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USE OF SEDIMENT TRAPS TO MONITOR CONTAMINANT FLUX TO CITY WATERWAY SEDIMENTS: INTERIM REPORT

by
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SUMMARY

Preliminary indications from Phase 1 of this study are that concentrations of most problem chemicals (metals and semivolatile organics) associated with suspended particulate matter (SPM) currently entering City Waterway are lower than those measured in existing deposits. Two exceptions are mercury and lead at the mouth of City Waterway. Levels of problem chemicals in bottom sediments during the present study were similar to those recorded in 1984 during the Commencement Bay Nearshore/Tideflats Remedial Investigation. Comparisons of contaminant levels in SPM with available Apparent Effects Threshold values indicates mercury, lead, zinc, bis(2-ethylhexyl)phthalate, benzyl alcohol, and benzoic acid at the head (head to 11th street bridge) of City Waterway are at levels which could adversely affect marine benthic communities.

Average sediment accumulation rates in the traps and sedimentation rates on the bottom for City Waterway calculated from trap data were 1.0 g/cm^2/year and 1.2 cm/year respectively. These values are in good agreement with rates determined by other investigators from Pb-210 dated cores.

The sediment trap design used here successfully collected undisturbed samples of SPM in sufficient quantity to allow analysis of a variety of physical and chemical parameters. This suggests that the trap design would also perform well when deployed in similar environments: nearshore marine areas with current velocities approximately in the range of 2 - 28 cm/sec. In addition, under the conditions present in City Waterway, the chemical and physical data presented suggest that the amount of resuspended material collected by the traps is probably low. However, additional data will be required to quantify the amount of resuspension. The results to date indicate the value of extending sediment trap monitoring in City Waterway past the initial year. This data is expected to provide the only empirical measure of the effectiveness of source control efforts in reducing the inputs of problem chemicals to the waterway. This is especially true since the City of Tacoma currently has no plans to continue monitoring storm drain discharges to the waterway. A final report which will include complete results from the first year of the sediment trap study is scheduled for publication in July 1990.

INTRODUCTION

Contamination of City Waterway bottom sediments with a variety of organic compounds and metals was documented during the Commencement Bay Nearshore/Tideflats Remedial Investigations (CBRI) (Tetra Tech, 1985). However, the extent to which ongoing source control efforts are succeeding in reducing inputs of problem chemicals to the waterway has not been adequately addressed. In addition, present bottom sediment accumulation rates after initiation of source control have not been determined.

The Washington State Department of Ecology's (Ecology) Hazardous Waste Cleanup Program and Commencement Bay Urban Bay Action Team therefore requested the Toxics Investigations and Ground Water Monitoring Section to conduct a year long sediment monitoring study in City Waterway with the following objectives:

- Measure concentrations of problem chemicals (identified during the CBRI) associated with particulate matter currently being deposited in the waterway.
- Estimate current sedimentation rates in the waterway.

Results from this study in conjunction with existing information will help refine estimates of sediment recovery rates for City Waterway. In addition, the results should be useful in evaluating sediment traps as a monitoring tool for contaminant discharges to nearshore marine waters from a range of sources. The purpose of this interim report is to evaluate and report the results of Phase 1

(November 1988 - June 1989) of the study and make recommendations for continued monitoring beyond the first year. A final report will be prepared that includes all results from the first year (November 1988 - December 1989) of sampling. This report is scheduled for completion in July 1990.

METHODS

Sample Collection

To characterize present conditions in City Waterway water samples, current measurements, suspended particulate matter (SPM), and bottom sediments were collected between November 10, 1988, and June 29, 1989. Sample locations, shown in Figure 1, were selected to correspond with major contaminant sources (twin 96-inch storm drains, 15th street storm drain, Wheeler-Osgood storm drain and D-street tank farm) identified during the CBRI.

Water Sampling--To assist interpretation of the distribution of particulates in the waterway vertical profiles of temperature, salinity, and total suspended solids (TSS) were collected during deployment and retrieval of the sediment traps. All samples were obtained with a Van Dorn bottle equipped with a precision thermometer.

Current Meter Deployment--To characterize current velocities present in City Waterway during the study, two Aanderra Current Meters Model RCM-4 were deployed for one month at the locations shown in Figure 1. Details of the mooring configuration is also shown in Figure 2. Deployment of the meters was timed to coincide with the period of maximum tidal exchange (May 30, 1989 - June 29, 1989) during the study.

SPM Sampling--SPM was collected with the use of moored sediment traps. The traps were deployed November 10, 1988, and sampled at a frequency of three months. The traps are a straight-sided glass cylinder with a collection area of 64 cm^2 and a height-to-width ratio of five. Previous studies indicated that cylindrical sediment traps with these characteristics would provide low biased samples of the vertical particle flux in current velocities expected to occur in City Waterway (Butman, 1986a,b; Baker, *et al.*, 1988; Larsson, *et al.*, 1986). A schematic of the construction details of the traps and their moorings is presented in Figure 2. To assess resuspension of particulates in the water column, sediment traps were deployed at multiple depths on a single mooring at the mouth of the waterway (Station ST-4). During deployment, the traps were filled with two liters of high salinity water (4% NaCl) which contained sodium azide (2%) as a preservative to reduce microbial degradation of the samples. Prior to deployment, the cylinders were cleaned with sequential washes of hot tap water/Liquinox detergent, 10 percent nitric acid, distilled/deionized water, and pesticide grade acetone, then air-dried and wrapped in aluminum foil until used in the field.

The contents of the traps were transferred in the field to one-gallon priority pollutant-cleaned glass jars with teflon-lined lids (I-Chem, Hayward, California) and stored on ice for transport to the Ecology/EPA Environmental Laboratory at Manchester, Washington. All samples were centrifuged within 24 hours of collection to isolate the particulate fraction. In order to obtain sufficient volume for grain size and semivolatile organics analyses, particulate samples from the first quarter (November 1988 - February 1989) and the second quarter (February 1989 - May 1989) at the head (station ST-1) of City and entrance to Wheeler-Osgood Waterway (ST-3) were composited. Particulates were stored frozen until analyzed. Sediment trap preservative was also analyzed before and after [supernatant after centrifugation: metals--filtered (0.4 um); organics--unfiltered] use to evaluate the uptake of contaminants by the preservative during deployment.

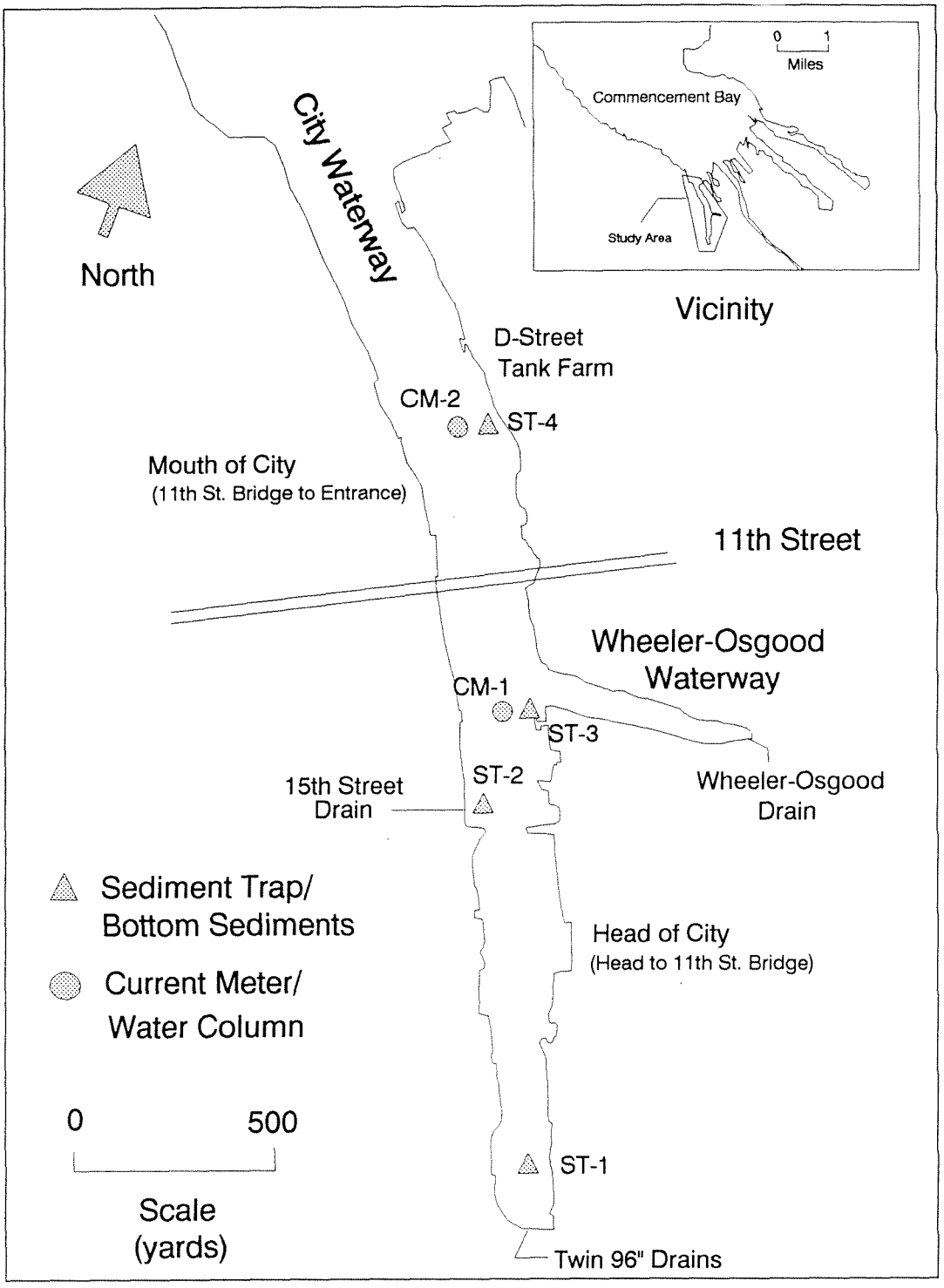

Figure 1: City Waterway Station Locations

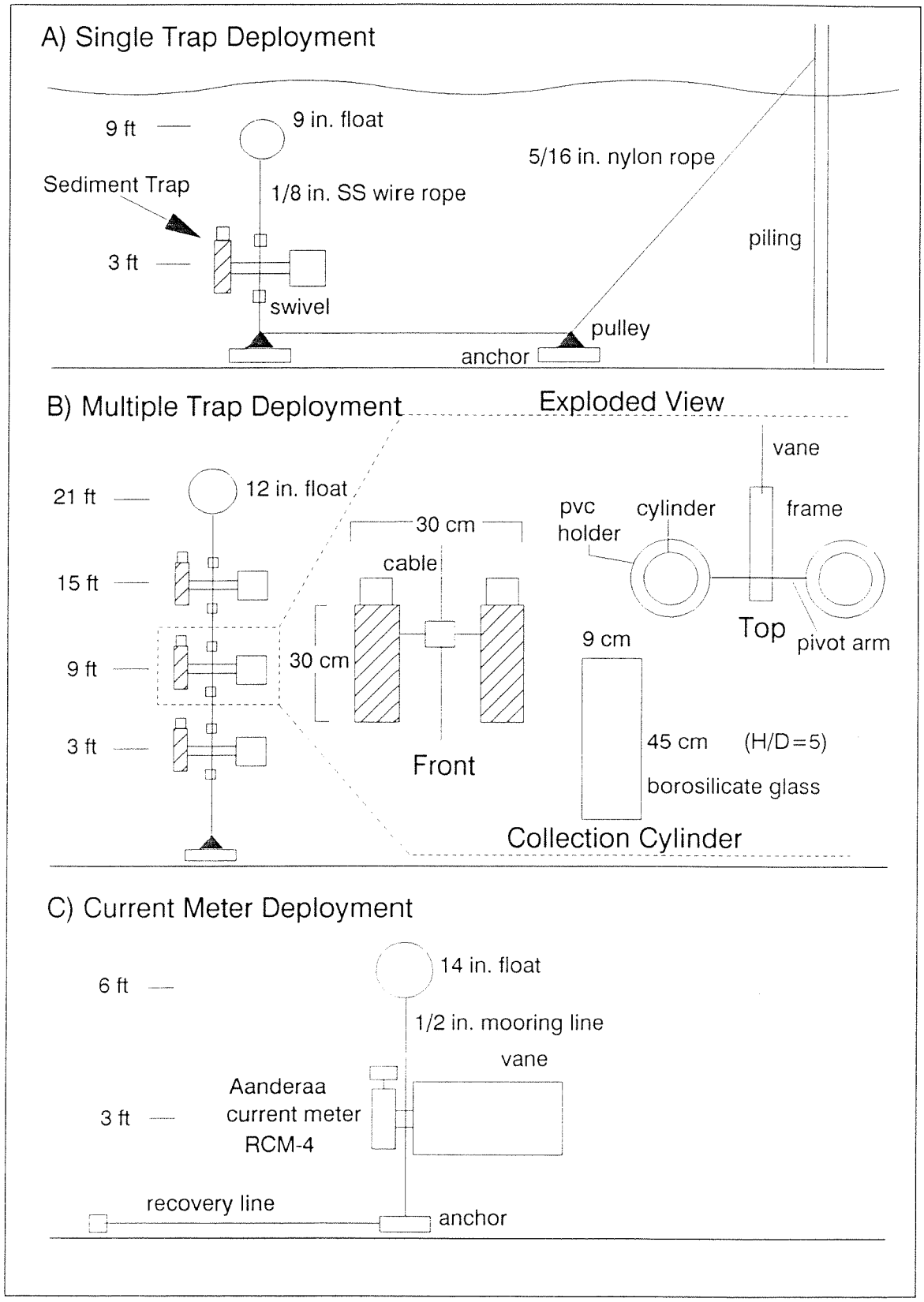

Figure 2: Sediment Trap and Current Meter Deployments

Bottom Sediment Sampling--Sampling procedures followed Puget Sound Protocols where applicable (Tetra Tech, 1986). Surface sediment samples were collected at each sediment trap site on November 9, 1988, using a stainless steel $0.1m^2$ Van Veen grab. After retrieving the grab, the top 2cm layer of each sediment sample was transferred to a stainless steel beaker and homogenized by stirring with a stainless steel spoon. Three individual grabs were composited for each sample. To assess field variability, replicate samples (i.e. two separate samples collected at a similar location) were collected at the mouth of the waterway. Spoons and beakers were pre-cleaned before use as previously described for sediment trap collection cylinders. All samples were placed in priority pollutant-cleaned glass jars with teflon-lined lids supplied by I-Chem, Hayward, California, wrapped in polyethylene bags and stored on ice for transport to the laboratory. Aliquots for metals analysis were stored frozen.

Analysis and Quality Assurance

The chemical analyses, methods, and laboratories used in this study are listed in Table 1. Quality of the data set was assessed by analysis of blanks, internal standards, labeled compound recoveries, duplicates, and standard reference materials.

Results of metals analysis of standard reference materials are shown in Table 2. There was good agreement with certified values for all target metals.

Laboratory precision, calculated as relative percent difference (RPD) of duplicates (range as percent of mean), was good for conventionals and metals analyses (+/- 20% conventionals and target metals in water; +/- 10% target metals sediment) except for total suspended solids (+/- 60%), mercury and lead in water (+/-40%), and cadmium in water (+/- 60%).

Precision estimates for organics analyses calculated from laboratory prepared standards (spiked reagent water analyzed in duplicate) was excellent (+/-10%) for all target compounds. Analysis of blind field duplicates (i.e. one sample homogenized and split in the field), varied more but was still acceptable for particulate samples (less than +/-50% for most compounds). Semivolatiles analysis of bottom sediments varied the most, being approximately +/- 100% for the majority of target compounds. This data indicates that precision of the results decreased in the following order; water < particulates < bottom sediments. Results of analysis of blind field duplicates for sediment and particulate samples are given in Appendix 1.

Quality assurance review of the organics data was performed by Roger McGinnis of Ecology and Environment, Inc., Seattle, Washington. Evaluation of the data is based on criteria outlined in EPA, 1988a "Laboratory Data Validation Functional Guidelines for Evaluating Organics Analyses", modified to include requirements of EPA method 1625c. In the opinion of the reviewer, the data set was considered acceptable for use with the following qualifications. Several contaminants were detected at low levels in laboratory method blanks during analysis of samples collected in May 1989. Results for these compounds have been flagged J (estimated quantity) when the analyte concentration reported in the sample was less than five times the blank concentration. Due to low recoveries on calibration standards, results for hexachlorocyclopentadiene are not reported and several other compounds are reported as estimates. In addition, isotope labeled compound recoveries were outside quality assurance limits specified in method 1625c for a number of compounds. Positive results for compounds with recoveries of <10 percent have also been flagged as estimates.

Reconstructed ion chromatograms for all sediment/particulate samples exhibited a large broad peak characteristic of a unresolved complex mixture. While method 1625c does not analyze for tentatively identified compounds, the presence of polycyclic aromatic compounds and selected n-alkanes supports this interpretation. This complex matrix may be partly responsible for the low isotope labeled compound recoveries observed.

Table 1: Summary of analytical methods for City Waterway sediment trap study.

Analysis	Method	Reference	Laboratory
		SEDIMENT/PARTICULATES	
Percent Moisture	Dry @ 105 C Method 209F	APHA, 1985	Ecology/EPA Manchester, Wa.
Total Organic Carbon	Combustion/CO2 Measurement	In-House	Laucks Testing Seattle, Wa.
Grain Size	Sieve and Pipet	Holme and McIntyre, 1971	" " "
Metals			
Hg	Cold Vapor/AAS	Bloom and Crecelius, 1984	Battelle Northwest Sequim, Wa.
Cd	AAS	" "	" " "
Cu,Ni,Pb,Zn,As,Mn,Se, Ga,V,Br,Rb,Sr,Al,Si, P,S,Cl,K,Ca,Ti,Fe	X-Ray Fluoresence	Nielson and Sanders, 1983	" " "
Semivolatiles	Stable Isotope Dilution Method 1625C w/GPC Cleanup	EPA, 1988b	Pacific Analytical, Inc. Carlsbad, Ca.
		WATER	
Current Velocity	Aanderaa Current Meter Model RCM-4	Aanderra Instruments	Field
Temperature	Precision Thermometer	APHA, 1985	Field
Salinity	Refractometer	American Optical	Ecology/EPA Manchester, Wa.
Total Suspended Solids	Gravimetric Method No. 205C	APHA, 1985	" "
Metals			
Hg	Cold Vapor/AAS	Bloom and Crecelius, 1983	Battelle Northwest Sequim, Wa.
Zn	Direct Injection/AAS	EPA, 1983	" " "
Cd,Cu,Ni,Pb	APDC Preconcentration/AAS	Bloom and Crecelius, 1984	" " "
Semivolatiles	Stable Isotope Dilution Method 1625C	EPA, 1988b	Pacific Analytical, Inc. Carlsbad, Ca.

Table 2: Results of analysis of certified reference materials for water (CASS-1) and sediment (SRM 1646).

Material	CASS-1		SRM 1646	
Element	Certified Range ug/L	Battelle Result ug/L	Certified Range ug/g	Battelle Result ug/g
Cadmium	0.026+/-0.005	0.033	0.36+/-0.07	0.38
Copper	0.291+/-0.027	0.28	18+/-3	19.0
Mercury	NC		0.063+/-0.012	0.085
Nickel	0.290+/-0.031	0.22	32+/-3	32.0
Lead	0.251+/-0.027	0.27	28.2+/-1.8	29.0
Zinc	0.980+/-0.099	1.0	138+/-6	138

CASS-1 = Nearshore Seawater Reference Material for Trace Metals; Nat. Res. Council of Canada
SRM 1646 = Estuarine Sediment; National Bureau of Standards
NC = Not certified

Metals data are reported in terms of parts per billion (ug/L) for water and parts per million (mg/kg, dry weight basis) for sediment. Organics data are reported in parts per billion for sediments (ug/kg, dry weight basis) and water (ug/L). Results for semivolatile organics have been recovery corrected.

Results of analysis of sediment trap preservative solutions, shown in Appendix 2, indicate that copper, zinc, and to a lesser extent lead and nickel concentrations were higher in the preservative after retrieval of the traps. However, the levels do not appear to be high enough to have significantly altered the particulate concentrations. Benzoic acid was the only organic compound detected at substantially increased levels in the preservative after retrieval. This compound was also detected in the associated particulate samples. Since the preservative solutions were not filtered prior to organics analysis, the increase in benzoic acid levels may be due to solids in the sample rather than desorption of the compound from the particulate phase.

RESULTS

Water Column--Temperature, salinity, and total suspended solids (TSS) data from vertical profiles of the water column at two locations in City Waterway are shown in Table 3. This data indicates the presence of stratification in the water column, with a layer of lower salinity and higher temperature (based on May data only) water at the surface compared to the mid-depth and bottom samples. Total suspended solids (TSS) concentrations were low and similar, both vertically and horizontally throughout the waterway generally ranging from 1-5 mg/L.

Current Velocity Measurements--Current velocity distributions for two locations in City Waterway during the month of June 1989 are shown in Figure 3. Current velocities ranged from 2-28 cm/sec with a median of 2 cm/sec. The lower value represents the lower limit of detection of the instrument. Slightly higher current velocities were measured near the mouth compared to the mid-waterway station, being less than or equal to 6 and 4 cm/sec respectively, 80 percent of the time. This data indicates that, on the average, current velocities in City Waterway are generally low even during periods of high tidal exchange.

SPM--The results of percent moisture, total organic carbon (TOC) and grain size analysis of SPM samples from City Waterway are presented in Table 4. Average percent moistures ranged from 74-82 percent after centrifugation indicating the samples had a high water content. Average TOC values ranged from 4.6-8.5 percent with the highest levels occurring at the head of the waterway. Grain size analysis suggests that SPM collected by the sediment traps consisted primarily of silt size particles. Grain size results for SPM samples should be considered estimates since a portion of the composite was frozen prior to analysis.

Summarized in Table 5 are the results of metals analysis of SPM samples. In addition, miscellaneous elements detected in SPM are listed in Appendix 3. Zinc, lead, and mercury concentrations (mg/kg, dry weight) associated with SPM during the first quarter collection period were: zinc 180-500 mg/kg, lead 130-440 mg/kg, and mercury 0.44-0.67 mg/kg. Similar concentrations were observed in mid-depth and bottom samples from the mouth of the waterway. Zinc and lead concentrations peaked in SPM at the head of the waterway and decreased moving towards the mouth. In contrast, mercury levels were comparable at the head and mouth of the waterway with peak concentrations occurring near the middle of the waterway at stations ST-2 and ST-3. These gradients suggest the predominant zinc and lead source(s) is at the head of the waterway and the predominant mercury source(s) is located near the middle of the waterway. Zinc, lead, and mercury were all identified as Priority 1 problem chemicals at the head of City Waterway during the CBRI.

During the second quarter collection period, cadmium, copper, and nickel were added to the list of target metals. Concentrations of mercury and lead in SPM during the second quarter were similar to the first quarter. Zinc was slightly higher during the second quarter. Based on these data, the

Table 3: Water column profile data for City Waterway during sediment trap deployment period.

Location	Mid-Channel @ mouth			Mid-Channel near Wheeler Osgood		
Station #	CWP2			CWP1		
Depth	Surface	Mid	Bottom	Surface	Mid	Bottom
November 10, 1988						
Depth (ft)	0	20	35	0	15	28
Temperature (°C)	-	11.4	11.4	-	11.5	11.4
Salinity (o/oo)	21	29	30	22	30	30
TSS (mg/L)	4	2	2	4	3	4
February 8, 1989						
Depth (ft)	0	19	37	0	16	32
Temperature (°C)	6.2	-	-	5.7	-	-
Salinity (o/oo)	10	30	32	16	30	30
TSS (mg/L)	2	1	1	3	1	2
May 15, 1989						
Depth (ft)	0	18	36	0	15	30
Temperature (°C)	15.5	10.0	9.5	15.6	11.0	9.6
Salinity (o/oo)	19	28	28	19	26	28
TSS (mg/L)	4	3	3	2	5	8

- = No data

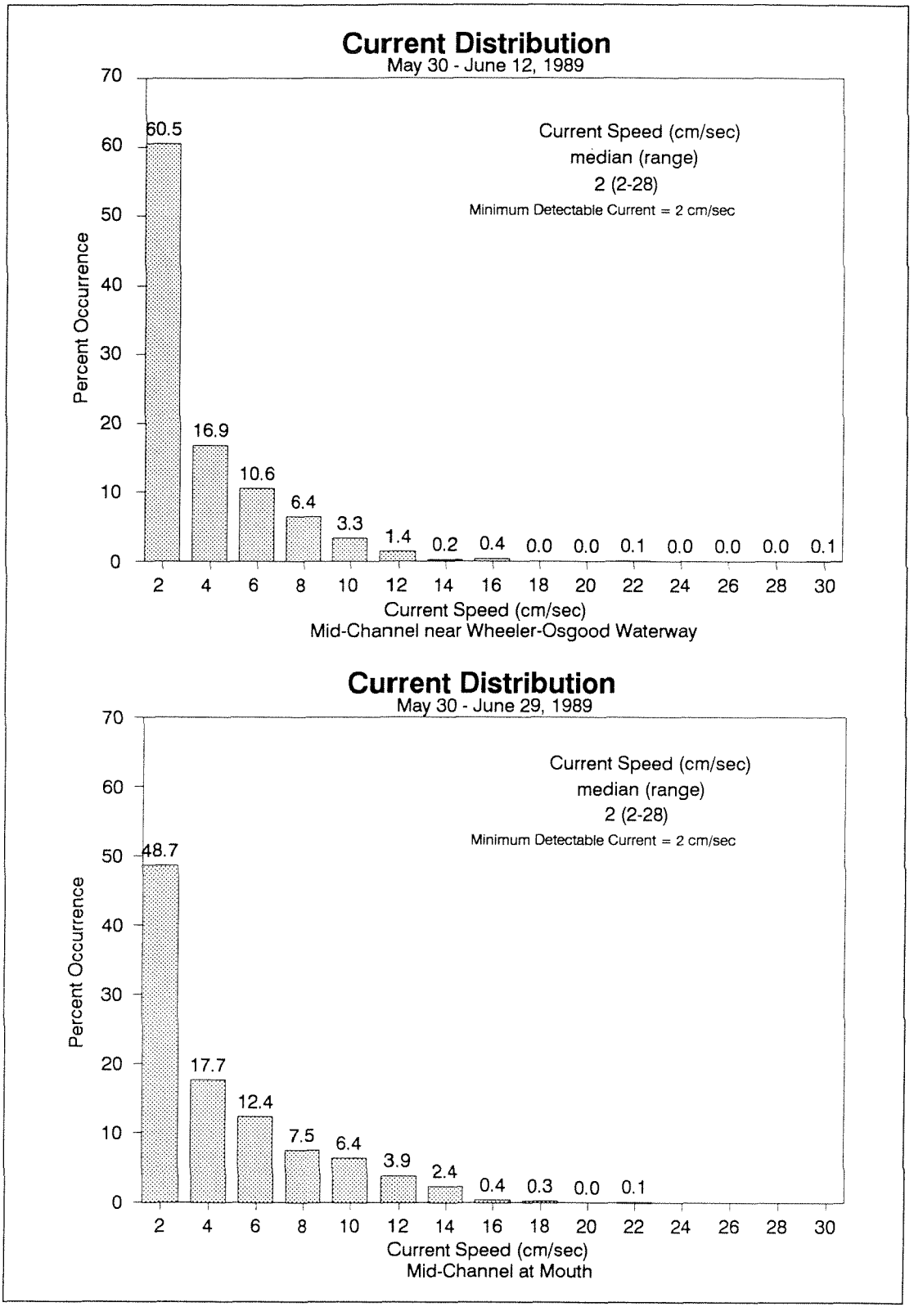

Figure 3: Current record for City Waterway (May 30 - June 29, 1989)

Table 4: Conventionals data on City Waterway suspended particulate matter collected by Ecology November, 1988 - May, 1989 (reported as averages from collection period).

Location	Head @ 96" Drains	Near 15th Street	W. Osgood @ Mouth	Mouth @ D-street
Station No.	ST-1	ST-2	ST-3	ST-4
Depth @ MLLW (ft)	12	18	20	26
Collection Period	Nov-May	Nov-Feb	Nov-May	Nov-Feb
Moisture (%)	79	79	82	74
Total Organic Carbon (%)	8.5	4.7	6.3	4.6
Grain Size (%)				
Sand	28.3	-	5.1	-
Silt	56.0	-	70.1	-
Clay	15.7	-	24.8	-

- = Not analyzed

Table 5: Summary of metals analysis of City Waterway suspended particulate matter samples collected by Ecology November, 1988 - May, 1989 (mg/kg, dry weight unless otherwise indicated).

Location	Head @ 96"	Drains	Near 15th Street	Wheeler Osgood @ Mouth		@ Mouth near D-Street Tank Farms+	
Station No.	ST-1	-	ST-2	ST-3	-	ST-4M	ST-4B
Sample No.	8080	8230/42*	8082	8084	8232	8087	8088
Collection Period	Nov-Feb	Feb-May	Nov-Feb	Nov-Feb	Feb-May	Nov-Feb	Nov-Feb
Cadmium	NA	2.3	NA	NA	2.4	NA	NA
Copper	NA	140	NA	NA	220	NA	NA
Mercury	0.44	0.44	0.67	0.65	0.61	0.46	0.49
Nickel	NA	66	NA	NA	44	NA	NA
Lead	440	460	400	240	270	130	140
Zinc	500	570	420	350	390	180	200

* = Reported as mean of duplicates
M = Mid-depth sample
B = Bottom sample
\+ = Surface sample destroyed during centrifugation
NA = Not analyzed

gradients in mercury, lead, and zinc concentrations appear to be similar for both quarters. However, because two of the trap deployments (ST-2 and ST-4) were damaged during the second quarter of monitoring, it was not possible to evaluate conditions throughout the waterway. Concentrations (mg/kg, dry weight) of target metals measured in City Waterway SPM samples during the second quarter were: cadmium (2.3-2.4 mg/kg), copper (140-220 mg/kg), mercury (0.44-0.61 mg/kg), nickel (44-66 mg/kg), lead (270-460 mg/kg), and zinc (390-570 mg/kg).

The results of semivolatile organics analysis of SPM samples are summarized in Table 6. A total of twenty-four semivolatile organic compounds (primarily PAH and straight-chained hydrocarbons) were detected in City Waterway SPM samples. Maximum SPM concentrations for most semivolatile organics occurred at the head of City Waterway near the twin 96-inch drains. Low molecular weight polynuclear aromatic hydrocarbons (LPAH) and high molecular weight polynuclear aromatic hydrocarbon (HPAH) levels at the head of the waterway (LPAH=2700 ug/kg and HPAH=9800 ug/kg) were approximately one-to-two orders of magnitude higher than those seen in the remainder of the waterway. Concentrations of bis(2-ethylhexyl)phthalate ranged from 870-2500 ug/kg dry weight. Benzoic acid, a plasticizer used in the manufacturing of resins, was detected throughout City Waterway. Benzoic acid levels were highest (5700 ug/kg dry) at the head of the waterway and gradually decreased moving toward the mouth (460 ug/kg dry). The remaining compounds detected in City Waterway SPM samples consisted of several straight-chained hydrocarbons commonly found in the paraffin fraction of petroleum, and acetophenone which is a component in the heavy oil fraction of coal tar (Verschueren, 1983).

Sediment accumulation rates for City Waterway generated from sediment trap data are shown in Table 7. Two types of accumulation rates have been calculated. Mass accumulation ($g/cm^2/year$) which is the measured sediment flux into the traps, and sedimentation rate (cm/year) which is calculated to represent the actual sediment layer thickness on the bottom once the particulates have consolidated. Both these values should be viewed as estimates of gross sedimentation in the waterway since it was not possible, with the available data, to quantitatively define the extent of bottom sediment resuspension. In addition, no attempt was made to remove macrozooplankton from the trap samples.

Mass accumulation rates for the waterway ranged from 1.8 $g/cm^2/year$ at the mouth of waterway to 0.5 $g/cm^2/year$ in the middle of the waterway near the entrance to Wheeler-Osgood Waterway. The mean accumulation rate for City Waterway was 1.0 $g/cm^2/year$. Slightly lower accumulation rates were seen in the mid-depth trap (1.1 $g/cm^2/year$) vs the near bottom trap (1.8 $g/cm^2/year$) at the mouth of the waterway. Because the near surface samples were destroyed during centrifugation, it was not possible to evaluate a complete vertical profile at this location.

Sedimentation rates for City Waterway ranged from 1.8 cm/year at the head to 0.9 cm/year in both the middle and outer parts of the waterway. The mean rate was 1.2 cm/year. Sedimentation rates at the head of the waterway were slightly higher during the second quarter of monitoring than during the first quarter, despite similar rainfall totals (see Figure 4) during both quarters. Accumulation rates for the first and second quarters of monitoring probably overestimate sedimentation in the waterway on an annual basis, since particulate inputs are expected to be higher during winter runoff.

Bottom Sediments--The results of conventionals and metals analysis of City Waterway bottom sediments are shown in Table 8. TOC concentrations ranged from 0.4 - 8.1 percent with the highest concentration occurring at the head of the waterway and decreasing toward the mouth. TOC was identified as a Priority 1 problem chemical at the head of the waterway during the CBRI. Grain size analysis indicated the sediments consisted primarily of silt (49-69 percent) with the exception of sediments from the mouth of the waterway which were mostly sand (64-91 percent).

Table 6: Summary of semivolatile organic analysis of City Waterway suspended particulate matter samples collected by Ecology November 1988 - May 1989 (ug/kg, dry weight unless otherwise indicated).

Location	Head @ 96" Drains	Near 15th Street	W. Osgood @ Mouth	Mouth @ D-street
Station No.	ST-1*	ST-2	ST-3	ST-4
Depth @ MLLW (ft)	12	18	20	26
Sample No. 20-	8236/43	8237	8238	8241
Collection Period	Nov-May	Nov-Feb	Nov-May	Nov-Feb
Anthracene	970	60u	40u	70u
Phenanthrene	1700	60u	40u	70u
Sum LPAH	2700	-	-	-
Fluoranthene	3300	55	40	60u
Benzo (a) anthracene	1200	60u	50u	80u
Chrysene	1200	60u	40u	70u
Pyrene	2300	250	170	120
Benzo (b) fluoranthene	410	280	170	70u
Benzo (k) fluoranthene	370	50u	40u	60u
Benzo (a) pyrene	790	50u	56	70u
Benzo (g,h,i) perylene	260	50u	40u	70u
Sum HPAH	9800	590	440	120
Carbazole	390	60u	40u	70u
Diethylphthalate	80u	110u	92	140u
Bis (2-ethylhexyl) phthalate	2300	870	2500	110u
Benzyl Alcohol	91	ND	ND	ND
Benzoic Acid	5700	1300	1200	460
n-Decane	250j	150u	110u	190u
n-Docosane	120j	80uj	60uj	100uj
n-Eicosane	140	80u	60u	100u
n-Hexadecane	360	90u	70u	110u
n-Octadecane	100j	92j	52j	180uj
n-Hexacosane	70j	70j	66j	90uj
n-Octacosane	260j	60uj	75j	70uj
n-Triacontane	600	60u	36	70u
Acetophenone	41	ND	ND	ND

* = Mean of duplicates
u = Not detected at detection limit shown
ND = Not detected at unspecified detection limit
NA = Not analyzed
j = Estimated value

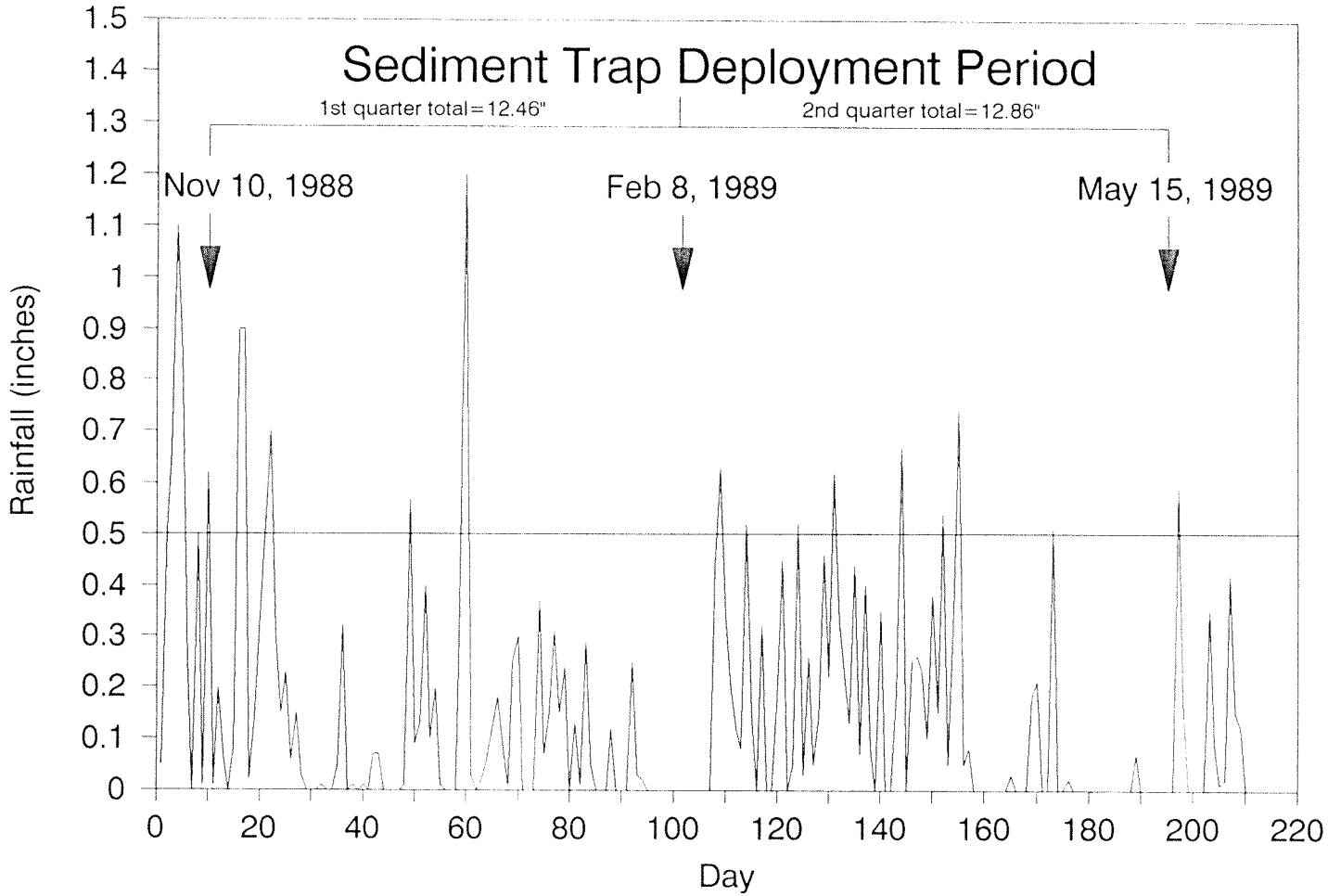

Figure 4: Tacoma rainfall data for sediment trap deployment period

November 10, 1988 - May 15, 1989

(rainfall data provided by Redding, 1989)

Table 7: Sediment accumulation rates for City Waterway determined from moored sediment traps (November 1988 - May 1989).

Station	Collection Period	Wet Sed. Collected grams	SPM Solids %	Dry Sed. Collected grams	# Days Sampled	Mass Accum. $g/cm^2/year$	Sediment Solids %	Dry+ Density g/cm^2	Sedimentation Rate* cm/year
ST-1	11/88-2/89	231.2	11	25	90	0.8	43.6	0.6	1.3
"	2/89-5/89	144.4	25	36	96	1.1	"	"	1.8
ST-2	11/88-2/89	206.8	12	25	90	0.8	43.1	"	1.4
ST-3	11/88-2/89	188.3	8	15	"	0.5	41.5	"	0.9
"	2/89-5/89	98.1	18	18	96	0.6	"	"	1.0
ST-4M	11/88-2/89	189.3	18	34	90	1.1	70.7	1.3	0.9
ST-4B	11/88-2/89	180.5	31	56	"	1.8	"	"	1.4
mean (range)						1.0(0.5-1.8)			1.2(0.9-1.8)

+ = Calculated from Puget Sound Density Model (Crecelius, 1989) using % solids data from in-situ bottom sediments
M = Mid-depth
B = Bottom

$$\text{Sedimentation Rate (cm/year)} = \frac{\text{Mass Accumulation } g/cm^2/year}{\text{Dry Density of Bottom Sediments } g/cm^3}$$

Table 8: Summary of conventionals and metals analysis of City Waterway surface sediment samples collected by Ecology November 9-10, 1988 (mg/kg, dry weight unless otherwise indicated).

Location	Head @ 96" Drains	Near 15th Street	W. Osgood @ Mouth	@ Mouth near D-Street Tank Farms	
Station No.	ST-1	ST-2	ST-3	ST-4	(REP)
Depth @ MLLW (ft)	12	18	20	26	-
Sample No. 46-	8030	8031	8032	8033/34*	8035
Moisture (%)	56.4	56.9	58.5	22.2	43.5
Total Organic Carbon (%)	8.1	4.5	4.9	0.7	3.1
Grain Size (%)					
Sand	22.6	37.4	11.4	90.4	64.0
Silt	64.7	49.0	68.8	6.8	25.3
Clay	12.7	13.6	19.8	2.8	10.7
Metals					
Cadmium	3.0	3.2	3.3	0.4	0.9
Copper	190.0	180.0	250.0	60.0	99.0
Mercury	0.75	1.24	0.84	0.11	0.29
Nickel	61.0	41.0	41.0	31.0	36.0
Lead	580.0	620.0	320.0	57.0	100.0
Zinc	500.0	450.0	380.0	170.0	190.0

* = Reported as mean of duplicates

Most metals exhibited a similar longitudinal gradient in the waterway. Concentrations tended to be relatively high at the head of the waterway, off the 15th Street drain, and at the entrance to Wheeler-Osgood Waterway. Then, except for nickel, these metals declined sharply at the mouth of City Waterway. The highest lead concentration (620 mg/kg, dry) was present near the 15th Street drain. Lead concentrations on the opposite side of the waterway (320 mg/kg, dry) were approximately half of those measured near the 15th Street drain. Stormwater discharged from the 15th Street drain consists primarily of urban street runoff from downtown Tacoma. Copper was moderately elevated near the entrance to Wheeler-Osgood Waterway compared to other parts of the waterway sampled. This station is located near Martinac Shipbuilding where nearshore sediments have been contaminated by granulated slag from sand blasting operations at the facility (Norton and Johnson, 1984).

The results of semivolatiles analysis of bottom sediments are presented in Table 9. A total of twenty semivolatile organic compounds [primarily polynuclear aromatic hydrocarbons (PAH), phthalate esters and straight-chained hydrocarbons] were detected in the bottom sediments. LPAH concentrations ranged from 940 - 7200 ug/kg, dry. HPAH concentrations ranged from 3500 - 33000 ug/kg, dry. LPAH and HPAH were both identified as Priority 2 problem chemicals in City Waterway during the CBRI. Replicate samples from the mouth of the waterway differed substantially in PAH concentrations. Based on the results of duplicate analysis the variability in LPAH and HPAH concentrations at this site could be a reflection of poor laboratory precision.

Phthalate esters were identified as Priority 2 problem chemicals at the head of City Waterway. Elevated concentrations of three phthalates esters butylbenzlphthalate, di-n-octylphthalate and bis(2-ethylhexyl)phthalate were detected in bottom sediments from the head of the waterway during the present study. Non-target compounds detected in City Waterway sediments included benzathrone and picoline, which are both used in making dyes, and three straight chained hydrocarbons n-eicosane, n-octadecane, and n-tetradecane, which are redistributed in the environment primarily from the general use of paraffin based petroleum products (Verschueren, 1983).

DISCUSSION

Shown in Table 10 is a comparison of chemical data on City Waterway SPM with storm drain particulates collected by centrifugation as part of a routine monitoring study conducted by the City of Tacoma (City of Tacoma, 1989). For perspective, also included are contaminant levels associated with muddy sediments in depositional areas of the main basin of Puget Sound (Tetra Tech, 1989). In general, City Waterway storm drain particulates can be characterized as having high temporal variability in contaminant levels compared to SPM from the waterway. In spite of this variability, median concentration of metals in the traps and storm drains were similar. Exceptions to this generality were nickel and zinc concentrations which were somewhat lower in the sediment trap samples. In contrast, concentrations of most organics in SPM from the waterway were much lower than in the storm drain particulates.

Compared to muddy sediments from the main basin of Puget Sound, cadmium and lead levels in SPM were an order of magnitude higher, and mercury levels in SPM were approximately three times higher. Nickel concentrations in the sediment traps were similar to those in the main basin. Organic levels in sediment trap samples were similar to those measured in the main basin with the exception of LPAH and bis(2-ethylhexyl)phthalate which exceeded the main basin values by an order of magnitude.

To place bottom sediment results from this investigation into perspective, Table 11 shows historical data on metal and organic concentrations in City Waterway bottom sediments generated during the CBRI. Concentrations of metals and organics measured during the current study and historical data on the waterway agree well, despite the passage of approximately four years between collection of the two data sets. This finding is consistent with the fact that there is often a long lag time in Puget

Table 9: Summary of semivolatile organics detected in City Waterway surface sediment samples collected by Ecology November 9-10, 1988 (ug/kg, dry weight)

Location	Head @ 96" Drains	Near 15th Street	W. Osgood @ Mouth	@ Mouth near D-Street Tank Farms	
Station No.	ST-1	ST-2	ST-3	ST-4	(REP)
Depth @ MLLW (ft)	12	18	20	26	-
Sample No. 46-	8030	8031	8032	8033/34*	8035
LPAH	**7200**	**3400**	**940**	**4300**	**4000**
HPAH	**33000**	**11000**	**4500**	**7800**	**17000**
Carbazole	**830**	**370**	120u	**160**	**26**
2-phenylnapthalene	ND	ND	ND	**390**	**1300**
Butylbenzlphthalate	**1700**	220u	220u	130u	170u
Di-n-octylphthalate	80u	**14000**	80u	50u	60u
Bis (2-ethylhexyl) phthalate	**12000j**	**13000j**	**3300j**	100u	140u
Benzanthrone	ND	ND	ND	**740+**	**2400**
alpha Picoline	**2800j**	430u	430u	240u	330u
n-Eicosane	**1400**	160u	160u	**350**	120u
n-Octadecane	300u	300u	300u	**620j**	220u
n-Tetradecane	**810j**	260u	260u	**170j**	200u

* = Reported as mean of duplicates
u = Not detected at detection limit shown
j = Estimated value
ND = Not detected at unspecified detection limit
\+ = Based on single value

Table 10: Comparison of chemical data on SPM from City Waterway sediment traps and storm drains to muddy sediments from the main basin of Puget Sound. (Values shown are median (range)).

Location	Sediment Trap Particulates	City Waterway Storm Drains+ Dry Weather	Wet Weather	Puget Sound Main Basin-1
Collection Period	11/88-5/89	5/87-1/89	5/87-1/89	3/89
Number of Samples	7/4*	28	22	6
TOC (%)	5.9(4.1-11)	5.2(0.1-34)	2.2(0.3-32)	2.0(1.6-2.2)
Metals (mg/kg, dry)				
Cadmium	2.4(2.3-2.4)	2.1(ND-24)	4.0(ND-23)	0.25j(0.15j-0.33j)
Copper	180(140-220)	330(97-1100)	260(29-1200)	46(34-50)
Mercury	0.56(0.44-0.67)	0.50(0.18-5.4)	0.62(0.13-2.5)	0.20(0.13-0.24)
Nickel	55(44-66)	210(43-10000)	370(59-2100)	37(35-41)
Lead	330(140-450)	280(18-2000)	590(62-1200)	38(18j-51)
Zinc	400(190-540)	660(170-32000)	1200(440-15000)	100(89-110)
Organics (ug/kg, dry)				
LPAH	2700(2700)	3000j(ND-32000j)	9500j(60j-43000j)	96j(28-126j)
HPAH	520(120-9800)	5600j(ND-140000)	39000j(5500j-300000)	780j(190j-960j)
Diethylphthalate	100u(80u-140u)	140(ND-5100)	330(ND-4000j)	29u(17u-68u)
Bis(2-ethylhexyl) phthalate	1600(110u-2500)	36000(ND-3100000)	80000(9300-830000)	83j(38-190)
Benzyl Alcohol	ND(ND-91)	ND(ND)	ND(ND-1000j)	140u(86u-340u)

* = Number of samples:metals=7;organics=4
ND = Not detected at unspecified detection limit
u = Not detected at detection limit shown
j = Estimated concentration
\+ = Includes Twin 96", Wheeler-Osgood and 15th Street drains-Reported as flow weighted average of medians (range); Concentration data from City of Tacoma Monitoring; Flow data Tetra Tech, 1987.
1 = Tetra Tech, 1989-Central Basin muddy sediments (>67% fines) from deep areas (>150m), includes Stations 24, 29 and 38.

Table 11: Comparison of metals and selected organics detected in City Waterway sediments during the present study and the Commencement Bay Remedial Investigation. (Values shown are median (range))

Source	City Waterway	
	Present Study	Historical+
Number of Samples	5	15
TOC (%)	4.5(0.7-8.1)	5.9(1.2-18)
Metals (mg/kg, dry)		
Cadmium	3.0(0.4-3.3)	5.7(1.5-6.9)
Copper	180(60-250)	170(40-310)
Mercury	0.75(0.11-1.2)	0.32(0.1-1.1)
Nickel	41(31-61)	25(9-40)
Lead	320(57-620)	300(49-730)
Zinc	380(170-500)	240(44-550)
Organics (ug/kg, dry)		
LPAH	4000(940-7200)	4000(1900-8800)
HPAH	11000(4500-33000)	9500(4700-20000)
Butylbenzlphthalate	220u(130u-1700)	56(25-660)
Di-n-octylphthalate	80u(50u-14000)	130(27-290)
Bis(2-ethylhexyl)phthalate	3300j(100u-13000j)	1000(430-8000)

+ = Historical-Retrieval of detected values from SEDQUAL Database (PTI, 1989)
u = Not detected at detection limit shown
j = Estimated value

Sound sediments before changes in chemical concentrations associated with newly arriving particulates are fully reflected in the well mixed surface sediment layer (Carpenter, 1985).

Table 12 compares concentrations of problem chemicals measured in SPM and bottom sediments during the present study to AET values for Puget Sound sediments. AET values were developed to estimate contaminant concentrations above which deleterious affects would always be observed in marine benthic communities (PTI,1988). Two sets of AET values are shown in Table 12. The first are "Sediment Cleanup Objectives" (SCO) for the Commencement Bay Nearshore/Tideflats site and the second are Ecology's "Interim Sediment Quality Standards" (ISQS). The two sets differ in that non-polar organic compounds are evaluated on a dry weight basis for the cleanup objectives and on a TOC normalized basis for Ecology's ISQS. Chemicals exceeding an AET value are underlined in Table 12.

The following chemicals exceeded an AET value in both sediment and SPM in one or more locations at the head of City Waterway: mercury, lead, zinc, and bis(2-ethylhexyl)phthalate. Chemicals exceeding an AET in bottom sediments only from the head of City Waterway include: LPAH, HPAH, butylbenzlphthalate and di-n-octylphthalate. Compounds exceeding an AET in SPM only from the head are as follows: benzyl alcohol and benzoic acid. At the mouth of City Waterway (11th Street bridge to entrance), LPAH and HPAH concentrations in sediment were the only samples exceeding AET values.

Table 13 compares current levels of problem chemicals (reflected by SPM) with historical contamination (bottom sediments) in City Waterway. Since these comparisons are based on a limited amount of data, the reader is cautioned against drawing strong conclusions concerning trends in contaminant levels. Preliminary indications are that concentrations of most problem chemicals associated with SPM currently entering the waterway were lower than those measured in existing deposits, two noteworthy exceptions being mercury and lead at the mouth of the waterway. Summarized at the bottom of Table 13 are subjective criteria developed to evaluate differences in chemical concentrations between bottom sediments and SPM. These criteria are based on consideration of measures of precision (previously discussed under Quality Assurance) available from the present study. Applying these criteria to the data in Table 13 suggests that there may have been decreases in mercury and HPAH levels at the head of City Waterway, and HPAH at the mouth of the waterway. Mercury at the mouth was the only location where a contaminant concentration appears to have increased. Additional data being collected as part of Phase II on contaminant concentrations associated with SPM will be critical to further assess these apparent trends in concentrations.

Sedimentation rates for City Waterway, determined from Pb-210 dated cores collected as part of the CBRI and from sediment traps during this study, are compared in Table 14. Also shown are typical values for other areas of Puget Sound. There is good agreement between core data and mean sedimentation rates from the traps at the head and mouth of City Waterway. These two approaches gave rates differing by less than a factor of two. Mass accumulation in the traps at the mouth of the waterway were slightly higher than core values, differing by a factor of 2.5. Agreement between core and trap rates suggests that the amount of resuspend sediment collected by the traps is probably low. This conclusion is further supported by the fact that differences were seen in metals (Tables 5 and 8) and organics (Tables 6 and 9) concentrations between SPM and bottom sediments. However, additional data will be required to quantify the amount of resuspension. This data is currently not being collected.

Poor agreement between core data from Wheeler-Osgood Waterway and the nearest sediment trap station (ST-3) was not unexpected, since sedimentation rates from cores in Wheeler-Osgood are considered questionable (erratic Pb-210 profiles). In general, sedimentation rates measured by the traps in City Waterway appear to be within the range of values reported for other Commencement Bay waterways. In addition, the rates reported for City Waterway appear to be somewhat higher than values typically reported in the deeper areas of Puget Sound.

Table 12: Comparison of problem chemicals* detected in bottom sediments and SPM from City Waterway to Apparent Effects Thresholds (units=mg/kg).

Segment	Head						Mouth			
Station	ST-1		ST-2		ST-3		ST-4		AET+	
Media	Sediment	SPM	Sediment	SPM	Sediment	SPM	Sediment**	SPM	CMB	Ecology
Metals (dry wt)										
Cadmium	3.0	2.3	3.2	NA	3.3	2.4	0.4/0.9	NA	5.1	5.1
Copper	190.0	140	180.0	NA	250.0	220	60/99	NA	390	390
Mercury	**0.75**	**0.44**	**1.2**	**0.67**	**0.84**	**0.63**	0.11/0.29	**0.48**	0.59	0.41
Nickel	61	66	41.0	NA	41.0	44	31/36	NA	>140	NV
Lead	**580**	**450**	**620**	400	320	250	57/100	140	450	450
Zinc	**500**	**540**	**450**	**420**	380	370	170/190	190	410	410
Organics										
LPAH										
-dry wt	**7.2**	2.7	3.4	-	0.94	-	4.3/4.0	-	5.2	
-TOC Normalized	88	32	76	-	19	-	**610**/130	-		370
HPAH										
-dry wt	**33.0**	9.8	11.0	0.59	4.5	0.44	7.8/**17**	0.12	17	
-TOC Normalized	410	120	240	13	92	6.9	**1100**/550	2.9		960
Diethylphthalate										
-dry wt	-	-	-	-	-	0.092	-	-	0.2	
-TOC Normalized	-	-	-	-	-	1.5	-	-		61
Butylbenzlphthalate										
-dry wt	**1.7**	-	-	-	-	-	-	-	0.9	
-TOC Normalized	**21**	-	-	-	-	-	-	-		4.9
Di-n-octylphthalate										
-dry wt	-	-	**14.0**	-	-	-	-	-	6.2	
-TOC Normalized	-	-	**310**	-	-	-	-	-		58
BEHP										
-dry wt	**12.0j**	**2.3**	**13.0j**	0.87	**3.3j**	**2.5**	-	-	1.3	
-TOC Normalized	**150j**	27	**290j**	19	**67j**	40	-	-		47
Benzyl Alcohol										
-dry wt	-	**0.091**	-	-	-	-	-	-	0.073	0.057
Benzoic Acid++										
-dry wt	-	**5.7**	-	**1.3**	-	**1.2**	-	0.46	0.65	0.65

* = Identified during the Commencement Bay Remedial Investigation (Tetra Tech, 1985)
** = Replicate samples
\+ = CMB AET-Based on cleanup objectives for Commencement Bay Nearshore/Tideflats (EPA, 1989), Ecology AET-Based on Ecology's Interim Sediment Quality Standards (Ecology, 1989)
++ = Not identified as a problem chemical
j = Estimated value
NA = Not Analyzed
NV = No value established
\- = Not detected, see Tables 5 and 6 for detection limits
BEHP = Bis(2-ethylhexyl)phthalate

Table 13: Comparison of problem chemicals* in suspended particulate matter and bottom sediments from City Waterway (metals=mg/kg, dry weight; organics=ug/kg, dry weight)

Chemical	ST-1			ST-2			ST-3			ST-4		
	Sediment	SPM	Change	Sediment	SPM	Change	Sediment	SPM	Change	Sediment	SPM	Change
Cadmium	3.0	2.3	(↓)	3.2	NA	-	3.3	2.4	(↓)	0.65	NA	-
Copper	190	140	(↓)	180	NA	-	250	220	(?)	80	NA	-
Mercury	0.75	0.44	↓	1.2	0.67	↓	0.84	0.63	(↓)	0.20	0.48	↑
Nickel	61	66	(?)	41	NA	-	41	44	(?)	34	NA	-
Lead	580	450	(↓)	620	400	↓	320	260	(?)	79	140	(↑)
Zinc	500	540	(?)	450	420	(?)	380	370	(?)	180	190	(?)
LPAH	7200	2700	(?)	3400	ND	(?)	940	ND	(?)	4200	ND	(?)
HPAH	33000	9800	(?)	11000	590	↓	4500	440	↓	12000	120	↓
BEHP	12000j	2300j	(?)	13000j	870	↓	3300j	2500	(?)	ND	ND	(?)

* = Identified during the Commencement Bay Remedial Investigation (Tetra Tech, 1985)
BEHP = Bis(2-ethylhexyl)phthalate
ND = Not detected (see tables 4-7 for detection limits)
NA = Not Analyzed
j = Estimated concentration

Legend of change indicators

Metals	Organics
(?) = 0-20% Uncertain	(?) = <10X Uncertain
(↑↓) = 20-30% possible change	↑↓ = >10X likely change
↑↓ = >30% likely change	

Table 14: Comparison of sediment accumulation rates for Puget Sound from Pb-210 dated cores with rates obtained from sediment traps during the present study.

Source	Location	Sedimentation Rate+ g/cm2/yr	cm/year
Present Study	Head of City Waterway	1.0(0.8-1.1)	1.6(1.3-1.8)
	Middle of City Waterway near Wheeler-Osgood	0.6(0.5-0.8)	1.1(0.9-1.4)
	Mouth of City Waterway	1.5(1.1-1.8)	1.2(0.9-1.4)
	City Waterway Range	1.0(0.5-1.8)	1.2(0.9-1.8)
Tetra Tech, 1987	Head of City Waterway	0.80	1.26
	Wheeler Osgood Waterway	0.04-0.19*	0.12-0.50*
	Mouth of City Waterway	0.45	0.67
	CMB Waterways Range	0.6(0.04-1.48)	0.75(0.14-1.78)
Carpenter et al, 1985	Near Browns Pt.	0.24(0.20-0.28)	0.42(0.25-0.58)
"	Central Sound Shallow Bays	0.16(0.11-0.26)	0.19(0.11-0.30)
"	Puget Sound Range	0.43(0.046-1.2)	0.68(0.04-2.4)
Lavelle et al, 1986	Puget Sound Range	0.72(0.26-1.2)	1.4(0.53-2.48)
Bloom and Crecelius, 1987	Main Basin Range	0.64(0.27-1.4)	-

+ = mean(range) where available, dry density used for cm/year calculations
* = Values considered questionable

CONCLUSIONS

Concentrations of problem chemicals measured in City Waterway bottom sediments during the present study were similar to those recorded in 1984 during the CBRI. Concentration gradients for metals associated with SPM in the waterway suggest that the predominant source(s) of zinc and lead is located at the head of City Waterway, while the predominant source(s) of mercury is located somewhere in the middle of the waterway. Comparisons of contaminant levels in the trap samples with available AETs indicate mercury, lead, zinc, bis(2-ethylhexyl)phthalate, benzyl alcohol, and benzoic acid at the head of the waterway are at levels which could adversely affect marine benthic communities.

Based on data from Phase 1 of the present study, this sediment trap design when deployed in nearshore marine areas with current velocities similar to City Waterway (i.e. 2-28 cm/sec) is capable of collecting undisturbed samples of SPM in sufficient quantity to analyze for a variety of physical and chemical parameters. In addition, sedimentation rates measured with the traps are in good agreement with rates determined by other investigators from Pb-210 dated cores. Mean accumulation in the traps and sedimentation on the bottom calculated from the trap data were 1.0 g/cm^2/year and 1.2 cm/year respectively. Under the conditions present in City Waterway, the chemical and physical data presented suggest that the amount of resuspended material collected by the traps is probably low. However, additional data will be required to quantify the amount of resuspension.

RECOMMENDATIONS

Investigate potential upland sources of mercury, lead, zinc, bis(ethylhexyl)phthalate, benzyl alcohol, and benzoic acid at the head of City Waterway.

Continue sediment trap monitoring in City Waterway beyond the initial year. The data generated is likely to provide the only empirical measure of the success of source control efforts. This is especially true since the City of Tacoma presently has no plans to continue monitoring storm drain discharges to City Waterway.

Expand the use and deployment of sediment traps into other nearshore areas of Puget Sound. The data will be useful in evaluating a wider range of conditions and discharge types, and traps could potentially be used to monitor.

REFERENCES

APHA-AWWA-WPCF, 1985. Standard Methods for the Examination of Water and Wastewater. 16th ed.

Baker, E.T., H.B. Milburn and D.A. Tennant, 1988. Field Assessment of Sediment Trap Efficiency under Varying Flow Conditions. J. Mar. Res., 46: 573-592.

Bloom, N. and E.A. Crecelius, 1983. Determination of Mercury in Seawater at Sub-nanogram Per Liter Levels. Marine Chemistry; 14:49-59.

Bloom, N. and E.A. Crecelius, 1984. Determination of Silver in Seawater by Coprecipitation with Cobalt Pyrrolidinedithiocarbamate and Zeeman Graphite-Furnace Atomic Absorption Spectrometry. Analytica Chimica Acta; 156:139-145.

Bloom, N. and E.A. Crecelius, 1987. Distribution of Silver, Mercury, Lead, Copper and Cadmium in Central Puget Sound Sediments. Marine Chemistry; 21:377-390.

Butman, C.A., 1986a. Sediment Trap Biases in Turbulent Flows; Results from a Laboratory Flume Study. J. Mar. Res., 44:645-693.

Butman, C.A., W.D. Grant and K.D. Stolzenbach, 1986b. Predictions of Sediment Trap Biases in Turbulent Flows: A Theoretical Analysis Based on Observations from the Literature. J. Mar. Res., 44:601-644.

Carpenter, R., M.L. Peterson and J.T. Bennett, 1985. Pb-210 Derived Sediment Accumulation and Mixing Rates for the Greater Puget Sound Region. Mar. Geo., 64:291-312.

City of Tacoma, 1989. City of Tacoma Surface Water Quality Study. Draft Report submitted by Tacoma Public Works/Sewer Utilities Div. to Wash. St. Dept. of Ecology.

Crecelius, E.A., 1989. Personal communication. Battelle Northwest, Sequim, Wa.

Ecology, 1989. Interim Sediment Quality Evaluation Process for Puget Sound. Wash. St. Dept. of Ecology, Olympia, WA.

EPA, 1983. Methods for Chemical Analysis of Water and Wastes. Environmental Monitoring and Support Laboratory, Cincinnati, OH. EPA 600/4-79-020.

EPA, 1988a. Laboratory Data Validation Functional Guidelines for Evaluating Organics Analyses. Complied by Sample Management Office for the Data Review Workgroup, Hazardous Site Evaluation Division. EPA R-582-5-5-01.

EPA, 1988b. Analytical Methods for the National Sewage Sludge Survey. Prepared by Viar and Co. for the Office of Water Regulations and Standards, Washington, D.C. Contract No. 68-01-6990.
EPA, 1989. Commencement Bay Nearshore/Tideflats Record of Decision. EPA Region X, Seattle, WA.

Holme, N.A. and A.D. McIntyre, 1971. Methods for Study of the Marine Benthos. Internat Biol. Prog. Handbook No. 16.

Larsson, U., S. Blomqvist, and B. Abrahamsson, 1986. A New Sediment Trap System. Mar. Ecol. Prog. Ser., 31:205-207.

Lavelle, J.W., G.J. Massoth and E.A. Crecelius, 1986. Accumulation Rates of Recent Sediments in Puget Sound, Washington. Mar. Geo., 72:59-70.

Nielson, K.K. and R.W. Sanders, 1983. Multielement Analysis of Unweighed Biological and Geological Samples using Backscatter and Fundamental Parameters. Adv. X-Ray Anal.; 26:385-390.

Norton, D. and A. Johnson, 1984. Completion Report on WQIS Project 5 (part 2) for the Commencement Bay Nearshore/Tideflats Remedial Investigation: Metals in City Waterway Sediment off American Plating Co., Inc., J.M. Martinac Shipbuilding Corp., and Fick Foundary Co., April 1984. Washington State Department of Ecology Olympia, Wa.

PTI, 1988. Sediment Quality Values Refinement: Vol. 1 Update and Evaluation of Puget Sound AET. Prepared for Tetra Tech, Inc. and EPA Region X Office of Puget Sound, Seattle, Wa.

PTI, 1989. SEDQUAL Environmental Data Management System, Ver. 2.0. PTI Environmental Services, Prepared for EPA Region X.

Redding, R., 1989. Personal Communication. City of Tacoma, Central Treatment Plant.

Tetra Tech, 1985. Commencement Bay Nearshore/Tideflats Remedial Investigation. Vols 1 and 2. Final Report. Prepared for Washington State Department of Ecology and U.S. Environmental Protection Agency. EPA-910/9-85-134b.

Tetra Tech, 1986. Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound. Prepared for Puget Sound Estuary Program.

Tetra Tech, Inc. and PTI Environmental Services, 1987. Commencement Bay Nearshore/Tideflats Feasibility Study: Assessment of the Potential Success of Source Control. Final Report. Prepared for the Washington State Department of Ecology and U.S. Environmental Protection Agency. 157pgs.

Tetra Tech, 1989. Marine Sediment Monitoring. Puget Sound Ambient Monitoring Program 1989. Draft Report, Prepared for the Wash. St. Dept. of Ecology.

Verschueren, K., 1983. Handbook of Environmental Data on Organic Chemicals. 2nd ed. Van Nostrand Reinhold Publ. 1310 pgs.

APPENDIX

Appendix 1: Results of analysis of blind field duplicates for City Waterway sediment monitoring.

Media	Sediment			Particulates		
Sample No.	46-8033	46-8034	RPD	20-8236	20-8243	RPD
Percent Moisture	23.4	20.9	10	71.5	70.4	2
Total Organic Carbon	0.9	0.4	76	11.0	11.0	0
Grain Size						
Sand	90.5	90.3	1	-	-	-
Silt	6.7	6.9	2	-	-	-
Clay	2.8	2.8	0	-	-	-
Metals						
Cadmium	0.4	0.4	0	2.3	2.2	4
Copper	58.0	62.0	6	140.0	130.0	7
Mercury	0.11	0.11	0	0.43	0.44	2
Nickel	29.0	32.0	10	69.0	62.0	10
Lead	60.0	54.0	10	460.0	460.0	0
Zinc	160.0	170.0	6	570.0	570.0	0
Organics						
Acenaphthylene	440	570	25	50uj	60uj	-
Anthracene	460	3200	150	1900	50u	-
Phenanthrene	540	3400	145	1700	1600	6
Fluoranthene	980	3400	110	3600	2900	15
Benzo (a) anthracene	770	2300	100	1300	1100	16
Chrysene	300	690	78	1700	760	76
Pyrene	1400	3500	85	2500	2000	22
Benzo (b) fluoranthene	60u	2100	-	780	40u	-
Benzo (k) fluoranthene	50u	60u	-	700	40u	-
Benzo (a) pyrene	-	60uj	-	870	700	22
Benzo (g,h,i) perylene	-	-	-	480	40u	-
Carbazole	70u	250	-	420	350	18
2-phenylnapthalene	230	550	82	ND	ND	-
Diethylphthalate	130u	120u	-	80u	-	-
Bis(2-ethylhexyl)phthalate	100u	100u	-	2300	2200	4
Benzyl Alcohol	ND	ND	-	61	120	65
Benzoic Acid	ND	ND	-	4000	7100	63
Benzanthrone	ND	740	-	ND	ND	-
Acetophenone	ND	ND	-	35	46	28
n-Decane	170u	160u	-	150	350J	80
n-Docosane	90u	90u	-	60uj	180J	-
n-Eicosane	340	360	6	210	60u	-
n-Hexadecane	100u	100u	-	240	480	67
n-Octadecane	580j	660j	13	78	130J	50
n-Tetradecane	140j	200j	35	100u	100u	-
n-Hexacosane	80u	80u	-	80j	50uj	-
n-Octacosane	70u	60u	-	230j	280j	20
n-Triacontane	70u	60u	-	600	600	0

RPD = Relative range of duplicates (range as percent of mean)
- = No data
u = Not detected at detection limit shown
j = Estimated concentration
ND = Not detected at unspecified detection limit

Appendix 2: Summary of metals and organics analysis of sediment trap preservative solutions (ug/L).

Description	1st quarter		2nd quarter	
	Prede-ployment	Postde-ployment	Prede-ployment	Postde-ployment
No. Samples	1	5*	1	1
Date	11/88	2/89	2/89	5/89
Salinity (o/oo)	57	31	57	35
Metals**				
Cadmium	0.094	0.24	0.068	0.22
Copper	0.41	12.0	0.83	32.0
Mercury	0.037	0.9	1.3	0.01
Nickel	0.82	4.9	0.76	27.0
Lead	0.099	0.6	0.078	0.62
Zinc	1.9	68.0	1.6	190.0
Semivolatiles+				
p-Cresol	ND	40	ND	ND
n-Triacontane	ND	ND	ND	9.5
n-Octadecane	ND	ND	ND	3.2j
Benzyl Alcohol	ND	ND	ND	2.7
Acetophenone	ND	ND	ND	2.5
Benzoic Acid	ND	ND	ND	810

* = Single sample analyzed for organics, composite from all traps
** = Metal samples filtered (0.4um) prior to analysis
\+ = Aliquots for organic analyses were unfiltered
ND = Not detected
j = Estimated value

Appendix 3: Concentrations of Miscellaneous Elements* in Surface Sediments and Particulate Samples Collected by Ecology from City Waterway, November 1988 - May 1989.

	SEDIMENT				
Location	Head @ 96" Drains	Near 15th Street	W. Osgood @ Mouth	Mouth near D-Street	Tank Farms
Station No.	ST-1	ST-2	ST-3	ST-4+	(REP)
Sample No.	8030	8031	8032	8033/34	8035
Collection Period	Nov,88	Nov,88	Nov,88	Nov,88	-
(Units=Percent)					
Aluminum	6.7	6.2	7.0	7.9	7.0
Silicon	25.0	26.0	24.0	29.0	26.0
Phosphorus	0.33u	0.3	0.3u	0.3u	0.3u
Sulfur	1.3	1.0	1.0	0.6	0.9
Chloride	2.2	1.8	2.2	0.5	1.1
Potassium	0.7	0.7	0.8	1.0	0.8
Calcium	1.9	2.1	2.6	4.5	4.8
Titanium	0.4	0.4	0.4	0.5	0.4
Iron	3.5	3.4	4.0	4.7	6.3
(Units=mg/kg, dry)					
Vanadium	81.0	69.0	67.0	65.0	66.0
Manganese	430.0	470.0	510.0	660.0	670.0
Gallium	8.7	13.0	14.0	18.0	17.0
Selenium	1.3u	1.3u	1.3u	1.3u	1.4u
Arsenic	12.0	11.0	22.0	8.6	17.0
Bromine	130.0	110.0	150.0	27.0	73.0
Rubidium	35.0	35.0	41.0	40.0	37.0
Strontium	280.0	310.0	370.0	530.0	530.0

* = Analysis by X-Ray Fluorescence
+ = Reported as mean of duplicates
u = Not detected at detection limit shown

Appendix 3: Continued

PARTICULATES

Location	Head @ 96"	Drains	Near 15th Street	Wheeler Osgood @ Mouth		Mouth @ D-Street	
Station No.	ST-1	-	ST-2	ST-3	-	ST-4M	ST-4B
Sample No.	8080	8230/42+	8082	8084	8232	8087	8088
Collection Period	Nov-Feb	Feb-May	Nov-Feb	Nov-Feb	Feb-May	Nov-Feb	Nov-Feb
(Units=Percent)							
Aluminum	5.2	5.2	6.1	6.4	5.5	7.1	8.2
Silicon	19.0	22.0	22.0	23.0	23.0	25.0	26.0
Phosphorus	0.33u	0.3u	0.3u	0.3u	0.3u	0.4	0.3u
Sulfur	0.3	0.5	0.7	0.7	0.7	0.7	0.7
Chloride	7.0	2.6	5.2	4.1	3.5	1.3	1.0
Potassium	0.5	0.6	0.6	0.7	0.7	0.8	0.9
Calcium	1.6	1.9	1.9	2.3	3.1	2.7	2.7
Titanium	0.3	0.3	0.3	0.4	0.4	0.4	0.4
Iron	3.0	3.3	3.1	4.1	4.1	3.9	4.2
(Units=mg/kg, dry)							
Vanadium	43.9	64.0	57.0	58.0	75.0	80.0	50.0
Manganese	480.0	550.0	440.0	540.0	540.0	540.0	570.0
Gallium	9.0	10.0	9.0	14.0	13.0	17.0	17.0
Selenium	1.2u	1.2u	1.3u	1.3u	1.3u	1.2u	1.2u
Arsenic	8.0	5.1u	9.7	17.0	19.0	13.0	17.0
Bromine	170.0	100.0	220.0	210.0	200.0	94.0	95.0
Rubidium	28.0	29.0	33.0	40.0	39.0	39.0	39.0
Strontium	240.0	260.0	280.0	360.0	330.0	440.0	440.0

* = Analysis by X-Ray Fluorescence
+ = Reported as mean of duplicates
u = Not detected at detection limit shown