765	
	Range	+/-0.09	+/-0.003	+/-0.007	+/-0.15	+/-0.016	+/-0.078	+/-0.093	
Percent Recovered		81%	89%	107%	107%	230%	57%	77%	
		65%	89%	150%	145%	288%	51%	68%	
1631c	Result	na	na	na	na	na	na	0.0291	
	Certified							0.0294	
	Percent Recovered							99%	

Appendix B. Commencement Bay QA Data (continued)

QA Sample	Cu	Cd	Pb	Zn	Cr	Ni	As	Hg
Matrix Spikes								
Percent Recovery, No. 8244	ns	ns	ns	ns	ns	ns	ns	102%
Percent Recovery, No. 8244 D	ns	ns	ns	ns	ns	ns	ns	104%
Percent Recovery, No. 8276	ns	ns	ns	ns	ns	ns	ns	102%
Percent Recovery, No. 8276 D	ns	ns	ns	ns	ns	ns	ns	97%
Method Blanks	0.001	0.0048	0.0040	0.056	0.13	0.0089	<0.025	<0.002
	0.0009	0.0052	0.0033	0.050	0.14	0.0083	<0.025	na
	0.015	0.053	0.0090	0.13	0.13	0.061	<0.025	na
	0.017	0.042	0.0097	0.21	0.14	0.052	<0.025	na
	<0.001	0.0026	0.0028	0.085	0.14	<0.005	<0.025	na
	<0.001	0.0029	0.0032	0.082	0.15	0.0052	<0.025	na

ns = not spiked
na = not analyzed

Appendix C

Appendix C. Dept. of Ecology Data on Metals in Commencement Bay (ug/L; parts per billion)

Location	Date	Time	Sample Number	Depth (m)	Temp. (oC)	Salinity (ppt)	TSS (mg/L)	Turbidity (NTU)	Filtered (0.45 micron) Zn	Cu	As	Pb	Cd	Cr	Ni
Commencement Bay	21/11/97	0855	8230	0.5	9.5	14	34	37	2.1	0.90	- -	0.013	0.044	0.21	0.48
"	21/11/97	0920	8232	8.0	11.1	28	3	0.7	1.5	0.46	- -	0.011	0.064	0.20	0.42
"	18/03/98	930	8080	0.5	9.0	21	4	1.7	2.0	0.60	- -	0.018	0.059	0.12	0.43
"	18/03/98	1000	8082	8.0	8.9	30	6	0.6	2.0	0.42	- -	0.023	0.072	0.14	0.44
"	13/08/98	1105	8230	0.5	16.0	20	7	5.6	1.6	0.61	0.68	0.025	0.031	0.20	0.24
"	13/08/98	1050	8233	8.0	12.6	28	5	1.4	0.56	0.34	0.77	0.022	0.040	0.22	0.17
Thea Foss WW @ mouth	21/11/97	0945	8234	0.5	10.5	24	6	3.3	20.1	1.6	- -	0.072	0.070	- -	- -
"	18/03/98	1020	8084	0.5	10.0	24	4	0.7	4.9	1.2	- -	0.010	0.066	- -	- -
"	13/08/98	1115	8236	0.5	14.9	15	13	12	1.7	0.67	0.57	0.026	0.027	- -	- -
Thea Foss WW @ middle	21/11/97	1000	8236	0.5	10.5	24	4	2.5	12.5	2.0	- -	0.16	0.071	- -	- -
"	21/11/97	1015	8238	8.0	11.5	28	6	0.7	1.8	0.50	- -	0.016	0.064	- -	- -
"	18/03/98	1035	8086	0.5	10.0	21	2	0.7	5.7	1.6	- -	0.019	0.064	- -	- -
"	18/03/98	1040	8088	8.0	9.4	28	4	1.5	2.6	0.42	- -	0.064	0.067	- -	- -
"	13/08/98	1130	8239	0.5	15.4	17	7	2.9	3.7	1.2	0.61	0.034	0.029	- -	- -
"	13/08/98	1140	8242	8.0	12.7	28	6	1.4	0.86	0.30	0.84	0.028	0.040	- -	- -
Thea Foss WW @ head	21/11/97	1035	8240	0.5	10.5	21	2	2.0	6.6	0.79	- -	0.079	0.061	- -	- -
"	18/03/98	1055	8090	0.5	10.2	12	2	1.0	4.2	0.81	- -	0.026	0.055	- -	- -
"	13/08/98	1150	8245	0.5	16.4	10	4	2.1	2.7	0.94	0.51	0.052	0.027	- -	- -
Blair WW @ mouth	21/11/97	1120	8244	0.5	9.2	20	4	3.7	5.2	1.1	- -	0.020	0.062	- -	- -
"	18/03/98	1135	8094	0.5	9.5	20	2	1.5	3.5	0.84	- -	< 0.006	0.061	- -	- -
"	13/08/98	1240	8250	0.5	13.3	22	12	4.4	3.0	0.73	0.78	0.026	0.040	- -	- -
Blair WW @ middle	21/11/97	1140	8246	0.5	10.5	26	3	3.4	5.6	0.79	- -	0.016	0.065	- -	- -
"	21/11/97	1150	8248	8.0	11.4	28	3	1.2	1.8	0.49	- -	0.007	0.060	- -	- -

Appendix C. Commencement Bay Data (continued)

Location	Date	Time	Sample Number	Depth (m)	Temp. (°C)	Salinity (ppt)	TSS (mg/L)	Turbidity (NTU)	Filtered (0.45 micron) Zn	Cu	As	Pb	Cd	Cr	Ni
Blair WW @ middle	18/03/98	1145	8096	0.5	10.0	24	3	1.5	4.4	1.0	- -	0.016	0.064	- -	- -
"	18/03/98	1155	8098	8.0	8.9	29	3	1.1	1.9	0.43	- -	0.009	0.066	- -	- -
"	13/08/98	1255	8253	0.5	14.8	19	7	5.4	1.8	0.65	0.53	0.023	0.026	- -	- -
"	13/08/98	1305	8256	8.0	12.7	27	7	1.9	1.0	0.60	0.94	0.024	0.043	- -	- -
Blair WW @ head	21/11/97	1210	8250	0.5	11.0	27	3	2.1	5.0	0.84	- -	0.024	0.061	- -	- -
"	18/03/98	1205	8100	0.5	10.6	25	3	1.3	3.7	0.81	- -	< 0.006	0.066	- -	- -
"	13/08/98	1320	8259	0.5	17.9	20	6	3.4	1.3	0.64	0.82	0.022	0.036	- -	- -
Hylebos WW @ mouth	21/11/97	1245	8252	0.5	10.1	23	3	4.0	11.6	2.2	- -	0.032	0.063	0.13	0.55
"	18/03/98	1230	8102	0.5	9.9	20	2	1.3	8.5	1.5	- -	0.021	0.073	0.13	0.51
"	13/08/98	1345	8262	0.5	15.9	19	7	3.9	4.4	1.1	1.1	0.041	0.033	0.23	0.21
Hylebos WW @ middle	21/11/97	1325	8254	0.5	10.4	20	6	5.3	14.8	1.8	- -	0.026	0.070	0.15	0.79
"	21/11/97	1330	8255	0.5	- -	20	6	5.7	16.0	2.1	- -	0.046	0.072	0.15	0.81
"	21/11/97	1350	8258	8.0	11.0	28	6	1.5	3.6	0.63	- -	0.033	0.064	0.07	0.44
"	18/03/98	1245	8104	0.5	11.0	21	2	2.4	16.1	2.2	- -	0.007	0.14	0.13	0.72
"	18/03/98	1245	8105	0.5	- -	20	3	2.3	14.4	2.1	- -	0.010	0.078	0.13	0.74
"	18/03/98	1305	8108	8.0	8.9	28	3	0.8	8.3	0.63	- -	0.006	0.078	0.12	0.48
"	13/08/98	1400	8265	0.5	17.1	20	7	2.3	7.7	1.8	1.2	0.037	0.034	0.20	0.20
"	13/08/98	1400	8266	0.5	- -	20	6	2.2	6.8	1.6	1.1	0.051	0.033	0.33	0.23
"	13/08/98	1429	8271	8.0	11.2	27	5	2.0	2.8	0.43	1.2	0.040	0.040	0.25	0.20
Hylebos WW @ head	21/11/97	1405	8260	0.5	10.4	28	10	10	13.7	1.6	- -	0.040	0.069	0.14	0.81
"	18/03/98	1320	8110	0.5	11.7	10	3	4.8	13.1	1.6	- -	<0.006	0.070	0.14	0.82
"	13/08/98	1435	8274	0.5	17.6	20	6	2.6	6.3	1.2	1.6	0.039	0.038	0.21	0.20
Filter Blank	21/11/97	1050	8242	- -	- -	- -	- -	- -	0.92	0.20	- -	0.009	0.003	< 0.03	0.092
"	18/03/98	1110	8092	- -	- -	- -	- -	- -	1.1	<0.06	- -	<0.006	<0.006	0.011	0.053
"	13/08/98	1200	8248	- -	- -	- -	- -	- -	0.44	0.12	< 0.025	0.036	0.0054	0.17	0.045

Appendix C. Commencement Bay Data (continued)

Location	Date	Time	Sample Number	Depth (m)	Unfiltered								
					Zn	Cu	As	Pb	Cd	Hg	Cr	Ni	
Commencement Bay	21/11/97	0855	8231	0.5	5.4	6.3	1.9	0.28	0.047	0.0056	1.1	1.8	
"	21/11/97	0920	8233	8.0	18.7	0.59	1.5	0.028	0.066	0.0011	0.27	0.46	
"	18/03/98	930	8081	0.5	2.4	0.70	1.1	0.058	0.062	0.0067	0.19	0.43	
"	18/03/98	1000	8083	8.0	1.5	0.46	1.2	0.039	0.070	0.0069	0.17	0.46	
"	13/08/98	1105	8231	0.5	2.0	0.92	0.66	0.073	0.036	< 0.002	0.30	0.23	Hg unfiltered =# 8232
"	13/08/98	1050	8234	8.0	2.2	0.48	0.90	0.078	0.048	< 0.002	0.25	0.26	Hg unfiltered = #8235
Thea Foss WW @ mouth	21/11/97	0945	8235	0.5	18.3	3.21	1.6	0.90	0.091	0.0027	- -	- -	
"	18/03/98	1020	8085	0.5	- -	- -	1.3	- -	- -	0.0058	- -	- -	
"	13/08/98	1115	8237	0.5	- -	- -	0.49	- -	- -	0.0025	- -	- -	Hg unfiltered =# 8238
Thea Foss WW @ middle	21/11/97	1000	8237	0.5	14.1	3.1	1.5	1.2	0.086	0.0035	- -	- -	
"	21/11/97	1015	8239	8.0	4.7	0.63	1.6	0.10	0.070	0.0009	- -	- -	
"	18/03/98	1035	8087	0.5	6.2	1.9	1.0	0.12	0.068	0.0032	- -	- -	
"	18/03/98	1040	8089	8.0	2.8	0.74	1.1	0.57	0.072	0.0052	- -	- -	
"	13/08/98	1130	8240	0.5	3.2	1.5	0.66	0.17	0.034	< 0.002	- -	- -	Hg unfiltered = #8241
"	13/08/98	1140	8243	8.0	0.78	0.43	0.89	0.16	0.043	< 0.002	- -	- -	Hg unfiltered = #8244
Thea Foss WW @ head	21/11/97	1035	8241	0.5	8.5	1.6	1.4	0.79	0.090	0.0023	- -	- -	
"	18/03/98	1055	8091	0.5	- -	- -	1.0	- -	- -	0.0039	- -	- -	
"	13/08/98	1150	8246	0.5	- -	- -	0.48	- -	- -	< 0.002	- -	- -	Hg unfiltered = #8247
Blair WW @ mouth	21/11/97	1120	8245	0.5	6.5	2.2	2.0	0.41	0.077	0.0020	- -	- -	
"	18/03/98	1135	8095	0.5	- -	- -	1.2	- -	- -	0.0051	- -	- -	
"	13/08/98	1240	8251	0.5	- -	- -	0.81	- -	- -	0.0023	- -	- -	Hg unfiltered = #8252
Blair WW @ middle	21/11/97	1140	8247	0.5	8.4	1.2	1.9	0.32	0.077	0.0034	- -	- -	
"	21/11/97	1150	8249	8.0	6.3	0.67	1.6	0.059	0.069	0.0013	- -	- -	

Appendix C. Commencement Bay Data (continued)

Location	Date	Time	Sample Number	Depth (m)	Unfiltered Zn	Cu	As	Pb	Cd	Hg	Cr	Ni	
Blair WW @ middle	18/03/98	1145	8097	0.5	5.2	1.2	1.3	0.080	0.064	0.0024	- -	- -	
"	18/03/98	1155	8099	8.0	2.7	0.58	1.2	0.062	0.071	0.0098	- -	- -	
"	13/08/98	1255	8254	0.5	3.2	1.0	0.76	0.060	0.035	< 0.002	- -	- -	Hg unfiltered = #8255
"	13/08/98	1305	8257	8.0	1.5	0.82	0.92	0.059	0.043	< 0.002	- -	- -	Hg unfiltered = #8258
Blair WW @ head	21/11/97	1210	8251	0.5	5.6	1.2	1.7	0.22	0.086	0.0024	- -	- -	
"	18/03/98	1205	8101	0.5	- -	- -	1.3	- -	- -	0.0016	- -	- -	
"	13/08/98	1320	8260	0.5	- -	- -	0.79	- -	- -	< 0.002	- -	- -	Hg unfiltered = #8261
Hylebos WW @ mouth	21/11/97	1245	8253	0.5	10.7	3.3	2.1	0.23	0.080	0.0017	- -	- -	
"	18/03/98	1230	8103	0.5	- -	- -	1.4	- -	- -	0.0026	- -	- -	
"	13/08/98	1345	8263	0.5	- -	- -	1.0	- -	- -	< 0.002	- -	- -	Hg unfiltered = #8264
Hylebos WW@ middle	21/11/97	1325	8256	0.5	19.1	2.9	3.8	0.51	0.088	0.0050	0.50	1.2	
"	21/11/97	1330	8257	0.5	17.2	2.8	4.0	0.53	0.082	0.0046	0.50	1.2	
"	21/11/97	1350	8259	8.0	4.0	0.98	3.1	0.16	0.079	0.0015	0.14	0.60	
"	18/03/98	1245	8106	0.5	14.4	2.2	2.9	0.15	0.082	0.0044	0.22	0.79	
"	18/03/98	1245	8107	0.5	14.3	2.2	2.8	0.15	0.083	0.0036	0.20	0.76	
"	18/03/98	1305	8109	8.0	4.6	0.75	1.4	0.10	0.075	0.0029	0.18	0.48	
"	13/08/98	1400	8267	0.5	7.8	2.4	1.5	0.12	0.039	0.0044	0.29	0.27	Hg unfiltered = #8269
"	13/08/98	1400	8268	0.5	8.0	2.3	1.5	0.12	0.043	0.0039	0.26	0.26	Hg unfiltered = #8270
"	13/08/98	1429	8272	8.0	3.9	0.74	1.3	0.23	0.044	0.0020	0.35	0.24	Hg unfiltered = #8273
Hylebos WW @ head	21/11/97	1405	8261	0.5	13.2	3.5	3.2	0.86	0.067	0.0074	- -	- -	
"	18/03/98	1320	8111	0.5	- -	- -	2.6	- -	- -	0.0025	- -	- -	
"	13/08/98	1435	8275	0.5	6.3	1.4	1.8	0.13	0.040	0.0021	0.28	0.25	
Bottle (Transfer) Blank	21/11/97	1050	8243	- -	4.1	0.20	< 0.15	0.008	0.002	0.0003	< 0.03	0.17	
"	18/03/98	1110	8093	- -	1.1	< 0.06	< 0.014	< 0.006	< 0.006	0.0005	0.02	0.17	
"	13/08/98	1200	8249	- -	0.85	0.044	< 0.025	0.013	0.0022	< 0.002	0.23	0.083	Hg bottle blank = #8277

Appendix D

Ecology Ambient Monitoring Data
on Metals in the
Puyallup river

Appendix E

(from Crecelius, 1998)

The “total” metals data in this appendix was from the same analysis method and laboratory used for Ecology’s 1997-98 Commencement Bay samples, results of which are termed “unfiltered” in the present report.

Appendix F

(from Norton & Johnson, 1985)