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CONTAMINANT TRANSPORT FROM ELLIOTT AND COMMENCEMENT BAYS

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I. OVERVIEW AND EXECUTIVE SUMMARY

I.1 EXECUTIVE SUMMARY

Major sources of contamination to Puget Sound are concentrated in the urban embayments. Most of these contaminants are particulates or adhere to particles. If these particulates are dense, they tend to fall out of the water column near the source; thus analysis of the sediment within urban embayments can provide an indication of the level of contamination, and by proximity, of the probable source of that contamination. The question remains however, to what degree are contaminants transported, away from the original source, out of the embayment, and are carried into the main basin of the Sound. In other words, to what extent is incoming contamination localized, or Sound-wide in nature. In order to determine this we attempted to answer the following research questions:

1) What is the relative importance of the surface, fresh water plume versus the bottom resuspended (nepheloid layer)?
2) How much does transport vary seasonally, particularly as affected by winter runoff?
3) Is there loss to the bottom from the surface plume?
4) Are contaminants remobilized from the bottom sediments?

During spring and summer 1985, and again in January 1986, the Pacific Marine Environmental Laboratory (PMEL) of NOAA made a series of observations designed to determine to what degree contaminants in Elliott and Commencement Bays could leave the bays and enter the main basin of Puget Sound.

The approach employed in this study was to map the distributions of water properties (salinity, suspended particulate matter or SPM, and toxic trace metals and organics) during a period of high river runoff (April 4-5, 1985, Elliott and Commencement Bay) and during combined sewer overflow (CSO) events (January 8-9, 1986, Elliott Bay only) after heavy rainfall. Current meters and sediment traps were deployed in Elliott Bay south of the Pier 90 anchorage and in Commencement Bay in the outer, center of the bay. The current meters provide a continuous record of salinity, temperature, current speed and direction which allows a calculation of horizontal transport.

I.1.1 Physical Conditions

Elliott and Commencement Bays are similar in that they host a variety of urban and industrial activities, are deep (150-200 m), and have similar shapes with rivers at their heads.

However, Commencement Bay has approximately half the area of Elliott Bay. The waters of the bays are from two sources: large volumes of deep, salty water from the main basin and small amounts of river water which forms a brackish layer only a few meters deep within the bays. The brackish water is formed by mixing of the two sources within the river mouths. The two sources continue to mix as the upper layer flows out into the bay, becoming progressively saltier.

During the April sampling period light rain fell (less than 0.1 inch/day) under light and variable winds. The mean monthly flow of the Green-Duwamish River was 150% of the ten-year average for April and double the ten-year average for the sampling period. During the January sampling period rainfall was a quarter-inch per day or less, with somewhat stronger winds from the south. River flow was 67% of the ten-year January average. Rainfall had been much lower than usual earlier, but 1.85 inches of rain fell between December 31 and January 5. River flow was unaffected but the Denny Way CSO and six other CSOs overflowed during the sampling period (January 8-9). More than 83,000 m^3 of water was discharged by the CSOs over eight days. During the same period the Duwamish River discharged 21.4 million m^3. Thus the CSOs were equal to about 0.4% of the river flow.

The current meter moorings were in place from March 27 until July 9 of 1985. The mean flow at 4 m depth was only 3 cm/sec (0.06 mph) toward the west-northwest. This was equivalent to a mean transit time of 5 days from the mouth of the Duwamish River to Four Mile Rock. At 100 m, one meter off the bottom, the current was 0.8 cm/sec (0.02 mph) toward the southwest. The river water layer was very thin, only two meters deep, with a salinity difference more than sufficient to maintain a sharp vertical discontinuity.

I.1.2 Suspended Particulate Matter

If much of the contaminant load is associated with suspended particulate matter (SPM), it is instructive to examine the surface distribution of SPM and compare these distributions with the distribution of different pollutants. The same approach can be taken with salinity. The primary sources of contaminants are related to freshwater inputs.

In April 1985 the only source of SPM was the Duwamish River. Contours of both salinity and SPM show that the river plume hugs the north and east sides of Elliott Bay, exiting northwestward around Magnolia Bluff as it mixes with saltier, cleaner main basin water. In January, the same general pattern is seen, except that the Denny Way CSO is clearly a much more concentrated source of SPM. Rough calculations based on flow rates and sediment concentration of the river and the CSO suggest that the Denny Way CSO contributed close to 30% of the total SPM to the Bay.

Correlations between SPM and salinity (mixing curves) show that dilution of the surface river plume by marine water from the main basin was the principal factor in controlling the decrease of SPM in the bay; therefore SPM loss by settling or other processes is insignificant. In the surface SPM and salinity are inversely correlated because the SPM sources are controlled by fresh water sources. In deep water, SPM and salinity are positively correlated suggesting that the high turbidity of the deep water is caused by movement of main basin deep water into the Bay rather than local resuspension. The highest salinity water has the highest concentration of SPM.

Calculations of the total amount of SPM in the surface layer in April showed that nearly half of the SPM was in the upper half-meter; another thirty percent was in the next half-meter. Sediment traps were used to calculate the vertical loss or flux, which was 4% per day of the SPM in the 2 m deep plume. Vertical flux is proportional to the total loading at any given point. Since the mooring was located in the region of maximum loading, the figure of 4% should be a maximum, and should decrease away from the mooring. A more likely average would be 2.5% per day. This means that over 90% of the suspended material is transported out of the Bay in the buoyant plume rather than being deposited within the Bay.

I.1.3 Trace Metals

Since the maximum concentrations of contaminants were in the surface layer, with only background levels at depth, and no evidence of resuspension of bottom sediments, surface samples were taken to look for sources of toxic trace metals and organics to the bay and to map their distribution. In general, the highest concentrations of toxicants originated from the West Duwamish Waterway, the north end of Harbor Island, the Denny Way CSO and the Seattle waterfront including the King Street CSO. (The East Duwamish Waterway, while a source of fresh water and SPM in January, was not notable as a source of contaminants.)

In terms of total mass of material added to Elliott Bay, the West Duwamish Waterway is the major contributor to the system followed by the Denny Way CSO, Harbor Island waterfront and Seattle waterfront, in that order, because of the differences in flow. In April the flow of the West Waterway was 250 times that of the CSO; thus the West Waterway provided 56 times as much dissolved zinc, 35 times as much dissolved copper and 20 times as much particulate lead as the CSO. The West Waterway may be considered a chronic source, the CSO an acute source.

Copper originates from plumbing, marine anti-fouling products, plating plants and electrical wiring. In Elliott Bay soluble and particulate copper had similar distributions. In April the Duwamish West Waterway (DWW) was a principal source of particulate copper. However, during the heavy rainfall in January, the DWW was overshadowed by surface runoff from the northern tip of Harbor Island and the Denny Way CSO.

Zinc is quite soluble, originating from corrosion of galvanized products, zinc-based paint and plating plants. The DWW, Harbor Island the Denny Way CSO are all strong zinc sources in January.

In contrast, lead exists primarily in the particulate form. It originates as an aerosol in automobile exhaust, and from battery plants, smelters and paint. However, dissolved lead can diffuse from strong sources during light rainfall and to a greater extent during heavy rainfall. There was a very poor correlation between salinity and dissolved lead concentrations, indicating a multiplicity of sources, including atmospheric deposition in January. The DWW is clearly the principal source of particulate lead during high river runoff, probably collecting atmospheric deposition from throughout its watershed. However, heavy rainfall flushed surface particulates from Harbor Island and from the Denny Way CSO, as well as the Seattle Waterfront. Particulate lead concentrations were 4-10 times the dissolved lead concentrations.

Cadmium is an interesting element in Puget Sound in that the major source is ocean water even though there is a source from plating plants, plastics, paint and the electronics industry. In January, runoff from Harbor Island and the Denny Way CSO exceeded oceanic concentrations by three and two times, respectively. These relative increases are not nearly as high as they were for other metals.

Of the contaminant trace metals, the strongest sources of cadmium, zinc and lead were Harbor Island and the Denny CSO; nickel and chromium originated mostly from the West Waterway and Denny CSO. An assessment of source strengths and flow rates permits a calculation of the total contribution of the West Waterway, versus other sources, to the trace metals leaving Elliott Bay. In January the contribution of the West Waterway of dissolved metals was: copper, 32%, zinc, 46% and nickel, 63%. For particulate metals the contribution was: copper, 24%; zinc, 46%; lead, 29%; and nickel, 29%. The Denny Way CSO and Harbor Island runoff contributed most of the remainders.

A comparison was made of the relative horizontal and vertical fluxes of suspended matter and trace metals in Elliott Bay during April 1985. The vertical flux of all suspended matter is approximately 1.6% of the horizontal flux. For copper, it is 0.8% of the horizontal flux and for lead it is 2.4%. Thus, just as with SPM, most of this contaminate material is leaving Elliott Bay for the main basin.

I.1.4 Toxic Organics

The concentration of PAH entering Elliott Bay from the Duwamish River in April 1985 was very low (1 μg/g SPM), and is equivalent to values found in Admiralty Inlet. Surface values averaged 5 μg/g. However, as a result of urban runoff, values were much higher in source areas: 35 μg/g just off the Denny Way CSO, 18 μg/g at the mouth of the West Water and 11 μg/g along the waterfront. The concentration of PAH on suspended particulates from near-bottom waters in Elliott Bay averaged four times higher than on particulates from the near-bottom waters in the main basin. Values in sediment samples are indicative of long term sources; high values (up to 24 μg/g) are found in and north of the West Waterway, along the Seattle waterfront, just off the Denny CSO, at a point off Magnolia Bluff and at the Four Mile Rock dredge disposal site. There is some evidence from other studies at PMEL that PAH adheres to larger particles than do trace metals and may remain closer to the source areas.

The concentrations of polychlorinated biphenyls (PCB) and DDT, DDD and DDE in the water column were at, or below, limits of detection. Concentrations of some PCB isomers were higher in January 1986 than in April 1985 in surface waters, suggesting that there is still some leakage and subsequent runoff, but the concentrations were still quite low (less than 90 mg/g).

I.1.5 Commencement Bay

The situation in Commencement Bay was similar to that in Elliott Bay. Monthly mean flow in April 1986 was 133% of the ten-year monthly average. As in Elliott Bay, there is a very shallow, surface brackish layer only a few meters thick. The river plume is compressed against the north shore on rising tides and exits the bay down the center on falling tides. The maximum tidal currents are larger than in Elliott Bay, occasionally reaching 40 cm/sec at 4 m depth and 20 cm/s near the bottom. The non-tidal flow shows a cross-bay component as well as alternating periods of inflow and outflow. However, the net transport is very low: 2.4 cm/sec (0.05 mph) at 4 m and 0.3 cm/sec (0.01 mph) at 153 m. Water from the Puyallup River would take an average of two days to reach Reston in April. Near bottom water would take an average of eighteen days to cover the same distance. However, tidal excursions of a few kilometers per tidal cycle increase the contact period with the bottom and shoreline. It is clear from the coarser bottom sediments that tidal resuspension allows fine particles to diffuse from the Bay, even if at a very slow rate. This finding is supported by the presence of a thick (50 m) bottom resuspension (nepheloid) layer along the axis of the bay.

In general, the highest trace metal concentrations in Commencement Bay were one-half to an order of magnitude less than in Elliott Bay. For example, particulate lead ranged from 200-10,000 ng/L in Elliott Bay and from 400-700 ng/L in Commencement Bay. Particulate copper showed an ever greater disparity: 200-6,000 ng/L and 25-75 ng/L respectively.

Commencement Bay PAH concentrations in surface waters were slightly lower than in Elliott Bay: 3.5 µg/g vs 5.0 µg/g. PCB and DDT, DDE and DDD concentrations were all at or below detection limits.

The major source of both dissolved and particulate metals was the Puyallup River plume; whether from the river itself or entrained from anthropogenic sources along the waterfront could not be determined. Particulate metals increased with depth in the bottom nepheloid layer.

The low PAH concentrations on settling particulates in Commencement Bay is consistent with low values on surface sediments in the deeper waters of Commencement Bay found in other studies. The strong tidal currents prevent their accumulation. Thus this bay behaves much like the northern end of the main basin of Puget Sound.

I.1.6 Conclusions and Recommendations

It is quite clear that the dissolved contaminants, from whatever source, remain in the very thin, fresh water plume and are transported through the bays and into the main basin quite rapidly; roughly five days in Elliott Bay and two days in Commencement Bay. The West Waterway is a source of high concentrations of dissolved trace metals, but not as high as from the Denny Way CSO and Harbor Island during periods of heavy rainfall. Because of its limited duration this study could not determine the overall contribution of the three principal sources in Elliott Bay on an annual basis. Observations need to be made at the sources throughout a year. The sources for trace metals in Commencement Bay appear to be much more diffuse, with no strong point sources observed, although the industrial waterfront is strongly implicated. Trace metal concentrations there were much lower than in Elliott Bay.

It was not feasible to assess how much particulate material was deposited directly at the mouth of each source. It would be difficult but not impossible to do this in a monitoring program. The immediate deposition rate is a major data gap. Directly beyond the sources, however, most of the suspended particulate matter remained in suspension in the fresh water plume. If a maximum of 4% was lost per day from the plume, approximately 80% of the material would be exiting Elliott Bay after five days transit and 90% would exit Commencement Bay after two days transit. The percentages are probably higher than these. The losses from the fresh water plume would affect the most strongly particle-bound contaminants most significantly: toxic organics, lead and chromium. The high source strengths of the West Waterway and the Denny Way CSO were not unexpected. However, the runoff from the north end of Harbor island during high rainfall was unanticipated but, in retrospect, not surprising. It should be determined if the source strength is correlated with ship-building activity.

PCB and DDT isomers were undetectable in Elliott Bay and Commencement Bay water. Some PCB appears to be leaking into Elliott Bay, however. Extremely high concentrations of PAH were measured near the Denny Way CSO and the Duwamish West Waterway, which is substantiated by findings of high PAH concentrations in the sediments at these locations.

There was no evidence that resuspension and transport of contaminated bottom sediments was taking place in Elliott Bay. The presence of a resuspended layer suggests that this does occur in Commencement Bay, but at a very low rate.

This study strongly suggests that, just beyond the sources, most of the contaminants entering these two bays enter the main basin quite rapidly. There is virtually no resuspension of sediments in Elliott Bay and relatively little in Commencement Bay, especially in water less than 100 m deep.

Finally, it must be recognized that these studies took place over a period of only a few days during two different months. The values measured or calculated are probably "in the ball park" but the intermittent nature of rainfall, runoff, and river flow require measurements over longer periods of time to more accurately assess the total contributions of the various sources. The contribution of diffuse runoff from waterfront sources is ungauged and requires special attention.

I.2. INTRODUCTION

Elliott Bay and Commencement Bay are the two major commercial embayments adjacent to the main basin of Puget Sound (Fig. I.1.). The bays are major aspects of Puget Sound morphology, with horizontal dimensions of about 5×6 kms for Elliott Bay and 3×3 kms for Commencement Bay. Both embayments are deep, 150-200 m, have steep sidewalls, and there are few areas less than 50 meters deep.

The waters of the bays are mixtures from two sources. The larger source in volume is subsurface water from the main basin. The other source is the freshwater discharge from the rivers entering the bays, which appears as a relatively thin lens (a few meters thick at most) within the bays. Freshwater discharges into Elliott Bay from the Duwamish River and into Commencement Bay from the Puyallup River. Neither is a large river; the Puyallup is the fourth largest river entering Puget Sound proper, with an average annual discharge of 3,756 $ft^3\ sec^{-1}$. The Green-Duwamish River is the sixth largest at 1,790 $ft^3\ sec^{-1}$. Maximum discharge of the Duwamish (which is controlled by dams on its tributaries) can be as high as 200 m^3/sec primarily due to rain in winter; the Puyallup can be as high as 500 m^3/sec during snowmelt.

Prior to this study several investigations have focused specifically on transport processes in Elliott Bay and the main basin of Puget Sound. Transport studies in Elliott Bay have shown that

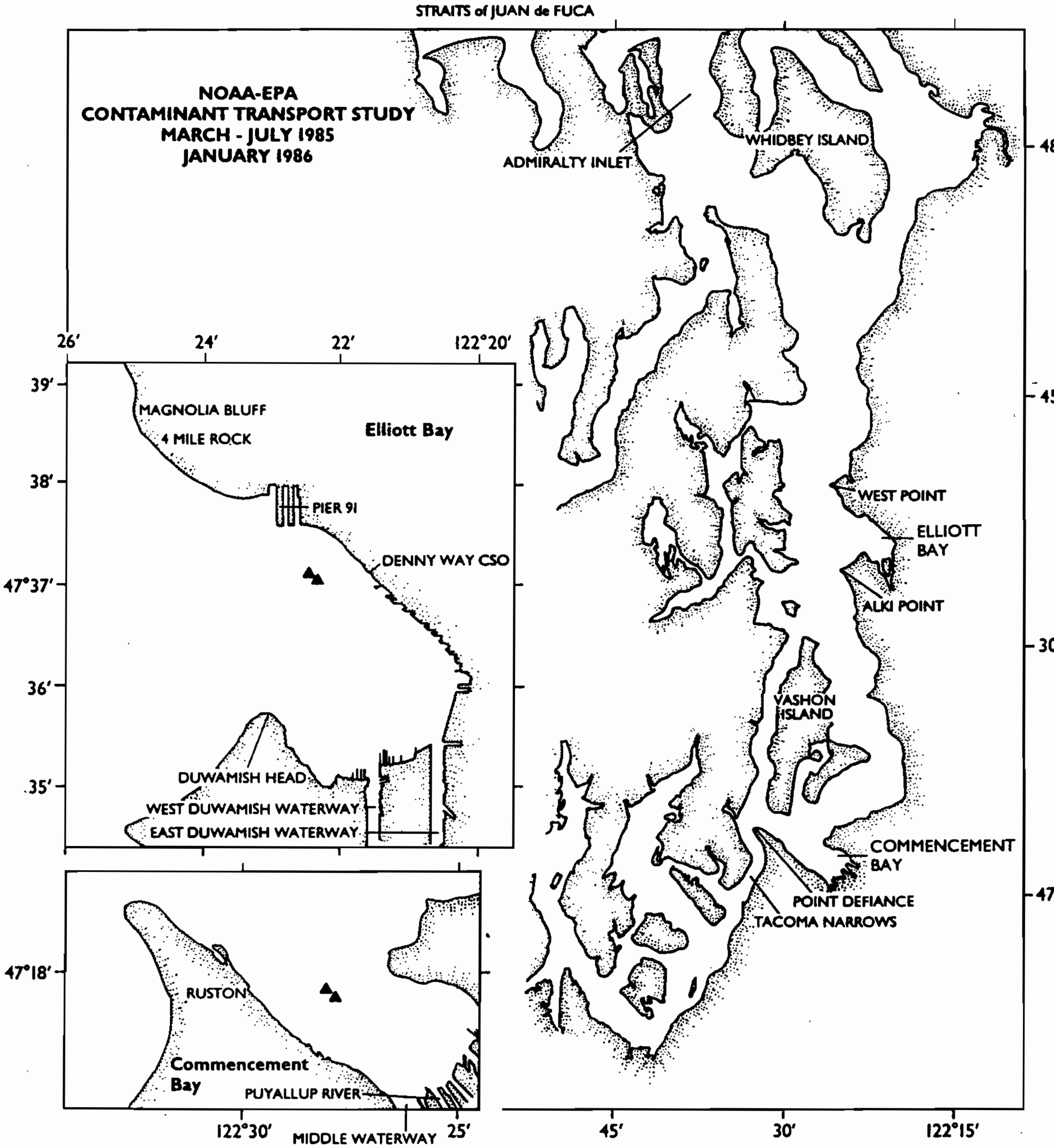


Figure I.1. Elliott Bay and Commencement Bay. Triangle marks the location of the moored arrays.

pollutant-bearing particles are added to the surface waters by river inflow, combined sewer outfalls, atmospheric deposition, urban runoff, and other routes. Those particles that remain suspended above the pycnocline are advected out of the bay by the estuarine circulation (Sillcox *et al.*, 1981; Baker *et al.*, 1983). Particles that rapidly settle out of the surface layer contribute to pollutant accumulation in the bottom sediments. Bottom sediments may be a net sink for particles rather than a source to the main basin (Baker *et al.*, 1983), but no quantitative information on the remobilization of bottom sediments by resuspension at specific locations (such as disposal sites) was available. Trace metal budgets constructed for Elliott Bay also suggest that, although the bay is a sink for particles, it is a net exporter of pollutants (Feely *et al.*, 1983). For example, surface advection and tidal exchange carry about 75% of the Mn input out of the bay. The enrichment of Pb, Cu, and Zn in the hydrous Mn oxide phase on suspended particles suggests that pollutants such as these are likewise lost from the bay to the same extent (Feely *et al.*, 1983; 1986).

This report includes data and information developed during 1985 and 1986 to determine how pollutants might be transported from Elliott Bay and Commencement Bay (two of five EPA priority marine embayments in Puget Sound) to the main basin of Puget Sound.

I.3. GENERAL APPROACH

The Puget Sound Action Program, under the direction of the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (DOE), developed a budget initiative and a FY 85 Work Plan. The Plan identified five priority marine embayments in Puget Sound as potential sources of pollutants for the rest of the estuary: Elliott Bay, Commencement Bay, Everett Harbor, Sinclair Inlet and Budd Inlet. The data presented here are from a study that addressed the question of pollutant transport from Elliott Bay in some detail and Commencement Bay to a lesser extent. There were four study objectives:

- obtain reliable, first-order estimates of the relative scale of each transport path (surface plume vs. bottom nepheloid layer);
- obtain information on the temporal variability within each path (e.g., is removal via the surface riverine plume predominated by a few winter runoff events?);
- determine the partitioning of pollutant contaminated sediments between the transport paths;
- identify the most profitable direction for obtaining quantitative estimates of specific pollutant fluxes.

The general approach was to map the distribution of properties in the water column (salinity, suspended particulate matter and toxic trace metals and organics) using a large ship for sampling the subsurface water and a small boat to sample the surface plume, which is only a few meters deep. One of the sampling periods (January 1986) was chosen in an attempt to capture a combined sewer overflow event in Elliott Bay (Unfortunately, the overflows are unpredictable, occurring when the mains can no longer accommodate inflowing water from heavy rainfall. An overflow event depends on the rate and location of rainfall over the city.).

Current meters and sediment traps were deployed on a mooring in Elliott Bay, to the south of the Pier 90 anchorage. A current meter was located in the Duwamish West Waterway (Fig. I.1). The sediment traps were designed to determine what proportion of the particulates in the surface plume is retained in the bay.

In Commencement Bay two moorings with current meters were deployed in late March in the center of the mouth of the bay. No sediment traps were used.

II. RESULTS

II.1. ELLIOTT BAY

II.1.1 Meteorological Setting

Light rain (<0.1 inch/day) fell on April 2-April 5 during the 1985 sampling period. The highest sustained wind speeds at Sea-Tac Airport for the period April 1-April 9 averaged 6.1 m/sec and varied between 4.5 and 8.0 m/sec. On the whole the winds were fairly light and constant in speed but variable in direction.

Rainfall during the January 1986 sampling period was 0.21 inches/day for January 8, 0.24 inches/day for January 9, and 0.08 inches/day for January 10. The winds during these three days were faster, more variable in speed, and more constant in direction than for the previous April. The highest sustained wind speed was 29 m/sec from the south on January 8. It decreased to 4.0 m/sec from the southeast on January 9, and increased to 12.5 m/sec from the south on January 10.

II.1.2 Hydrographic Setting

Green-Duwamish River

The Green River flows 99 km from its source in the Cascade Mountains through forest and agricultural land. Near Tukwila, it is joined by the Black River, and is thereafter known as the Duwamish River. This combined river system flows another 19 km through a heavily urbanized and industrialized region to Elliott Bay (Puget Sound Task Force, 1970). The USGS monitors river flow at several points along the Green-Duwamish River system. The highest flows normally occur during December and January due to direct runoff of rain. The winter flow usually decreases through March or April, followed by a less pronounced peak in April, May, or June due to snowmelt runoff. The flow values used in this report are those from the gauging station near Tukwila at river kilometer 20. The Black River flow contribution downstream of this gauging station is negligible (Santos and Stoner, 1972); so Green River flow is assumed to equal that of the Duwamish River.

April 3-9, 1985

Mean monthly flow in April 1985 was 150% of the ten-year average for April. During our sampling period, river flow was double the ten-year average for April (Fig. II.1). For the January sampling period the situation was exactly reversed.

The unusually high flow rates at this time were a result of 17 days of rain prior to our sampling dates. The freshwater flow of the Duwamish River peaked at a daily average discharge rate of 130 m^3/sec on the second day of sampling (Fig. II.2) and decreased gradually to 55 m^3/sec on April 9.

The Denny Way combined sewer overflow (CSO) had not discharged since a storm on March 22-24.

January 8-10, 1986

Rainfall for the end of 1985 was much lower than usual. In December the rainfall was 28% of the thirty-year monthly average. The January 1986 river flow was 67% of the ten-year average for January and during our sampling period was half the ten-year average (Fig. II.1). 1.85 inches of rain fell in a storm which occurred December 31-January 5, but did not markedly increase the river flow. The Duwamish River flow during our sampling period was 31 m^3/sec.

This storm prior to our sampling period did, however, cause the Denny Way CSO to discharge 23,000 m^3 on January 3 and 42,800 m^3 on January 5 (Fig. II.3). Six other CSOs also discharged during this storm. During the overflow event sampled on January 8, 1986, the Denny CSO discharged a total of 16,800 m^3 into Elliott Bay. The Harbor Island CSO also discharged 417 m^3 into the Duwamish River West Waterway several hours prior to our sampling. The time history of the Denny overflow event is shown in Fig. II.4. Trace metal samples S1 through S12 and organic sample J1 were collected while the Denny Way CSO was overflowing. Although the overflow events of early January are significant, a much larger ('100-year') storm occurred later in the month, the impact of which would be greater on the water quality of Elliott Bay than the impact found in this study of a smaller CSO event.

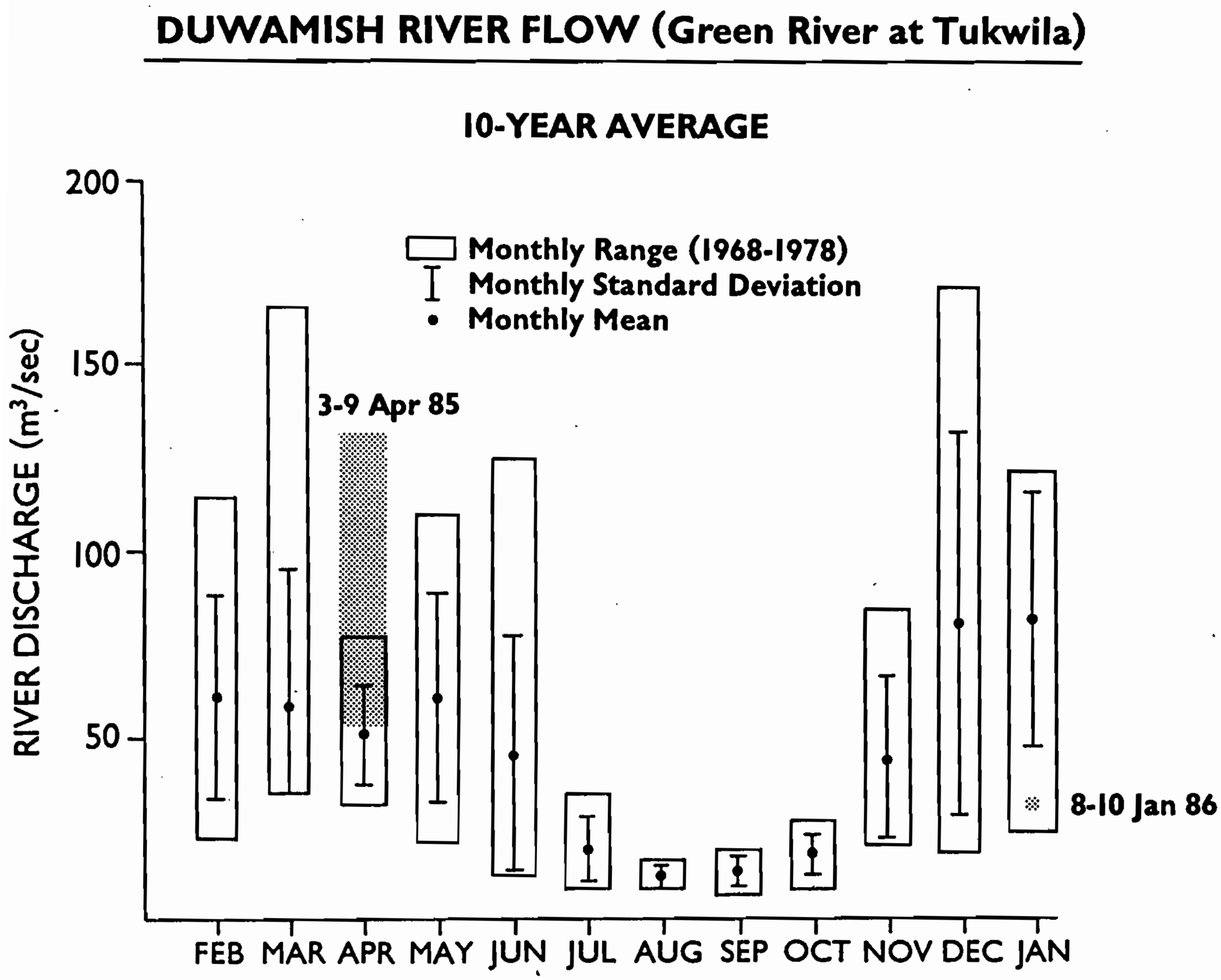


Figure II.1. Discharge rates of the Duwamish River: ten-year average (1968-1978) and monthly values (February 1985 - January 1986).

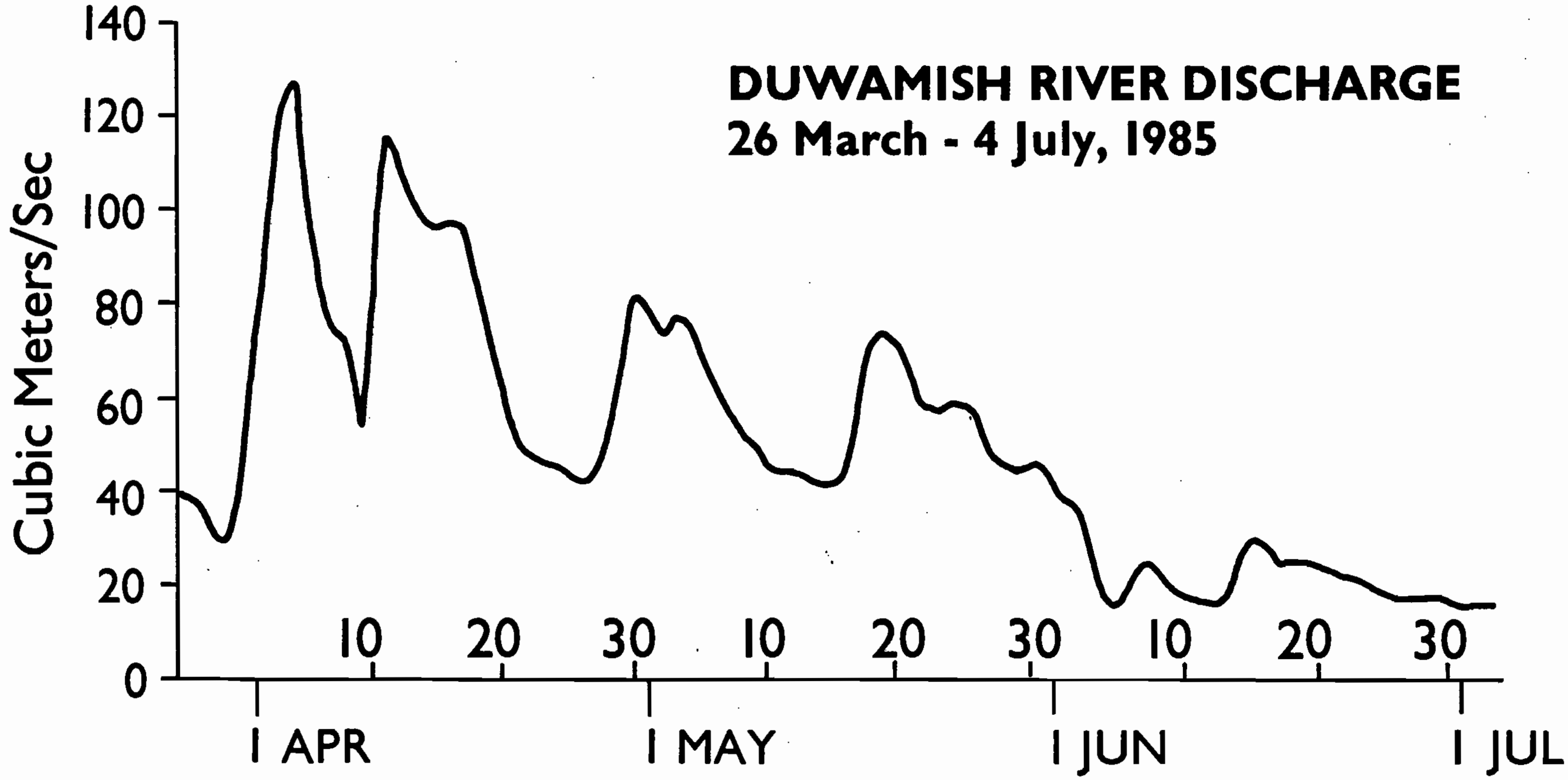


Figure II.2. Discharge of the Duwamish River measured at Tukwila, Washington.

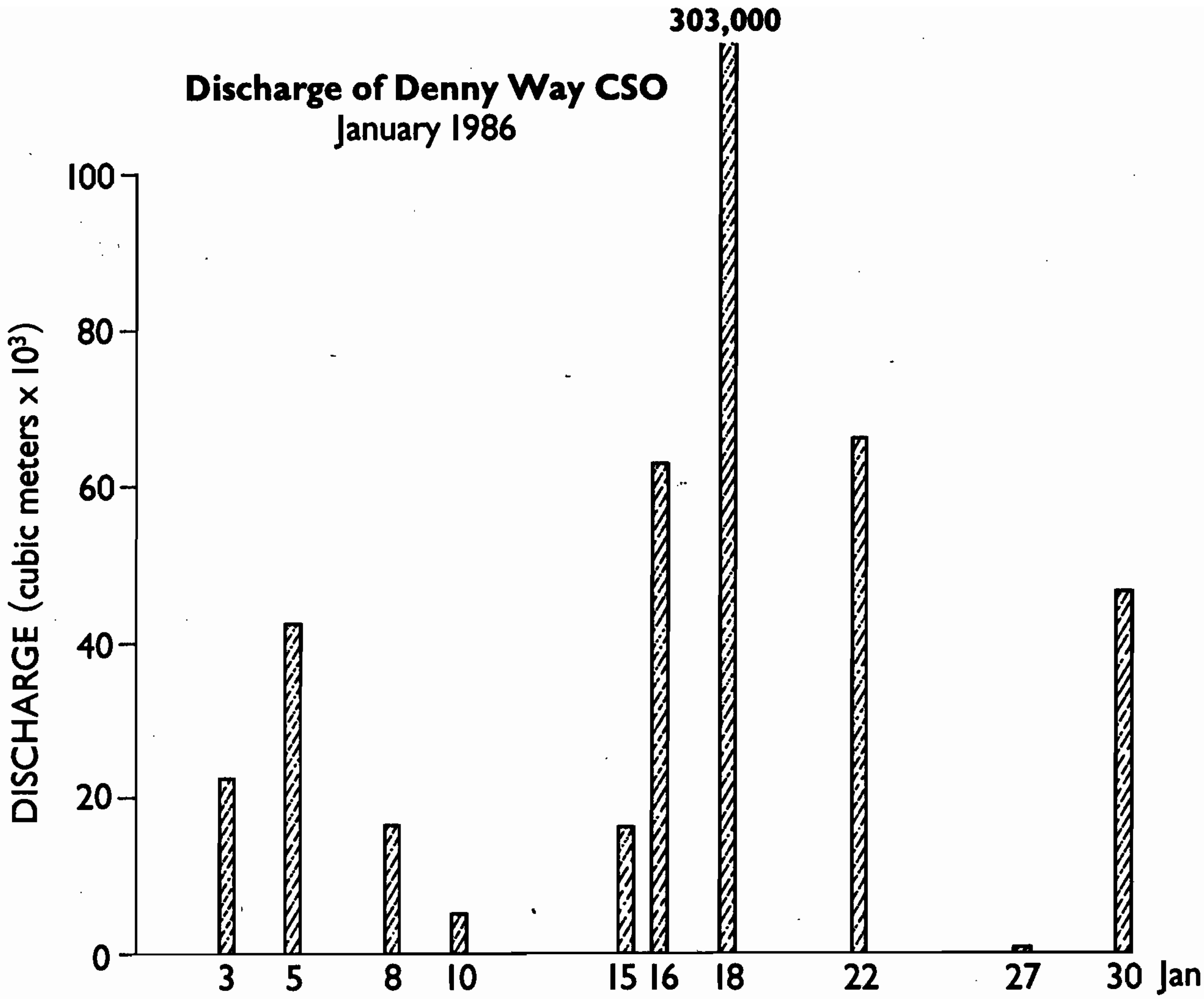


Figure II.3. Discharge of the Denny Way CSO, January 3-5, 1986.

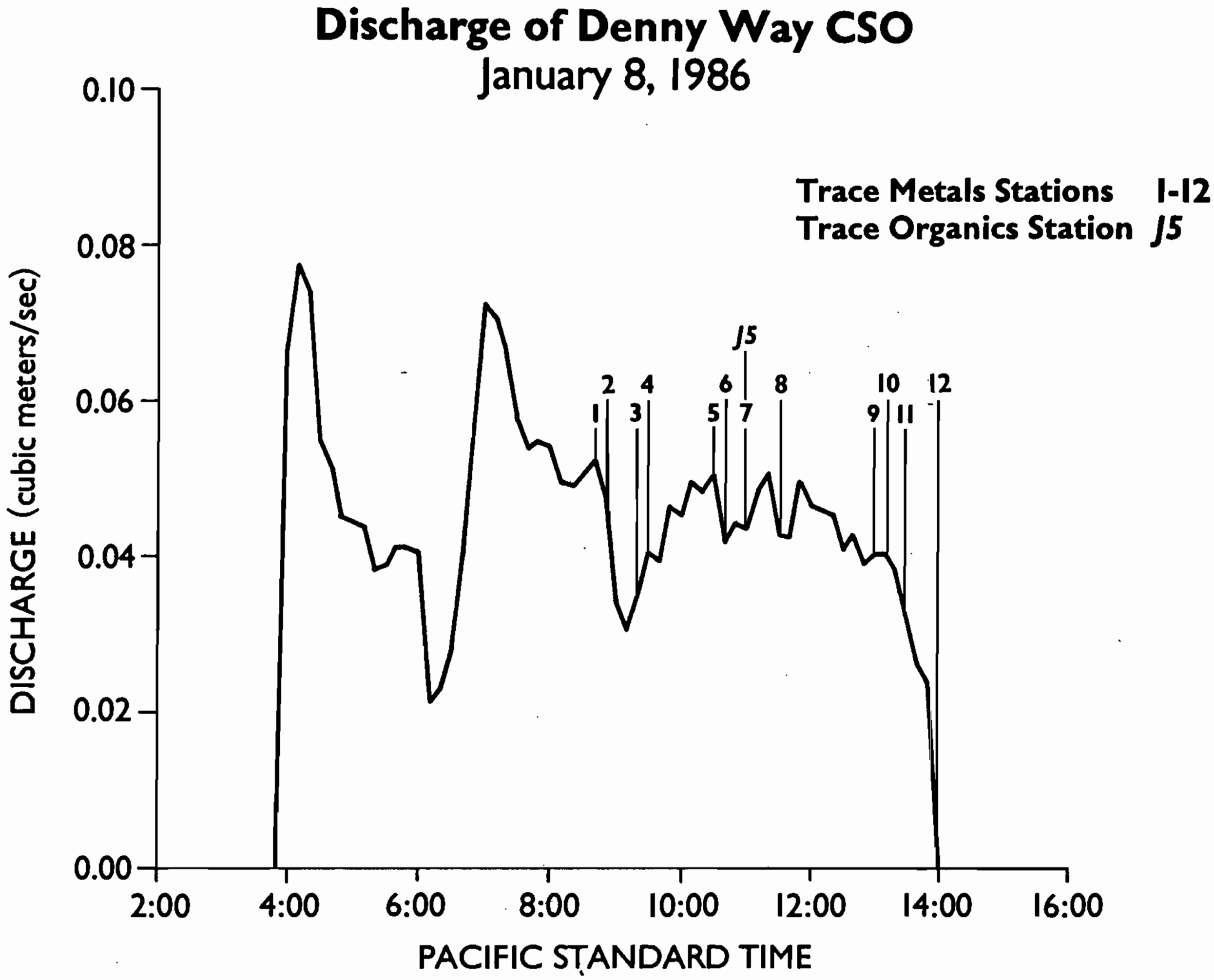


Figure II.4. Discharge of Denny Way CSO January 8, 1986.

II.1.3. Physical Oceanography

Previous studies of currents focused on the middle water column to avoid interference with moorings by shipping (Sillcox *et al.*, 1981; Cannon and Grigsby, 1980). Because those studies left an uncertainty in the magnitudes and variability of flow in the very near surface and near bottom layers and in the corresponding ability of those layers to transport particulate pollutants, we made observations in those layers during spring through early summer 1985. The observations are summarized in Tables II.1-II.3 and various spatial and temporal distributions are shown in Figs. II.2-II.13.

Observations were made in the northeastern portion of Elliott Bay using surface and subsurface moorings of currents and water properties at 1, 4, 50, 98, and 101 m, in a water depth of 102 m (Table II.1). This location was chosen because previous studies had shown that the surface plume from the Duwamish River flowed along the north side of the bay and that potentially erodable contaminated bottom sediments also existed on the north side near the Denny Way CSO. The moorings are at the base of the sloping bottom where the bottom current gradients begin to decrease rapidly. Records from these meters are nominally 114 days long starting in March.

In addition, a mooring to measure the variability in river discharge was placed in the mouth of the West Duwamish Waterway, approximately 50 meters east of the old fire boat station. An instrument was suspended at about 2 m depth with a sediment trap immediately below in 10 m of water at mean lower low water. Another meter was moored about 2 m above the bottom at the western edge of the channel in water of approximately 15 m depth. The mooring was in place from 27 March to about 12 June when it was struck and dragged to the south end of the waterway, where it remained until August. Current records from the surface meter proved to be unreliable due to a malfunctioning rotor counter. Direction, temperature, salinity, and attenuation records, however, appear to be reliable, as do all data from the bottom meter. Current data from the bottom meter are limited to 27 March to 13 May when fouling of the rotor occurred.

Water properties were measured throughout the bay on various tidal conditions using a shipboard CTD (Table II.2). Some measurements were conducted from the NOAA Ship MCARTHUR, a relatively large vessel, which disturbed some of the thin surface layer prior to measurement (Fig. II.2) and some were measured from a smaller launch (Fig. II.3). Means and variances from the moored instruments are given in Table II.3.

II.1.3.1. Salinity

Salinity distributions are presented for the disturbed surface layer and for the deeper water at 90 m (Fig. II.5). On March 28, the surface salinity gradient is very steep near the Denny Way CSO. However, at high tide on March 26, gradients are slight. The fresher water occurs along the eastern shoreline, apparently moving counterclockwise around the bay. At low tide the

Table II.1. Mooring Locations and Deployment Dates

Name	Location	Observation Depth (m)	Duration
PS8501	47-37-02N 122-22-42W	1	27 March - 9 July
		4	27 March - 22 April
		52	27 March - 9 July
PS8502	47-37-06N 122-22-42W	98	27 March - 9 July
		101	27 March - 9 July
PS8503	47-35-00N 122-21-34W	2	28 March - 12 June
		10	28 March - 12 June
PS8504	47-17-42N 122-27-31W	1	25 March - 15 April
		4	25 March - 15 April
PS8505	47-17-39N 122-27-15W	152	25 March - 15 April

Table II.2. CTD Observations

Date	No. Casts	Tide State	Location
27 March	14 casts	Higher High	EB
28 March	10 casts	Lower Low	EB
3 April	14 casts	Higher High	EB
4 April	3 casts	Lower Low	EB
2 July	23 casts	Lower Low	EB
25 March	7 casts	Higher High	CB
1 April	21 casts	Higher High	CB
15 April	11 casts	Ebb	CB

Table II.3. Moored Instrument Statistics

Mooring	Depth m	Vector Mean Flow cm/sec @°True	Total Vector Variance $(cm/sec)^2$	Maximum Variance Axis °True	Temperature Mean °C	Temperature Var	Salinity Mean ‰	Salinity Var
EB	1(1)	*********	*****	***	10.5	3.6	27.1	2.1
	4(2)	3.0 @ 287	50.0	314	8.3	0.2	29.0	0.4
	52(3)	*********	*****	***	8.8	0.8	29.8	0.1
	98	0.8 @ 270	24.9	272	8.5	0.5	30.0	0.1
	101	0.8 @ 239	16.7	264	8.4	0.5	30.2	0.0
D	2(4)	*********	*****	***	8.5	0.2	28.3	0.6
	10(5)	4.6 @ 190	30.5	004	8.3	0.1	29.7	0.0
CB	1(1)	*********	*****	***	8.5	0.5	27.5	3.5
	4	2.4 @ 252	677.0	332	8.1	0.2	29.3	0.1
	152	0.3 @ 262	143.2	315	7.6	0.0	30.3	0.0

(1) meter attached to bottom of float, no vane used
(2) short record, meter failed after 26 days
(3) vane fouled, no direction
(4) rotor failed
(5) rotor fouled after 40 days

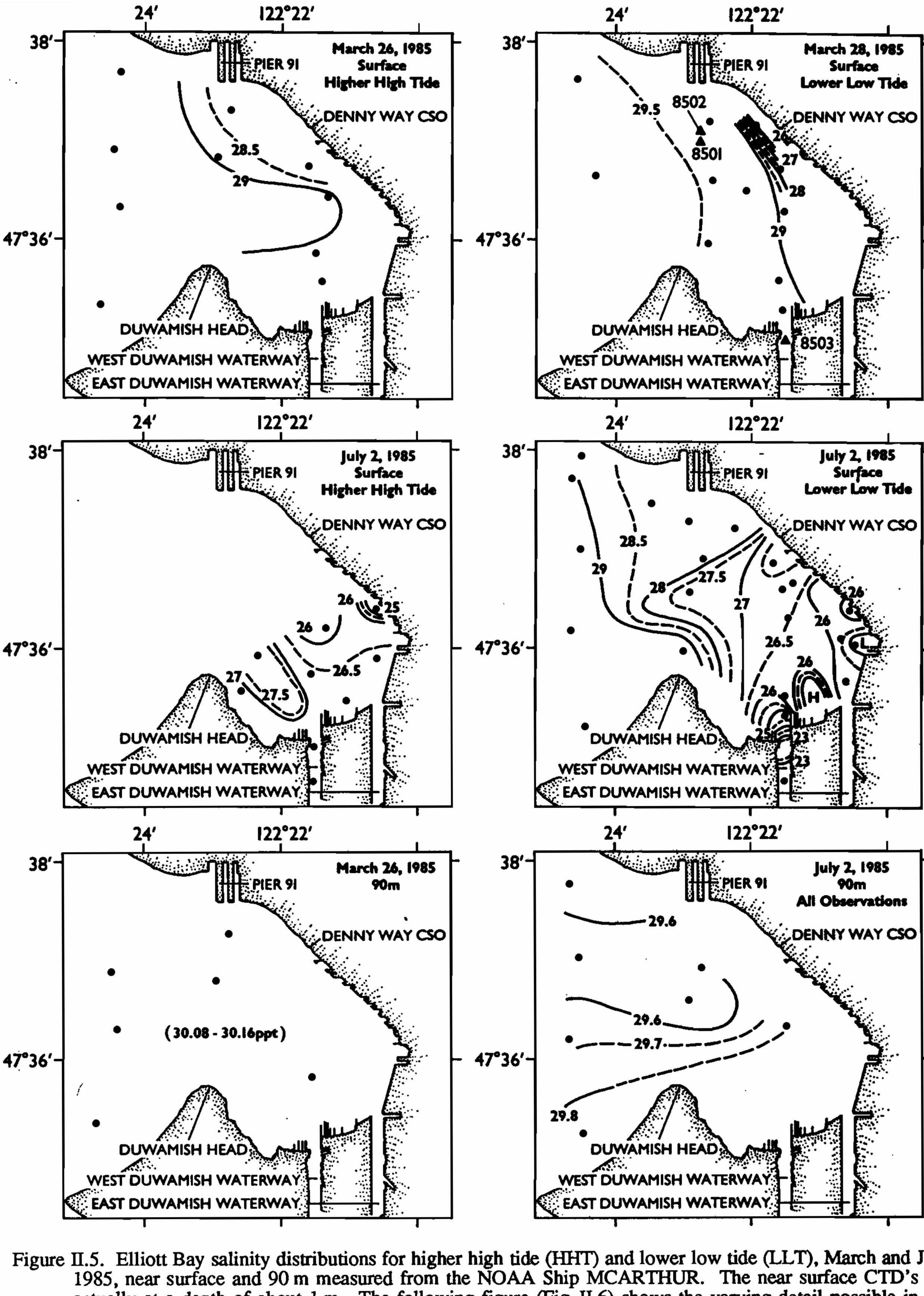


Figure II.5. Elliott Bay salinity distributions for higher high tide (HHT) and lower low tide (LLT), March and July 1985, near surface and 90 m measured from the NOAA Ship MCARTHUR. The near surface CTD's are actually at a depth of about 1 m. The following figure (Fig. II.6) shows the varying detail possible in the upper 2 m. The location of the moorings, indicated by triangles, are shown on the March LLT distribution only. Solid dots indicate sampling stations.

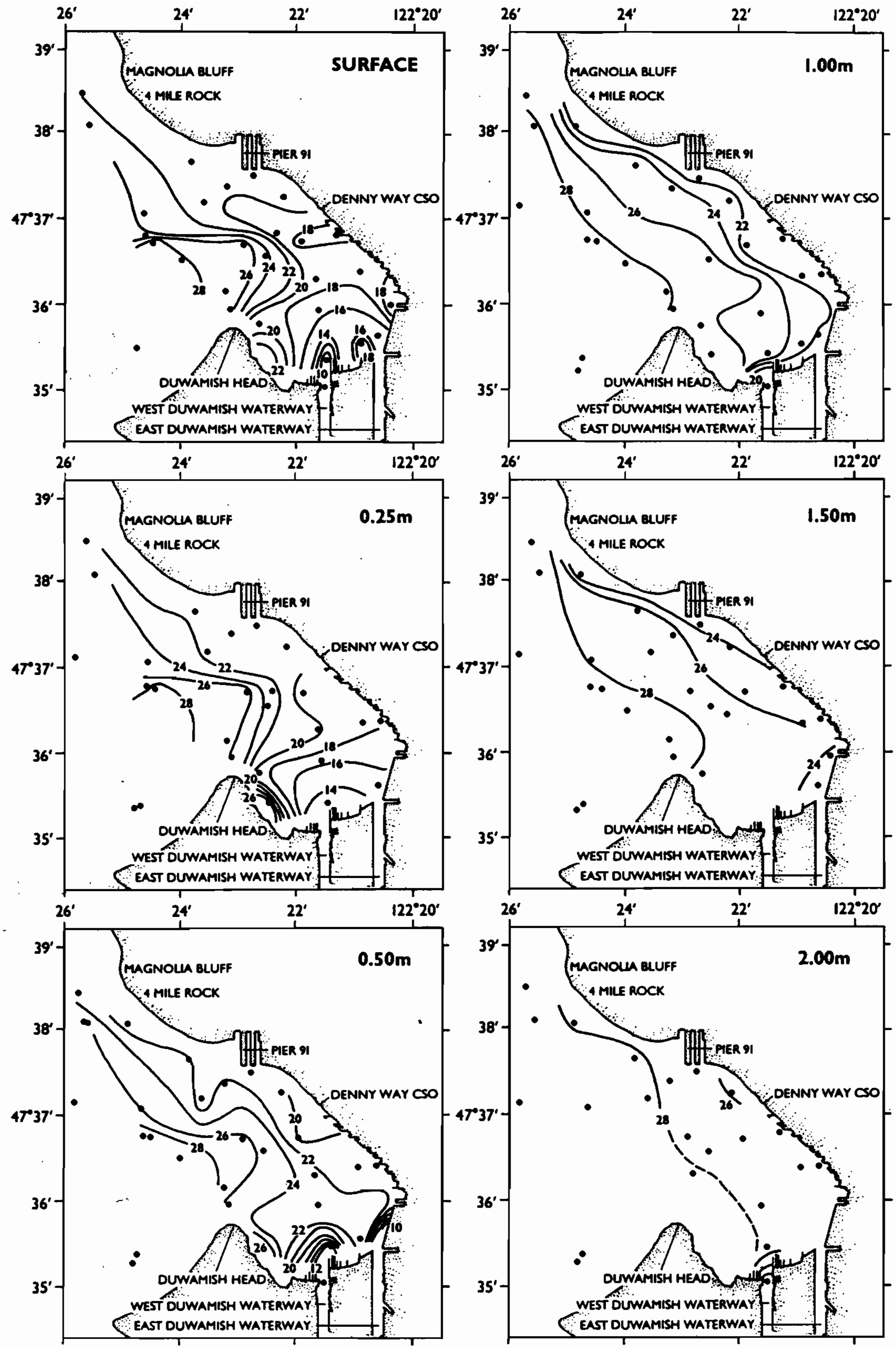


Figure II.6. Detailed salinity distribution in Elliott Bay over the upper 2 m measured from a small launch. Sampling began at lower low tide and was completed on higher high tide, 4 April 1985. Sample locations indicated where samples were obtained for each specific level.

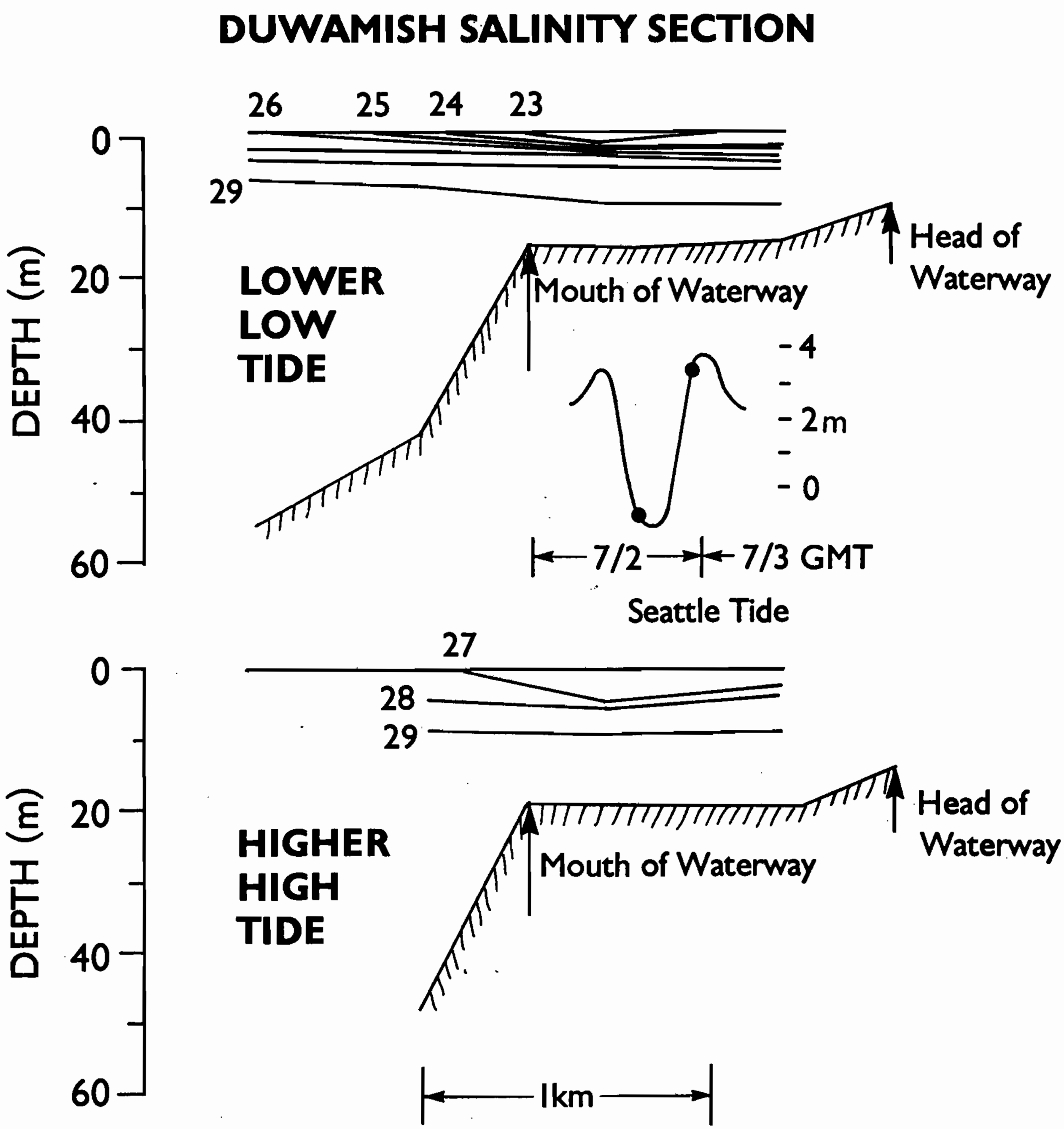


Figure II.7. Axial distribution of salinity along the Duwamish West Waterway at lower low tide and higher high tide, 2 July 1985.

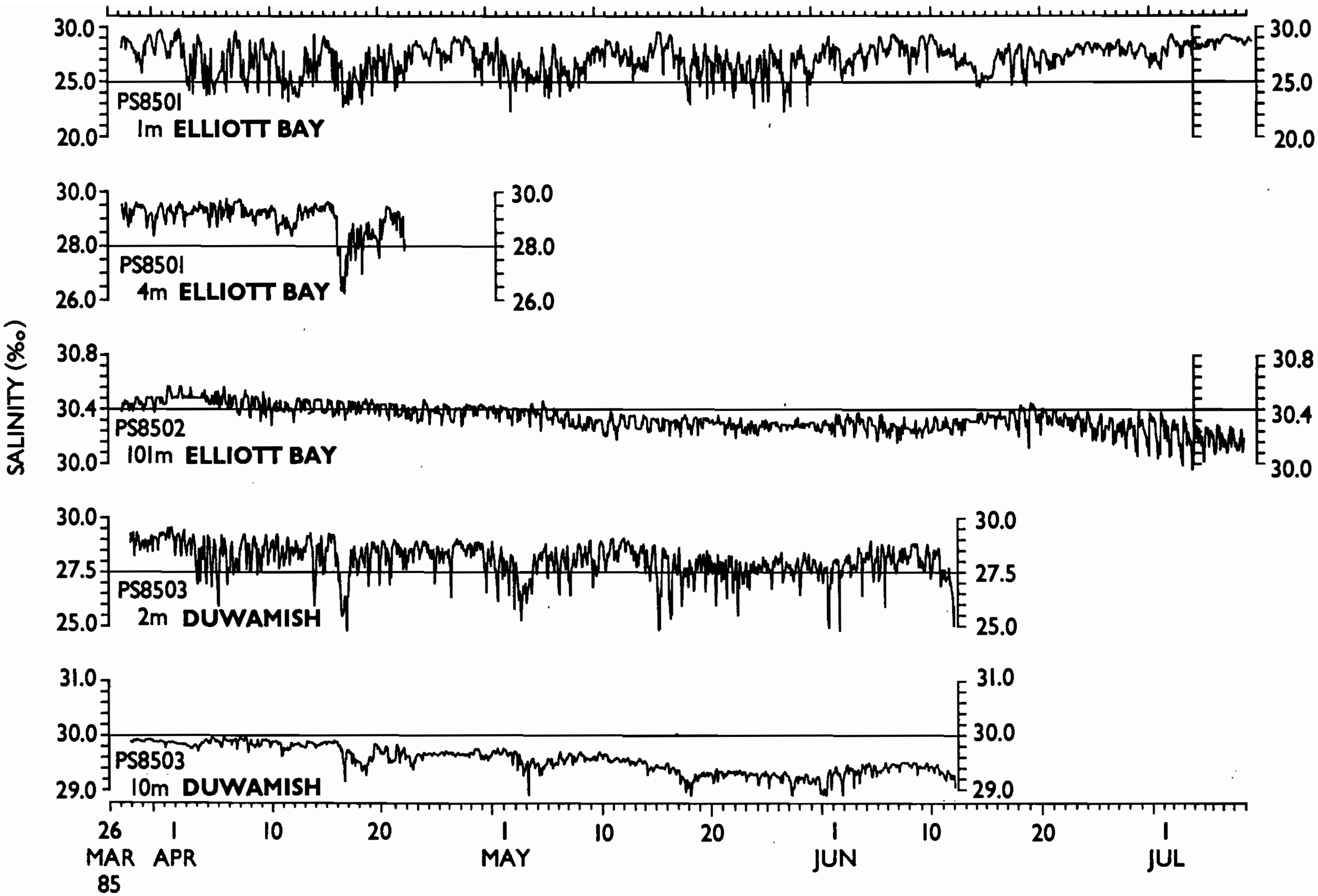


Figure II.8. Time series of salinity measured at fixed levels on the moorings in Elliott Bay and in the Duwamish West Waterway. Salinity scales vary for each instrument.

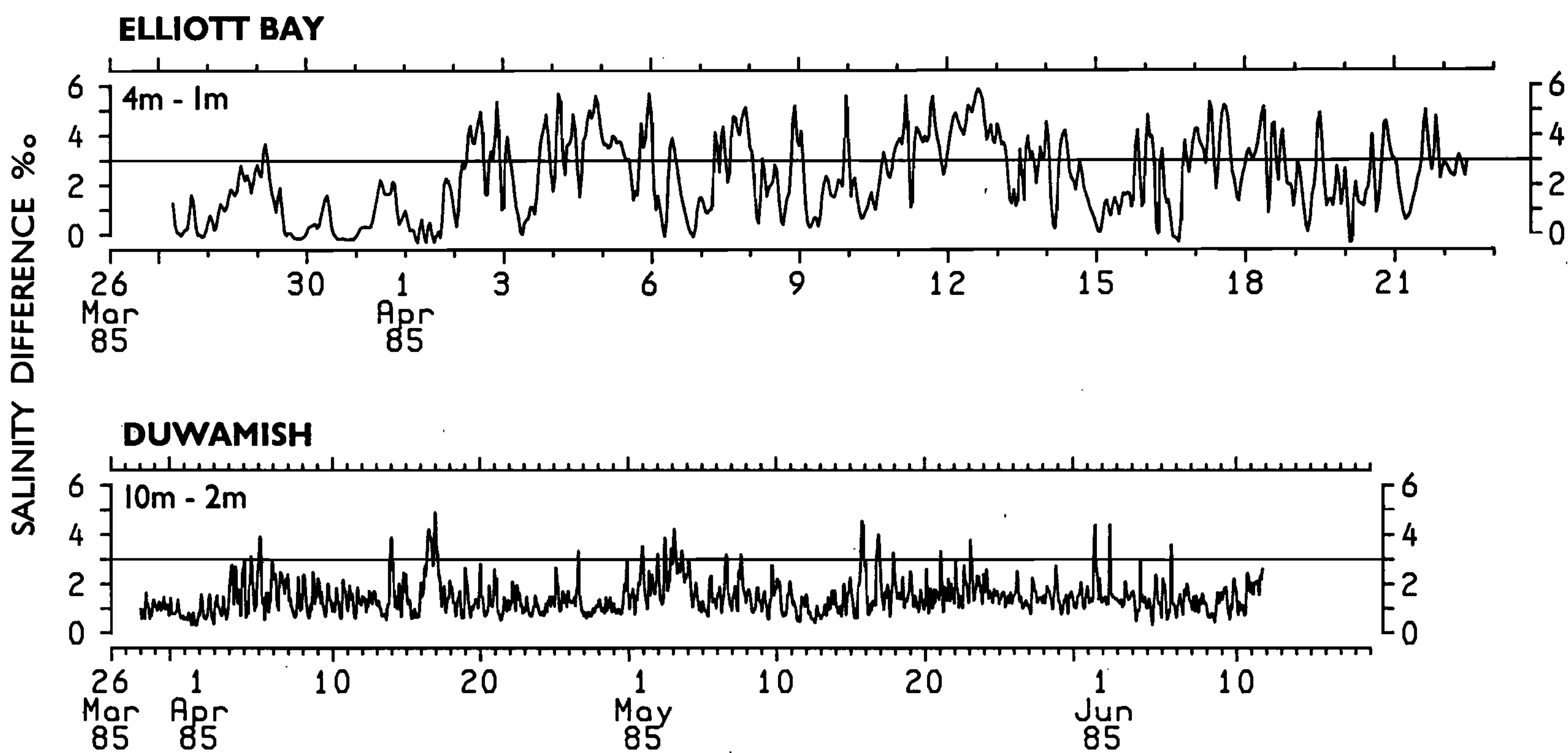


Figure II.9. Time series of salinity difference. For Elliott Bay the difference is between salinities at depths of 4 m and 1 m during April, and for the Duwamish the difference is for 10 m and 2 m from April to July 1985.

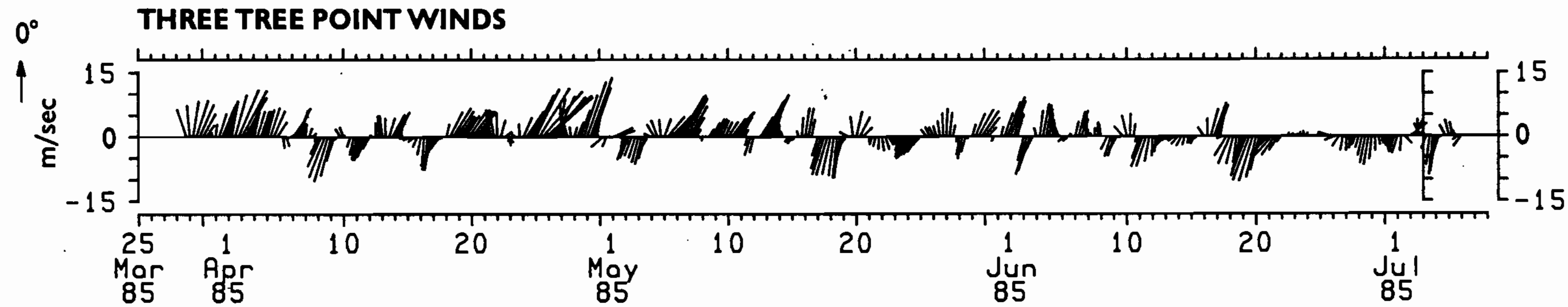


Figure II.10. Vector time series of low pass filtered winds measured at Three Tree Point, Puget Sound, located between Elliott Bay and Commencement Bay. The vectors display the direction toward which the winds are blowing relative to north.

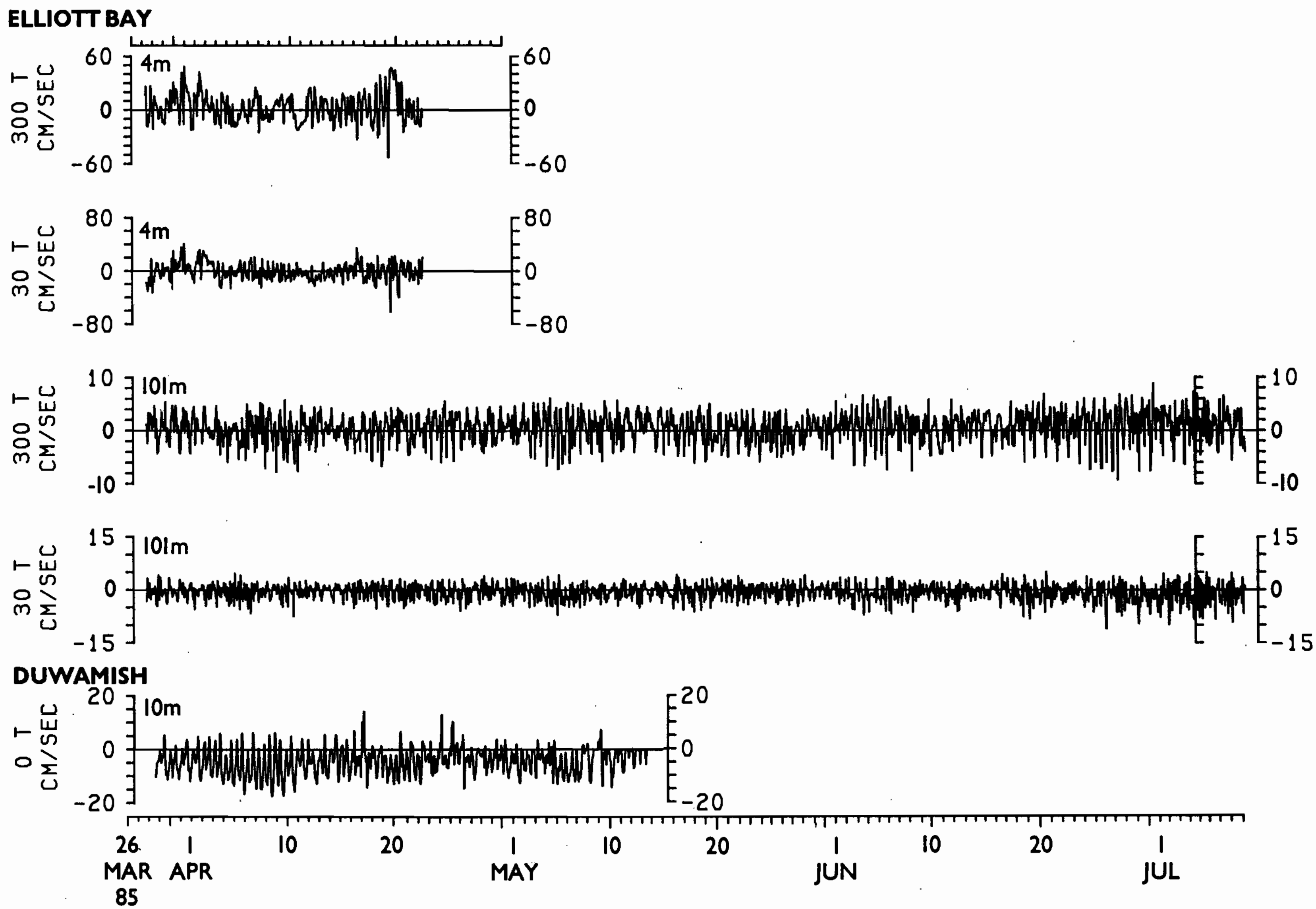
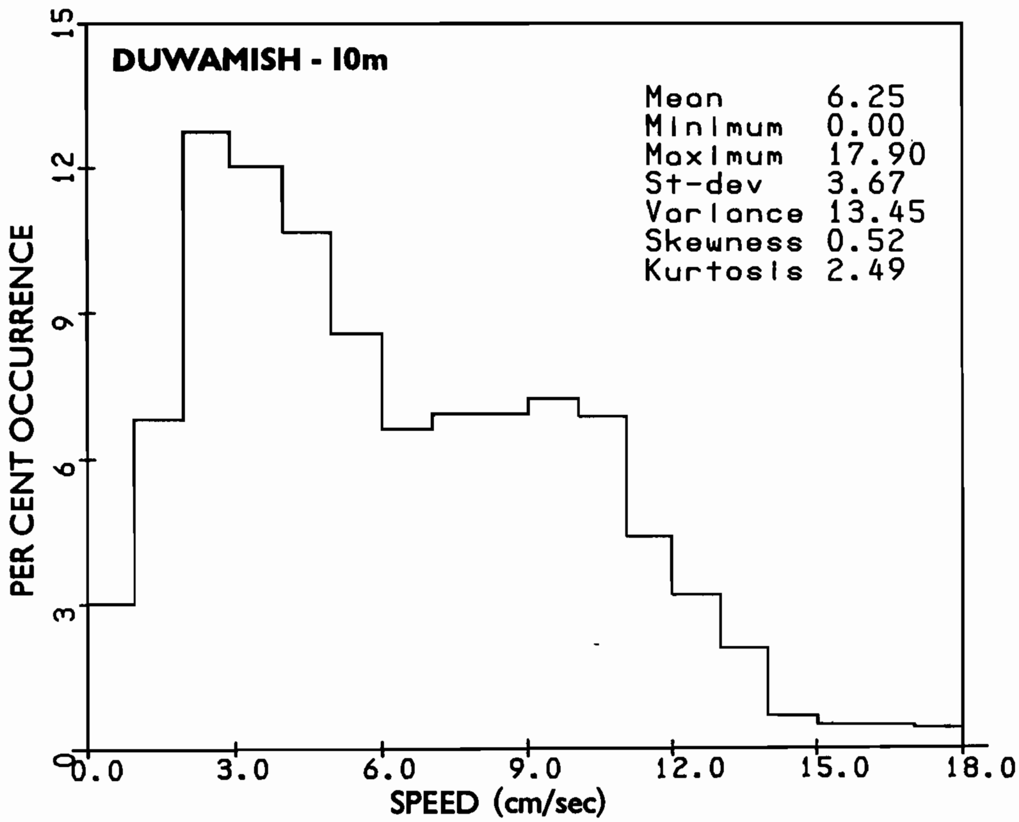


Figure II.11. Time series of currents resolved relative to the approximate bathymetry of the mooring sites. At the Elliott Bay mooring 300° T is along bathymetry and 30° T is across bathymetry. The orientation of the Duwamish West Waterway is along 0° T. Speed scales optimized for each record.



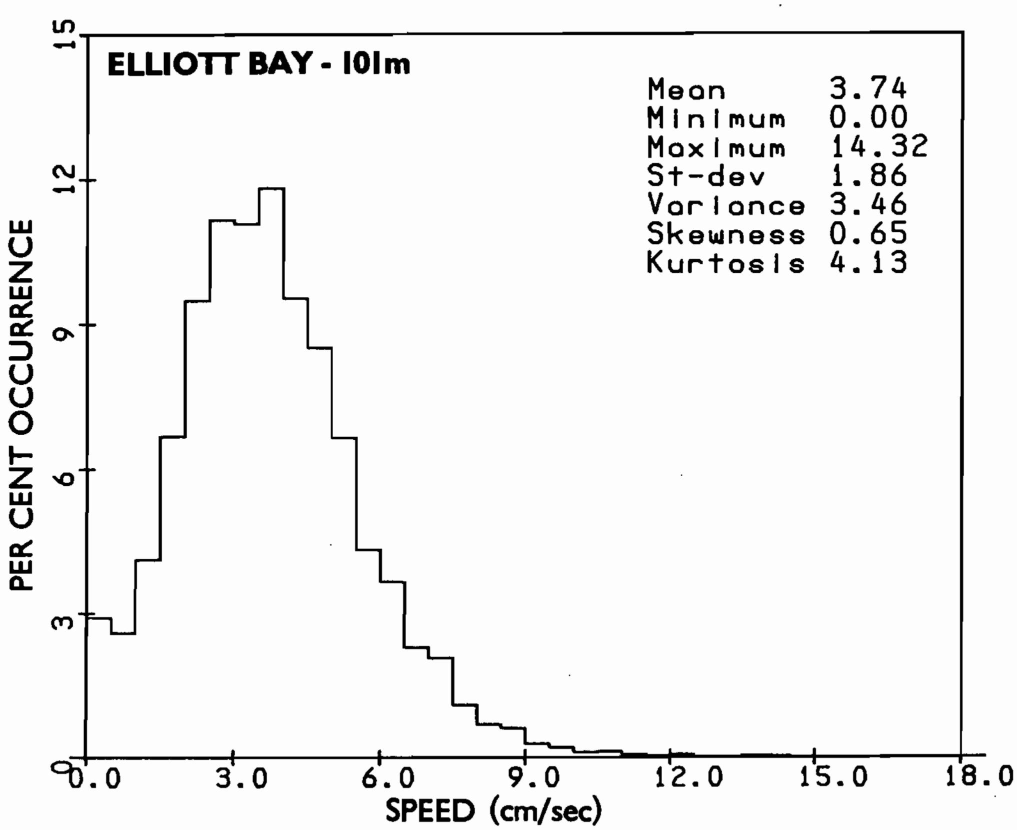


Figure II.12. Histograms of near-bottom current speeds in the Duwamish West Waterway and Elliott Bay.

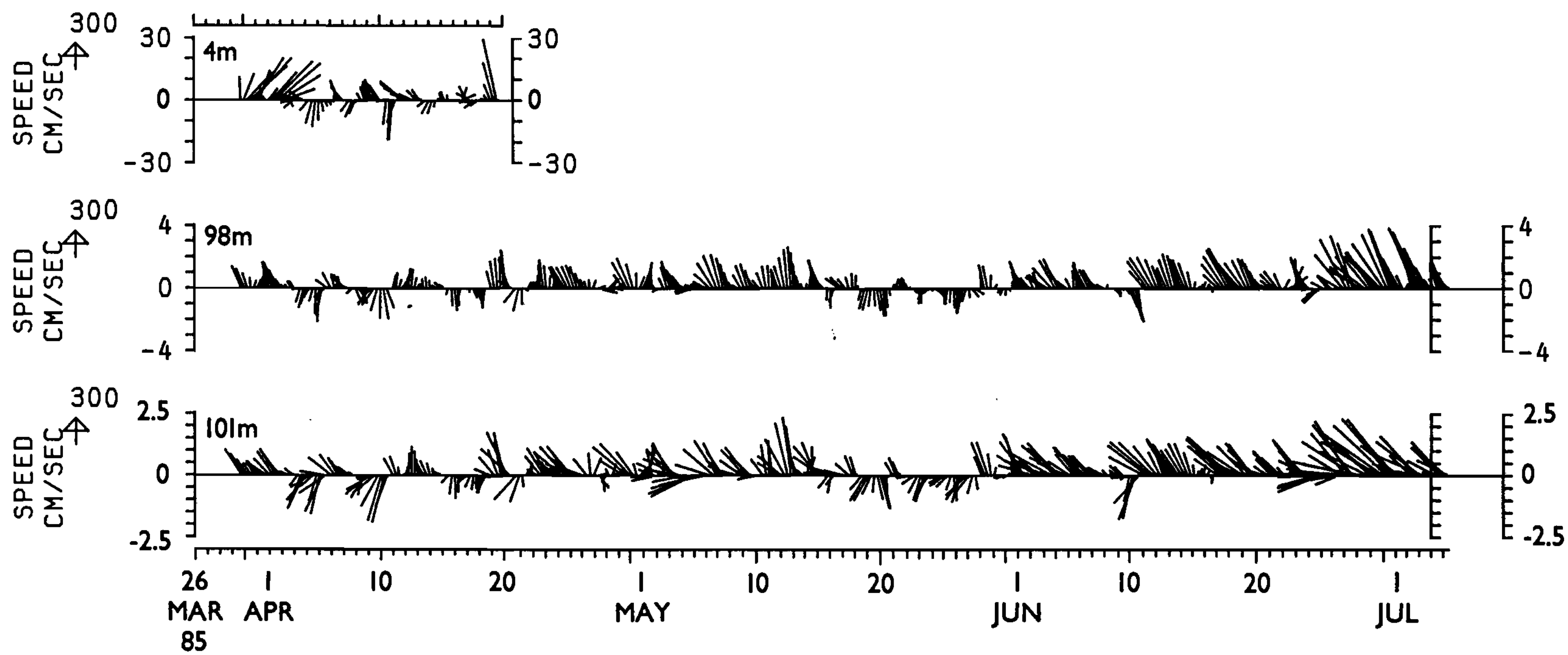


Figure II.13. Vector time series of low frequency currents at the Elliott Bay mooring oriented relative to 300° T, along the local bathymetry. The scales of magnitude of the vectors of each record are different because of the varied ranges of currents.

surface plume of freshwater flowed from the Duwamish to the right along the eastern shoreline of the bay. In April, samples collected from the upper 2 meters of the water column exhibit the extremely thin nature of the surface layer (Fig. II.3). Most of the freshwater is confined to the upper meter of the water column. In July, during a period of very warm, calm weather and low river runoff, observations from the launch also showed freshwater flowing along the eastern side of the bay at low tide with salt water entering around Duwamish Head at high tide (Fig. II.2). An area of higher salinity between the east and west waterways of the Duwamish occurred during July, and another area of saltier water was seen off Seattle near the Aquarium. Tidal currents observed in the plume indicate that the freshwater could exit the bay in one tidal cycle, and no water would be flowing from the Duwamish at high tide. It appears likely that Duwamish River flow transits the bay in tidally-driven pulses even during high river flow (See Section II.1.3.2., p. 39) At 90 m the salinity is indicative of its source from the main basin, and much less variability is seen. In March there was less than 0.1 parts per thousand (ppt) variation in salinity within the bay. In July some structure is apparent with higher salinity water entering around Duwamish Head. Salinity sections from the Duwamish West Waterway in July showed little change at depth between ebb and flood, while the surface variations range from a low salinity of 22.5 ppt on ebb to 26.5 ppt on flood (Fig. II.4). The freshwater exits during ebb and is driven up the estuary during flood. Within Elliott Bay the freshwater lens enters from the Waterway on ebb, is pinched off on flood, and then flows along the Seattle waterfront while more saline water is transported up the estuary from Duwamish Head. This can account for some patchiness in the salinity patterns within Elliott Bay, particularly if more than one tide is required for the freshwater to transit the bay.

The CTD survey showed the salinity at the Elliott Bay mooring identical to that recorded by the current meters (Fig. II.5). Also the salinity in the waterway was low at low tide, and high at high tide; thus the salinity might be correlated with tide stage. However, when the predicted tide series is correlated with the current meter salinity records from either the Elliott Bay or Duwamish moorings, there is nearly zero correlation. Since the upper meter at 2 m in the Duwamish River is in the strongest part of the halocline, a slight variation in vertical structure could lead to a large variation in salinity. In Elliott Bay, where the fresher surface salinity must be advected to the mooring from the Duwamish, the large variation in salinity in the upper 4 m indicates the patchy nature of the Duwamish discharge. The salinity variations at 10 m in the Duwamish are a consequence of the source waters from Elliott Bay. There are periods, approximately fortnightly, when a little freshening occurs in the deeper water of the Duwamish, indicating possibly greater mixing near the mouth of the West Waterway at those times.

The surface salinity in Elliott Bay frequently is lower than in the Duwamish. The vertical salinity gradient at times is up to 6 ppt over a depth of 9 m. There are also other times when the salinities at 1, 2, and 4 m are nearly the same, and only 1 or 2 ppt different from the salinity at 90 m, indicating the patchiness within the bay and the existence of mixing.

At depth the salinities in Elliott Bay were generally higher than those at the same level in the main basin of Puget Sound off Shilshole probably resulting from introduction from a deeper level (Baker *et al.*, 1983).

Time series of salinity difference in the Duwamish and Elliott Bay clearly demonstrate patchiness (Fig. II.9). Although the mean is about 2 ppt, the series shows spikes of of 4-6 ppt indicating extreme vertical stability within the patches. There are frequent thin freshwater lenses in the region of the mooring. The scale and form of the patches are highly variable; resulting from tidal forcing, variations in Duwamish outflow and wind forcing. Between 16 and 18 April the salinity at both the surface and at 4 m decreased significantly indicating a freshwater patch greater than 4 m thick. For five days prior to this event the Duwamish was discharging at 100 cubic meters per second, a rate twice the average for the study period (Fig. II.2). The winds over the Puget Sound region (Fig. II.10) during the discharge period were to the north which would tend to keep the freshwater confined nearshore. Beginning on 15 April the winds shifted to the south driving the accumulated fresh water from the nearshore out into the bay. This observation is an example of the strong effect the wind has on the location of the patches. On ebb tide during the April CTD cruises, a rip line ran roughly along the center of the bay from the mouth to the west waterway. At that time the moorings were in the middle of the fresh side of the rip line. The effect and significance of winds on transport are addressed in Sec. II.1.3.2., Currents (P.). Details of wind effects would require many wind observations within Elliott Bay at several points due to the complexity of the shoreline, particularly the adjacent, tall buildings. However, it is clear that the north-south alignment of the Duwamish valley and the Interbay valley strongly direct the winds.

II.1.3.2. Currents

Current measurements were made near the bottom and surface in Elliott Bay and near bottom in the Duwamish West Waterway (Fig. II.11). The records near the bottom in Elliott Bay extended over 100 days, but the record near the bottom of the Duwamish was limited to 40 days due to fouling of the current sensor by algal growth. The currents near the bottom were low, generally less than 10 cm/sec, up waterway in the Duwamish and westward in the bay.

An indication of the slow bottom currents is clearly seen in the nature of the sediments in the region of the measurements, which are fine silts and clays. The mean near bottom speeds observed, 3.7 cm/sec in Elliott Bay and 6.2 cm/sec in the Duwamish, are quite low (Fig. II.12). Near-bottom current observations support the conclusion of Baker *et al.* (1983) that resuspension of bottom sediment is negligible compared with the slow flux of fine sediment coming into the lower layer of Elliott Bay from the Main Basin. The vector mean flow (0.8 cm/s toward 239 T)

(Table II.3.) measured at 1 m above the bottom shows that the station lies in the northern sector of the weak, bathymetrically steered counterclockwise gyre observed in the bay. Currents in excess of 6 cm/s occurred less than eight percent of the time (Fig. II.12.). The suspended sediment concentration varies directly with salinity with time, indicating that the suspended sediment is being carried to the site by the currents rather than being resuspended locally (Fig. II.23). Because Elliott Bay is a quiet embayment with a deep entrance, the suspended sediment and water properties below the surface layer have essentially the same vertical distributions as those outside the entrance in the main basin.

Tidal currents at the bottom of Elliott Bay are very small, 1.5 cm/sec and 0.8 cm/sec for the semidiurnal and diurnal components, with major axis orientation along 93°. The surface record was too short to perform a complete tidal analysis. Spectral analysis, however, showed more energetic currents with a peak in variance in the semidiurnal range. The mean speed was an order of magnitude greater than at depth.

The low frequency data (35 hour low-pass filtered to remove the tidal signals) display an event-dominated environment (Fig. II.13). At depth the larger magnitude vectors tend to align with the local bathymetry. There are periods of reversal of flow into Elliott Bay, but these are infrequent and of short duration. The magnitude of the low frequency flow is up to 20-30 cm/sec in the surface but less than 5 and 3 cm/sec, respectively, in the two near bottom records. The decrease near bottom most likely results from the deepest meter being in the bottom boundary layer since the meter is only 1 m off the bottom.

Progressive vector diagrams of the Elliott Bay current records are more instructive of the low frequency flow (Fig. II.14). These are created by putting successive vector currents at a given location end to end to give an overall impression of the flow. However, because they are from the same location, they should not be interpreted as trajectories. The net flow near surface is westward, out of Elliott Bay. The diagram reveals that the flow is not steady, but is episodic in nature with periods of well-defined flow in directions other than westward, including toward shore, and there are periods of little or no defined flow. At depth, periods of weak net flow occur in early April and late May. A large change in direction (~45°) of flow occurred between 98 and 101 m and is not presently understood. The net flows imply a potential flow out of the bay in about 5 days in the surface layer and 14 days at depth. However, the direction of flow at the nearest bottom meter implies flow more nearly across the bay, perhaps toward Duwamish Head, but of course the flow may change direction farther on. The cross-bay flow would be somewhat surprising because it was anticipated that the net bottom flow would be more into the bay. Perhaps there is more inward flow at depth on the south side of the bay.

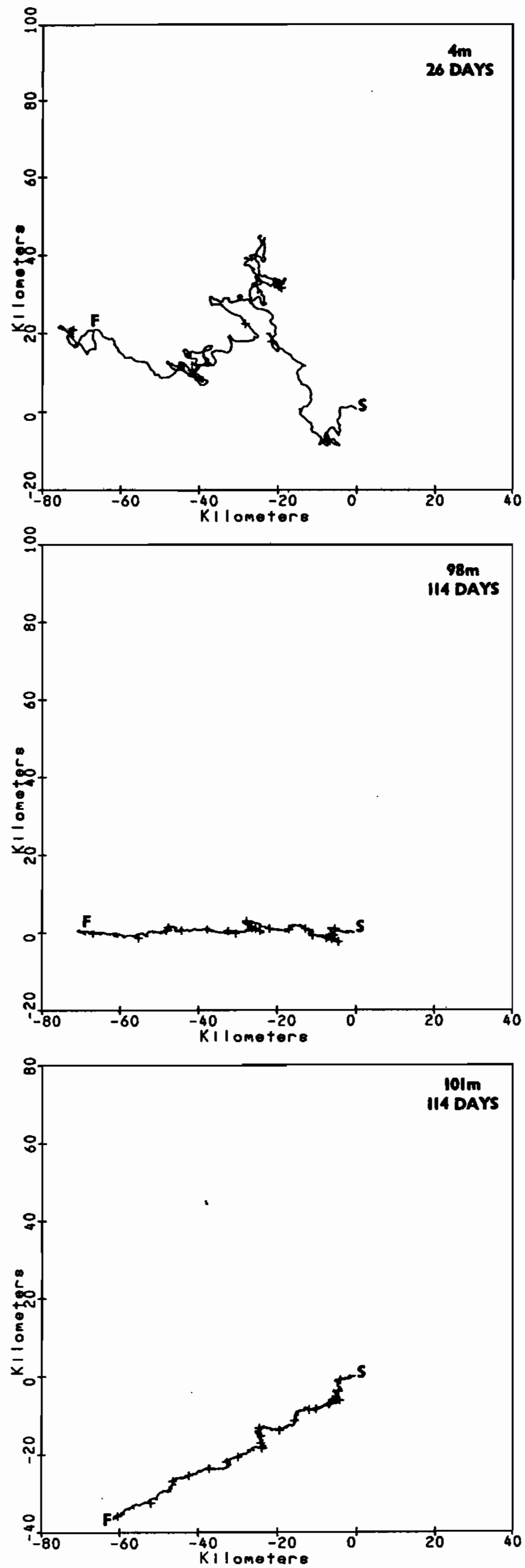


Figure II.14. Progressive vector diagrams of currents in Elliott Bay. The record at 4 m is only 26 days long, which indicates the higher velocities than at depth.

II.1.4. Particulate Matter Transport

The purpose of this portion of the study was to examine the nature and extent of the SPM surface plume in Elliott Bay during varying river flow and runoff conditions. Specifically, it will characterize the SPM plume in terms of its principal sources, extent, suspended load, vertical flux, and trajectory.

An understanding of the distribution of suspended particulate matter (SPM) in Elliott Bay is of fundamental importance to understanding related pollution problems, since most pollutants are in particulate form or absorbed to particles. The SPM distribution in Elliott Bay was characterized by Baker *et al.* (1983) as a thin (<5 m), turbid, surface layer and a thicker (10-100 m) benthic nepheloid layer (BNL) separated by a zone of uniform and low SPM concentrations. That study showed that the surface plume was restricted to the eastern inner bay and northern outer bay during August 1979 and February 1980 surveys. In a related study, Baker (1982) estimated that during a twelve day period, the Duwamish River supplied $\sim 214 \times 10^5$ g of the 298×10^5 g suspended load of the inner bay freshwater plume. Another plume source, the Denny Way CSO, discharged 850×10^5 g of suspended solids into Elliott Bay from March 3, 1978 to February 28, 1979 (Tomlinson *et al.*, 1980).

The stations/grids sampled are shown in Figs. II.15 and II.16 (1985 and 1986 surveys, respectively). Surface parameters measured in 1985 with the respective sampling locations are listed in Appendix XVI. A discussion of methods and instrumentation is in the Quality Assurance Project Report (Appendix XVII) (also see Baker and Milburn, 1983).

It should be noted that the SPM values reported in this section are derived from calibration regressions (see Appendix XVII). Since these correlations contain a degree of scatter, a slight disparity may occur between discreet sample SPM concentrations and corresponding values derived from attenuation. Scatter about the regression lines is from sampling error and particle population inhomogeneity. A persistent sampling problem is that of obtaining attenuation and discreet measurements on downcasts and upcasts respectively, i.e. they are not coupled in time and space. Errors associated with particle population inhomogeneity have been discussed by Baker and Lavelle (1985).

Plan view and vertical cross sectional maps of SPM and salinity concentrations were constructed to depict the distributional patterns.

II.1.4.1. April, 1985

(Note that in the vertical sections that the upper 2.5 m is shown separately in expanded scale and that the shallowest measurements of the full sections begin at 5 m).

The general distribution of SPM in Elliott Bay measured during the 1985 survey was similar to that described by Baker *et al.* (1983). The highest concentrations were in the surface

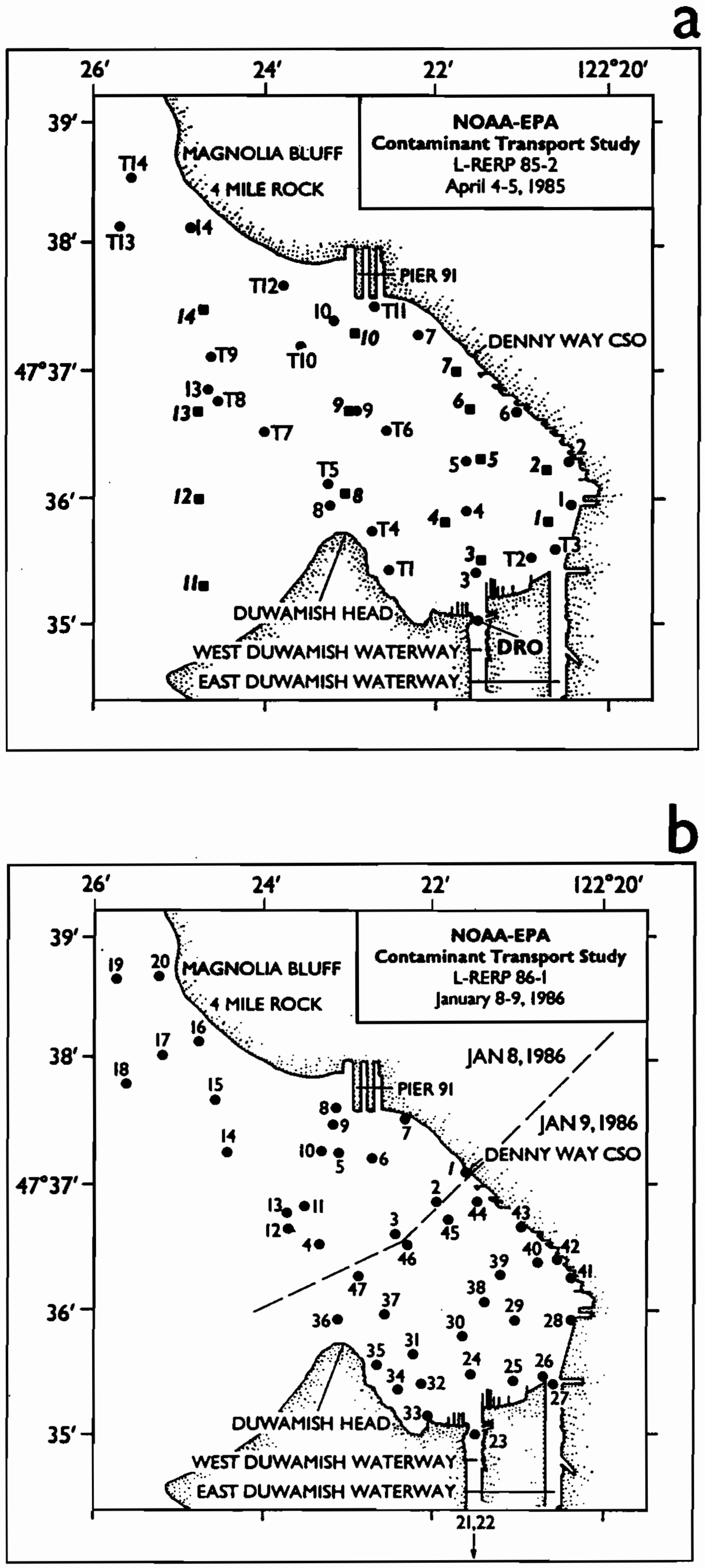
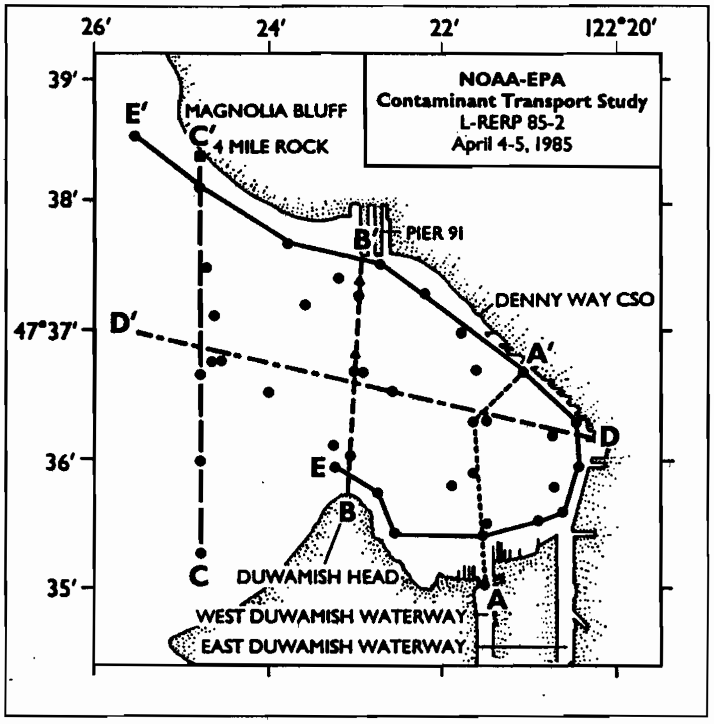
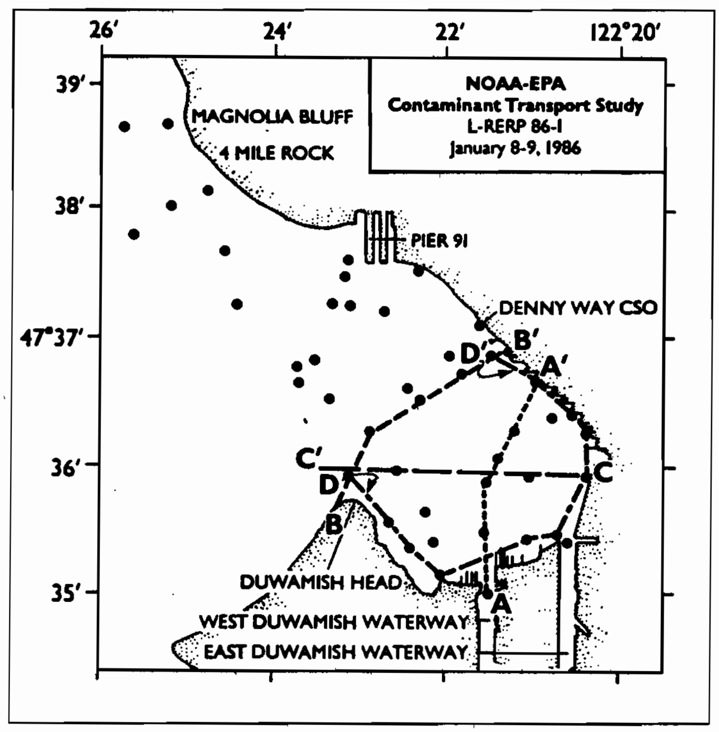


Figure II.15. Station locations in Elliott Bay during April, 1985 (a) and January, 1986 (b). For April, 1985 (a), the names for stations sampled from the *McArthur* (squares with bold italic numbering) are derived by adding the prefix 'EB85-' to the station number. Names for stations sampled by small boat (dots) are derived by adding the prefix 'EB85-SB' to the station number. For January, 1986 (b), names for samples collected by small boat are derived by adding the prefix 'S' to the station number.



Section lines for vertical cross sections
April 1985



Section lines for vertical cross sections
January 1986

Figure II.16 Location of transects sampled for SPM and salinity in Elliott Bay, April 1985 and January 1986. Data from these transects were used to construct vertical contours of SPM and salinity.

plume and BNL with uniform low turbidity water throughout the water column between the two layers.

The surface plume is well defined by both SPM and salinity gradients and its three dimensional extent throughout the bay is readily identified from the vertical (Figs. II.17, II.18) and areal (Figs. II.21., II.22) plots. Surface plume SPM concentrations ranged from ~10 mg/L at the West Waterway to ~1.0 mg/L in the central outer bay (Fig. II.20, Section C-C'). Section line A-A' (Figs. II.16) shows that the plume diminished rapidly with depth (from 10.0 to 2.0 mg/L within 2 m) at the West Waterway but only gradually with distance from the West Waterway. Section lines B-B' and C-C' show that the plume is constrained to the northern half of the bay. SPM concentrations in the northwest quadrant of the bay ranged from ~1 to 3 mg/L. Section line D-D' shows that the plume, well defined along the eastern shore (1.5 to 5 mg/L in the upper 1.5 m) diminishes gradually toward mid-bay where it is reduced in thickness (<0.5 m) and concentrations (1.5 mg/L). Section line E-E' which extends around the perimeter of the bay, shows relatively high concentrations from the West Waterway (10 mg/L) to the Bay's confluence with the main basin of Puget Sound (~1 to 3 mg/L). In general, the SPM concentrations around the Bay perimeter decreased gradually in a counterclockwise direction. The 1.5 mg/L isopleth, which tends to delineate the lower boundary of the plume at ~1.5 m depth, truncates west of the West Waterway. High SPM concentrations were also found at the East Waterway (8 mg/L), along the easternmost shore (5 mg/L) and about halfway between the Denny Way CSO and Pier 91. It appears that these high levels decrease to background plume concentrations (~2 mg/L) within a relatively short distance (several hundred meters).

The BNL SPM concentrations ranged from ~1.5 mg/L in the central outer bay to ~0.5 mg/L in the inner bay. Intermediate water SPM concentrations were relatively uniform (0.4-0.6 mg/L) throughout the bay (Fig. II.17).

II.1.4.2. January 1986

The patterns of SPM and salinity measured in January, 1986 was similar to those observed in 1985 but the concentrations were much lower and higher, respectively. Plume concentrations ranged from ~1-10 mg/L in the upper 3 m in the West Waterway decreasing in both magnitude and thickness from mid-inner bay to the northeast shore (Fig. II.19, Section A-A). In the outer bay, concentrations were less than 2 mg/L along the entire B-B' line. Section C-C' shows that SPM concentrations in the upper 2 m decreased from a high of 7.5 mg/L at the eastern end of the bay to ~1 mg/L at mid-bay. Shoreline SPM concentrations are dramatically reduced from the 1985 survey except at the West Waterway. The slight elevation in concentration near station S34 may be from the Fairmount CSO and nearby storm drains.

The near-surface salinity patterns (Fig. II.21) matched the SPM patterns (Fig. II.22) with some exceptions. The mid-outer bay plume is not discernable from the salinity measurement but

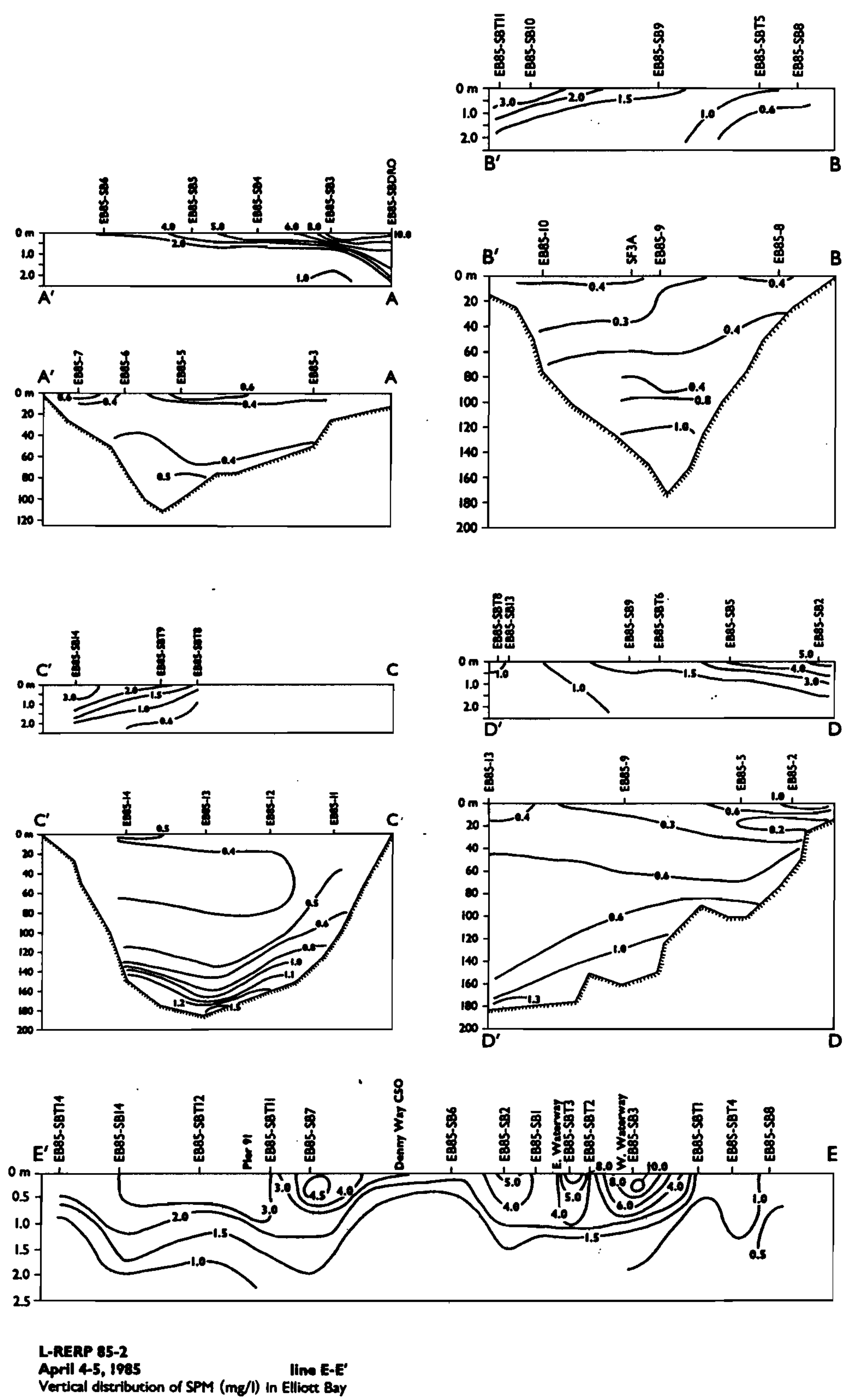


Figure II.17. Vertical sections of SPM in Elliott Bay, April 4-5, 1985.

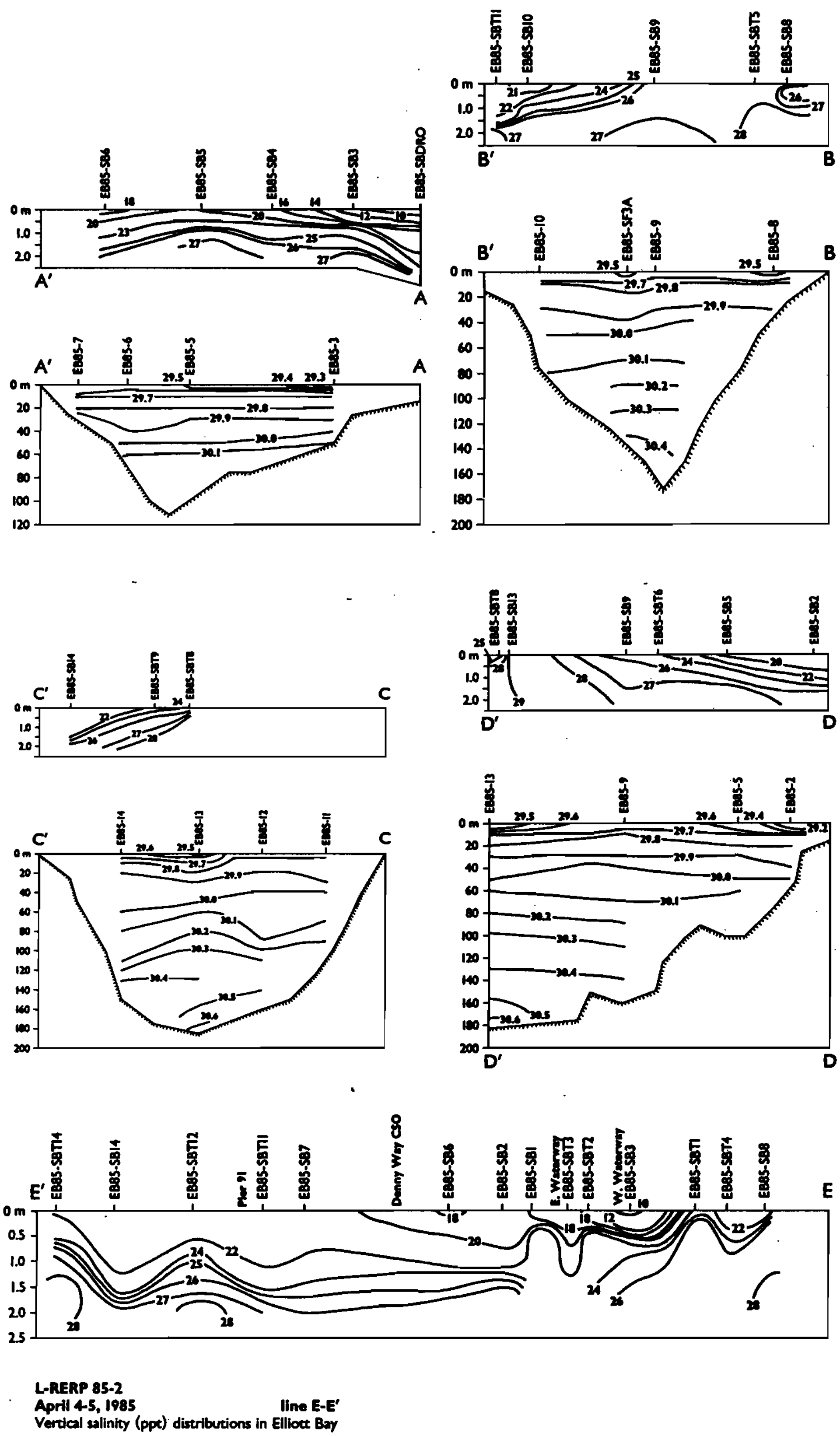
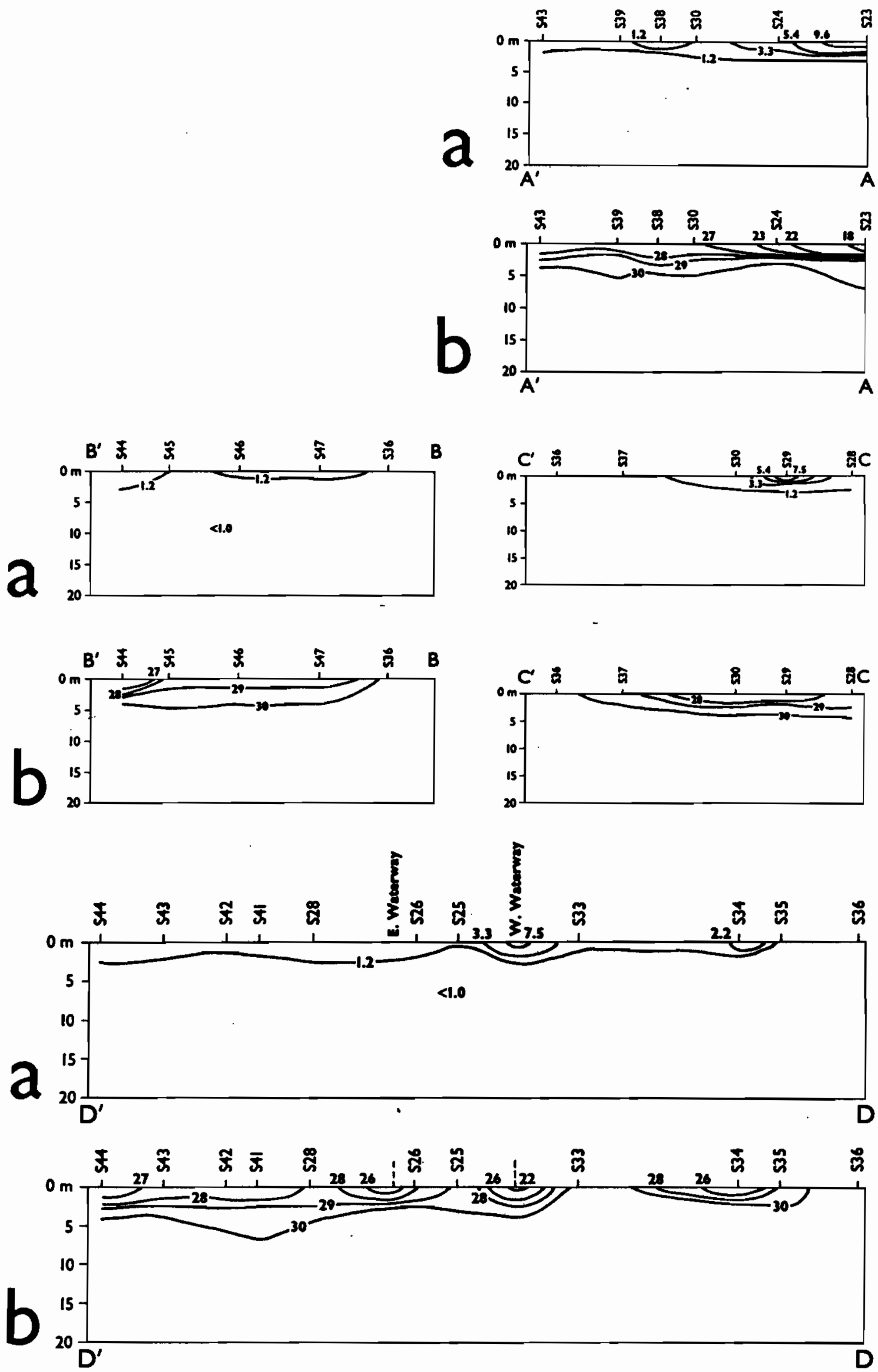
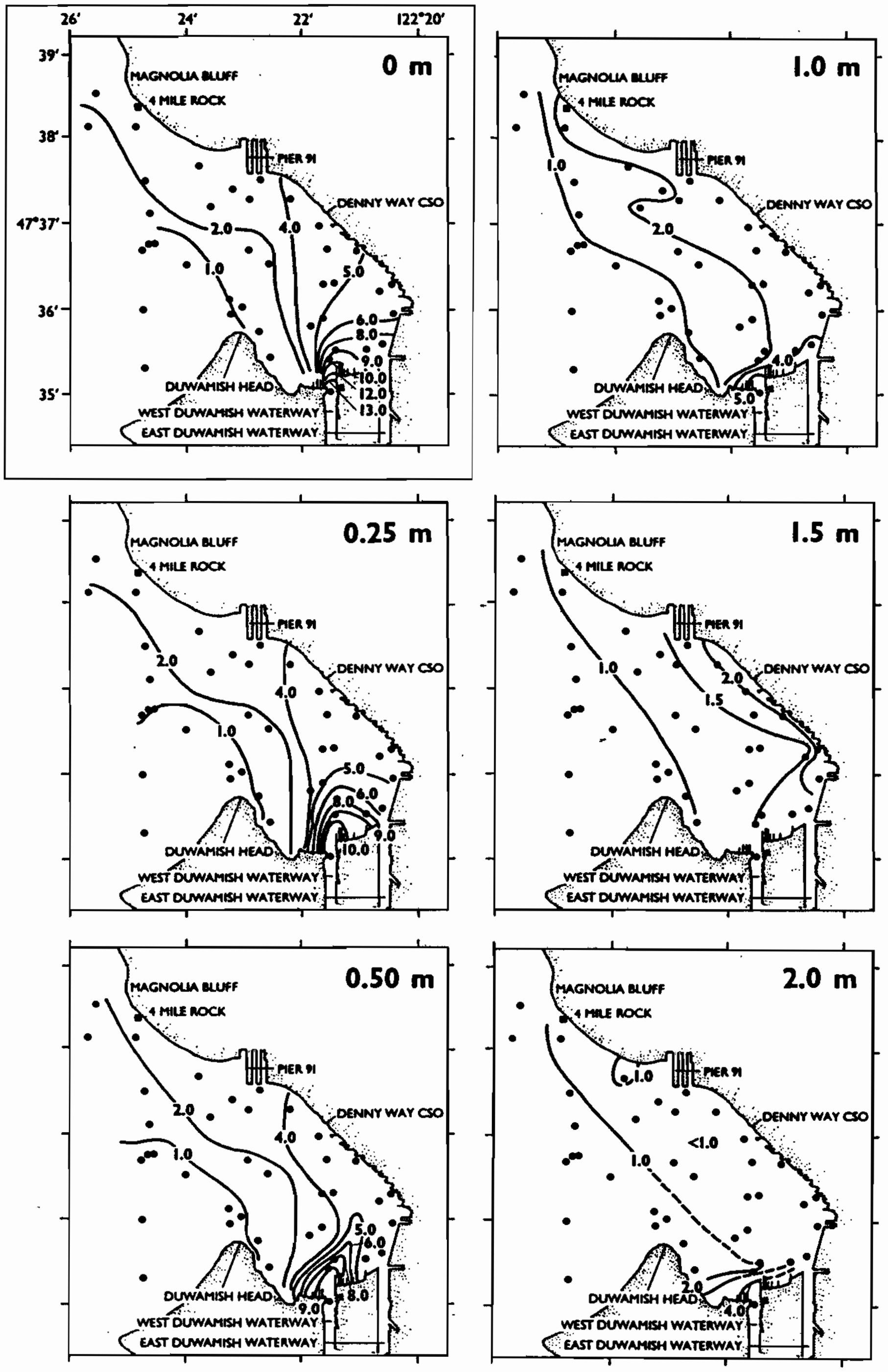


Figure II.18. Vertical sections of salinity in Elliott Bay, April 4-5, 1985.



L-RERP 86-1
January 8-9, 1986 line D-D'
a) Vertical distribution of SPM (mg/l)
b) Salinity (ppt) in Elliott Bay

Figure II.19. Vertical sections of SPM and salinity in Elliott Bay, January 8-9, 1986.



Near-Surface Concentrations of SPM (mg/l)
Elliott Bay
April 4, 1985

Figure II.20. Near-surface SPM 0-2 m in Elliott Bay, April 4, 1985.

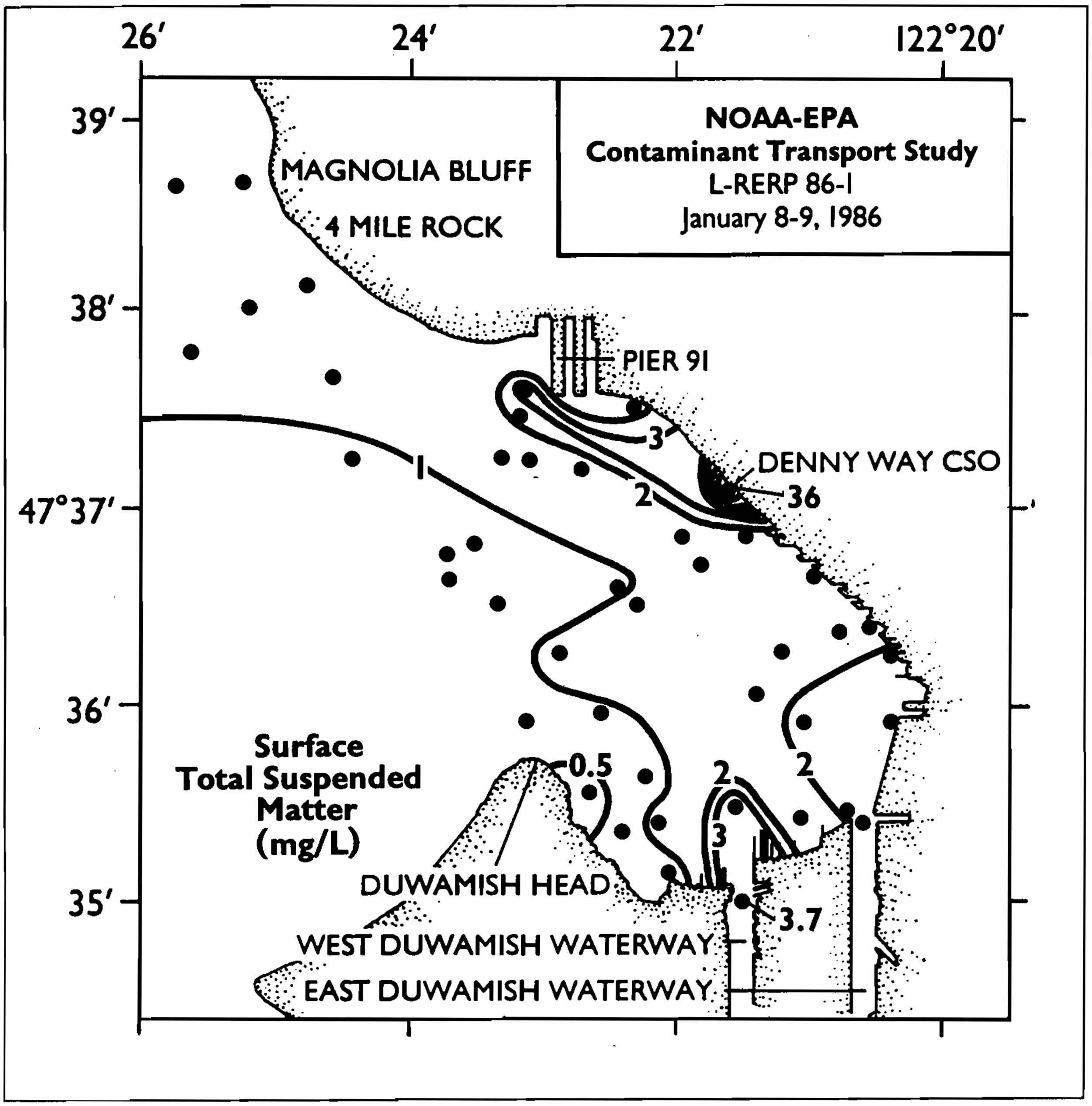


Figure II.21. Concentration of SPM in near surface of Elliott Bay January 8-9, 1986.

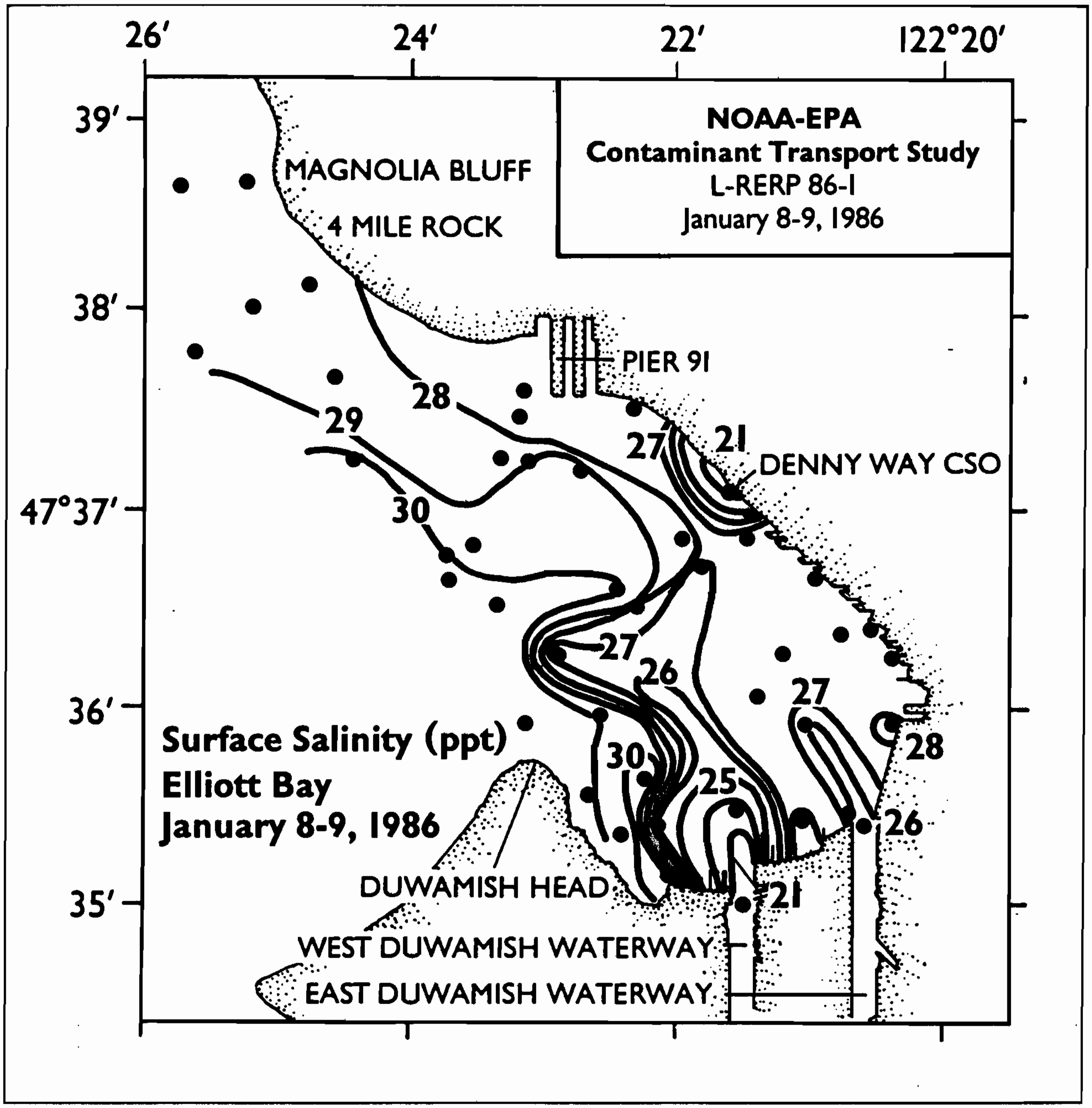


Figure II.22. Near surface salinity in Elliott Bay, January 8-9, 1986.

is apparent from the SPM measurements. In section D-D' (Fig. II.18) there appears to be a secondary but well-defined low salinity plume to the west of the West Waterway slightly off-shore of the Fairmount CSO (station S34). The nearshore plume is much better defined by the salinity than the SPM measurements, especially at the East Waterway.

The foregoing results and those of Baker (1982) show that the primary source of the SPM load of the surface plume in Elliott Bay is the West Waterway of the Duwamish River; secondary sources were shown to include the Denny Way CSO, East Waterway and the Fairmount CSO. The difference in magnitude of the plume SPM concentrations between the two surveys reflects the changes of the Duwamish discharge. The Denny Way CSO discharge, although relatively minor in volume, made a significant contribution to the plume suspended load in the northeast quadrant of the bay during the 1986 survey.

The extent of the plume was well defined by the SPM and salinity distributions and was found to be similar during both surveys. It was primarily located in the southeast and northwest quadrant of the bay and decreased in intensity from its source in the southeast quadrant to the northwest quadrant, and from the bay shoreline to the center. In general, the plume was thickest (~2-3 m) at the shoreline and thinned (to ~0.5-1 m) toward the center of the Bay.

The SPM and salinity distributions indicate that the plume spreads outwards from the Duwamish River in a thin, low salinity lens. The plume is transported counterclockwise throughout the bay, until it is carried into the main basin off Magnolia Bluff.

II.1.4.3. SPM-Salinity Relationships

The distribution and fate of SPM from the Duwamish Waterway is governed by processes such as advection, settling and dilution. An examination of the relationship between SPM concentrations and salinity provides some clues about the relative importance of these processes.

The 1985 surface salinity distributions in water less than 5 m clearly mimic SPM surface patterns (Figs. II.3. and II.19) suggesting that dilution of the river plume by marine water from the main basin was the major factor controlling the decrease of SPM concentrations in the bay. Least-squares fits to the salinity data greater than and less than 22 ppt produced separate regression lines with high correlations ($r^2 = 0.80$ and 0.94) (Fig. II.23a). These correlations imply that plume SPM behaves conservatively and that its distribution within the surface plume is governed by simple physical mixing (dilution) (Liss, 1976). Furthermore, the fact that two linear mixing curves can be fit to the data set implies that secondary sources mix with the Duwamish water. The linearity of the mixing curves argues that SPM loss (by settling or other processes) is insignificant.

The January 1986 surface SPM-salinity regression (Fig. II.3c) is considerably different from that of April 1985 (Fig. II.23a). Duwamish water (stations S21-S24) exhibited conservative mixing from station S24 riverward and into the West Waterway. The bay water SPM-salinity

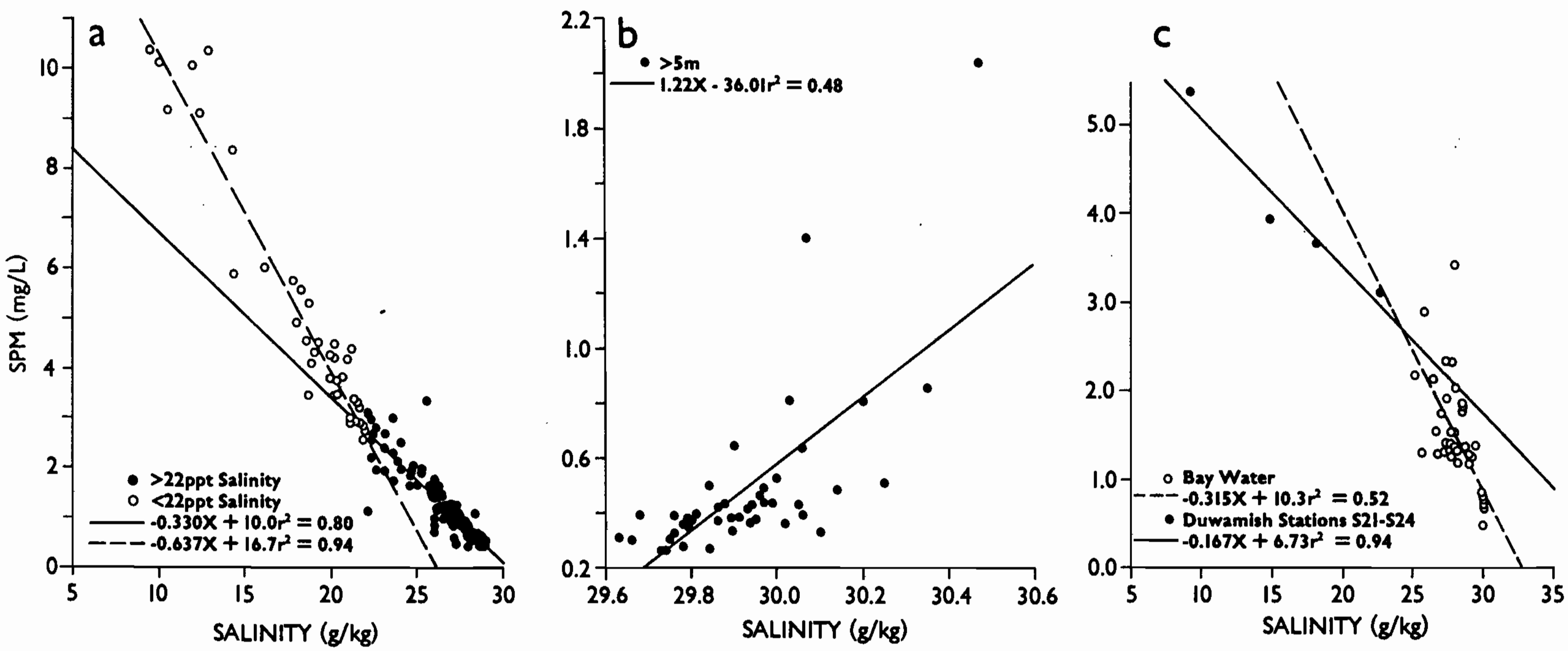


Figure II.23. Salinity-SPM regressions in Elliott Bay.
A. Surface - April 1985,
B. Intermediate depths - April 1985
C. Surface - January 1986

relationship is clearly different from that of the riverwater. It shows a linear trend with a steeper slope and a low correlation coefficient ($r^2 = .48$). It is possible that the scatter of the data is a result of multiple sources (Denny Way, Fairmount, and Hanford CSOs and waterfront runoff); the survey followed a period of moderate to heavy rainfall (see discussion on CSO discharge).

The SPM-salinity relationship within waters beneath the plume was the inverse of the plume water relationship (Fig. II.23b) and was qualitatively similar to those reported by Baker *et al.* (1983). Slopes differ between the present study and Baker *et al.* (1983) because midwater and bottom water samples were plotted in this study whereas only BNL samples were used by Baker *et al.* (1983). The direct relationship between SPM and salinity in the deep water indicates that the increased turbidity of the deep water is caused by advection of Main Basin deep-water rather than local resuspension.

II.1.4.4. SPM Loading and Vertical Mass Flux

The mass loading of the upper 2 m of Elliott Bay was estimated by the following procedure. First, attenuation measurements obtained at each station at several depths (0 m, 0.25 m, 0.50 m, 1.0 m, 1.5 m, and 2.0 m) were contoured. A separate contour map was constructed for each depth level. The area within each contour interval on each depth level was measured with a polar planimeter and the loadings of the subareas (contour intervals) calculated by

$$L_s = \left(\frac{\alpha - .34}{.74}\right) za*10^6 \qquad \text{(Eq. II.2)}$$

where L_s = loading (g) of each subarea

$\left(\frac{\alpha - .34}{.74}\right)$ = coefficients of the attenuation(α)/SPM regression

z = depth increment (m)

a = area of subarea (km^2)

The L_s values were summed to provide the loading of each depth increment and then successively deeper depth increment loadings were averaged and summed:

$$L_i = \left(\frac{L_z + L_{z+i}}{2}\right) \qquad \text{(Eq. II.3)}$$

and

$$L_p = \sum_{i=0}^{i=6} L_i \qquad \text{(Eq. II.4)}$$

L_i = loading of a depth increment

L_z = loading of upper depth increment

L_{z+i} = loading of lower depth increment.

The calculated loadings are given in Table II.4

Nearly half of the material was in the upper half meter. Thirty percent was in the next half meter. Only 22.3% was in the second meter.

The average vertical mass flux, from sediment trap data from mooring PS8501 (Table II.5), was calculated to be 0.155 $g/m^2/day$ at both 6 m and 50 m depth. Multiplying the flux by the area of the plume (13.5 km^2) gives the vertical mass flux of the plume as 29.9×10^5 g/day, assuming that the flux at mooring PS8501 is representative of the entire plume area. This is 4% of the total mass loading of the 2 m deep plume. This small loss would not be revealed in the regression of SPM and salinity (Fig. II.23). Moreover, this is a maximum figure, since the vertical flux should be proportional to the mass loading at any given point and the mooring was located in the region of maximum mass loading. A more likely value would be 2.5%.

II.1.5. Trace Metals and Organics in Elliott Bay

II.1.5.1. Trace Metals

Dissolved and particulate trace metal samples were collected in Elliott Bay on 4-5 April, 1985 (Fig. II.24), during a period of moderate to high river runoff when the combined sewer overflows were not discharging. Surface trace metal samples were collected in 1-L polyethylene bottles from the bow of a small boat deployed from the NOAA ship McArthur while subsurface samples were collected using Go-Flo bottles attached to Kevlar line or hydrowire. Additional trace metal samples were collected in Elliott Bay on 8-10 January 1986 from small boats. During early January 1986, a period of relatively high rainfall (7 inches in 14 days) caused numerous overflows of the combined sewers to discharge into Elliott Bay. The Denny Way CSO was discharging for a period of 12 hours prior to the sampling program.

Surface samples collected throughout Elliott Bay (Figs. II.26-II.39) were used to look for sources of trace metals to the bay. Near a source, a plume of water with high metal concentrations will be evident with concentrations decreasing as the plume is diluted with more saline water. Plumes in Elliott Bay which contain high concentrations of trace metals originate from the East and West Duwamish Waterways, the Harbor Island shipyards, Denny Way CSO and the Seattle waterfront. Although a single concentration in a given plume can not be used to precisely calculate trace metal fluxes, the concentration within a plume can be used to perform an order-of-magnitude estimate of the flux of contaminants if flow data are available. Areal distributions for each metal have been contoured for both the April, 1985 and January, 1986 data sets. In addition, vertical transects (Fig. II.24) were generated from the deep samples collected in April 1985. These transects show that the surface plume which contains high concentrations of metals

Table II.4. Mass loading of the upper 2.0 m of Elliott Bay.

Depth Increment	Mass $\times 10^5$ g	% of total
0 m - .25 m	169.0	20.2
.25 m - .50 m	233.2	27.9
.50 m - 1.0 m	247.6	29.6
1.0 m - 1.5 m	126.7	15.2
1.5 m - 2.0 m	59.5	7.1 $\Sigma = 836 \times 10^5$ g

Table II.5. Vertical mass flux at 6 m and 50 m at mooring PS8501 during the April, 1985 survey.

Cylinder No.	Hours of Collection	Mass Flux ($g/m^2/day$)	
		6 m	50 m
1	204	.09	0.11
2	204	.10	0.14
3	204	.14	0.15
4	204	.10	0.14
5	204	.23	0.21
6	204	.27	0.12
7	204	.14	0.10
8	204	.24	0.26
9	204	.11	0.11
10	204	.13	0.21
		$\bar{x} = 0.155$	$\bar{x} = 0.155$

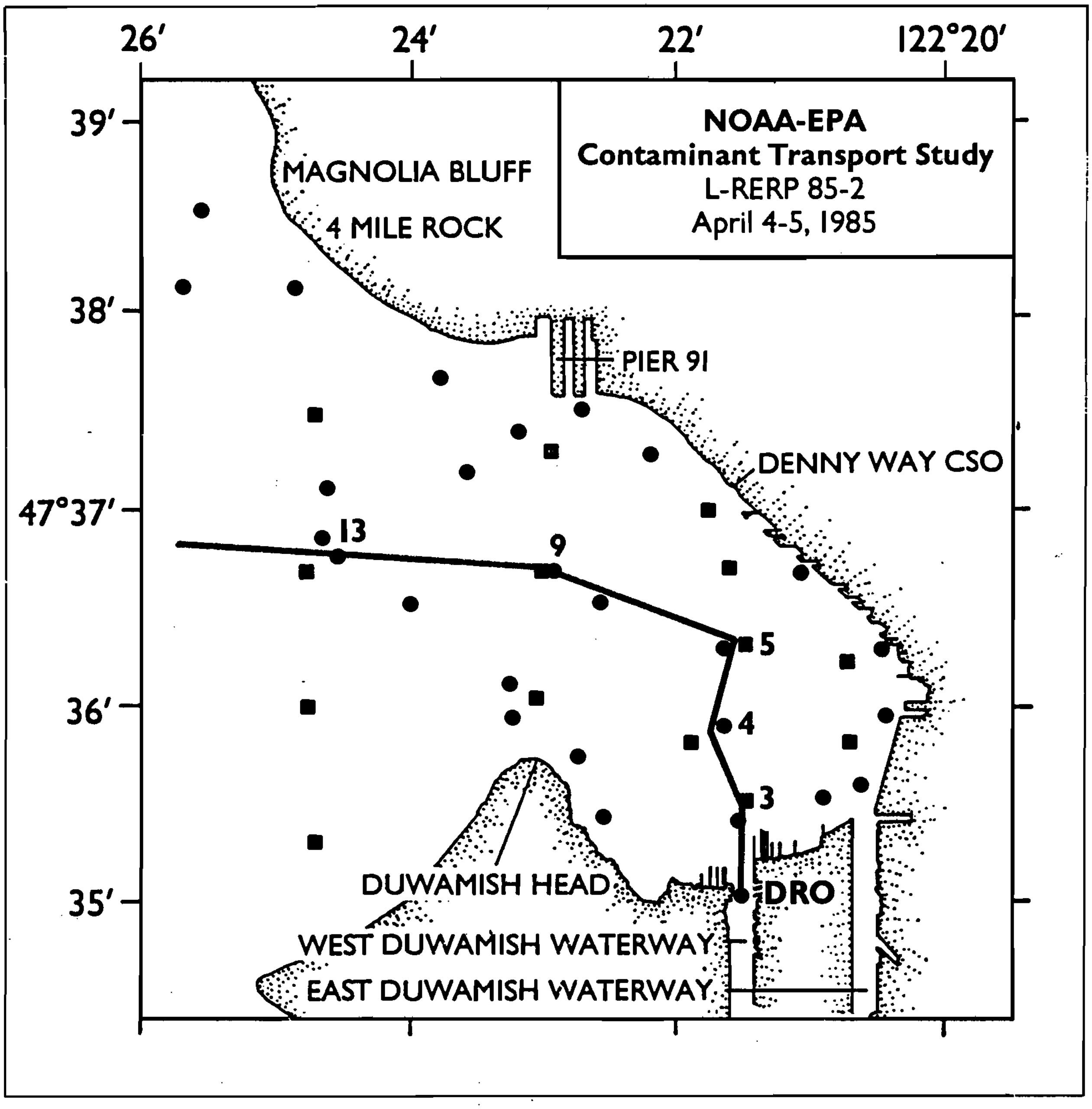


Figure II.24. Stations and location of vertical transect for metal sampling in Elliott Bay.

is confined to a very thin layer of surface water (<10 m). The salinity measurements provide a better definition of the thickness of the plume because of their higher vertical resolution. These vertical transects can also be used to identify sub-surface sources of metals such as diffusion from the sediments.

Trace metal-salinity plots were used to estimate "apparent river concentrations" which were then multiplied by the freshwater flow to calculate the flux of metals out of the Duwamish Waterway and out of Elliott Bay. After individual plumes merge together, the water from these plumes will exhibit characteristics of a single water mass and mix en masse with more saline water. If the metal is conservative, a plot of trace metal concentration vs. salinity will reveal a straight line between the single mixed water mass and more marine seawater. Boyle *et al.* (1974) have shown that the flux of a conservative element passing an iso-haline is equal to:

$$Q_r\,[C - (S-S_r)*dC/dS] \quad \text{(Eq. II.5)}$$

where Q_r and S_r are the flow and salinity of the river, respectively and where C and S are the concentration of the element and salinity at the iso-haline, respectively.

If the measurement of flow was made in freshwater, then S_r is equal to 0.0 and Q_r becomes the flow of freshwater. In this case, the part of the eq. II.5 in brackets is the y-intercept of a straight line. Fig. II.25 shows examples of idealized mixing curves for conservative trace metals from various sources. If plumes from different sources merge in the freshwater portion of the river, the line would be linear throughout the entire salinity range and the y-intercept would be the concentration of mixed river endmember (solid line in Fig. II.25). However, if there is an additional input of metals at some higher salinity, the curve would have a metal concentration-salinity plot which is convex upward (dotted line in Fig. II.25). After the plume has mixed laterally across the river plume, the mixture will again exhibit a linear metal-concentration vs. salinity plot. In this case, the y-intercept or "apparent river concentration" for the line segment seaward of the salinity of complete lateral mixing will be higher, reflecting the additional input. The portion of the metal concentration-salinity plot seaward of the salinity of complete lateral mixing would be identical to a line in which the same flux of metal originated entirely from the river with no additional sources being added at higher salinity (dashed line in Fig. II.25). In terms of eq. II.5, the flux of trace metals across the iso-haline of complete lateral mixing would be the same for both cases (dotted and dashed lines) since the same amount of metal was added upstream of the iso-haline. Plots of trace metals vs. salinity were generated for Elliott Bay data in April 1985 and January 1986. A linear regression analysis was performed on those samples that were 1) more saline than the inferred iso-haline of lateral mixing (14 g/kg for April 1985 and

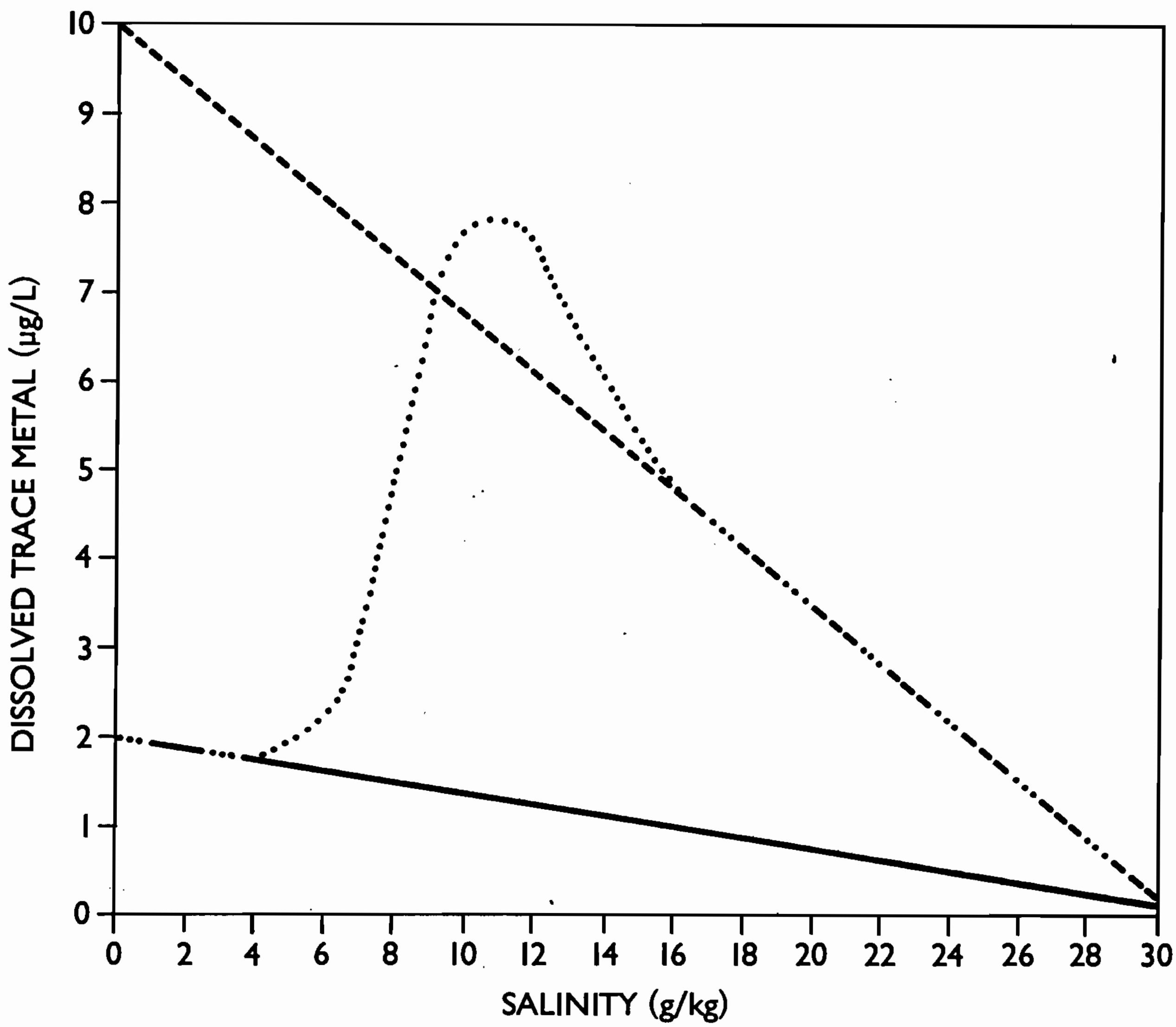


Figure II.25. Hypothetical Example of trace metal transport for a river with flow of 1 m^3/sec. Conservative mixing when river concentration is 2 ug/L which results in a transport of 2 mg/sec·(---). Conservative mixing when river concentration is 2 µg/L and 8 mg/sec is discharged at 10 g/kg salinity (0). In this case, the total transport of metal is equal to 10 mg/sec. Conservative mixing when river transport is 10 mg/sec with no additional input at higher salinity, i.e. river concentration is 10 µg/L (---). In all cases, the seawater concentration is 0.1 µg/L.

24 g/kg for January 1986; and 2) not part of an observed plume. For particulates, only samples that were taken on the day of the overflow event were used in regression analysis for transport out of the bay. If the r^2 of the linear regression was greater than 0.5, the y-intercept of the regression was multiplied by the average freshwater flow to calculate the flux of metals out of Elliott Bay. A linear line segment seaward of the salinity of complete lateral mixing does not demonstrate complete conservative behavior of a trace metal. Dissolved trace metals can be lost from solution during lateral mixing or on a time scale longer than estuarine mixing. The dissolved and particulate trace metal may also be non-conservative to an extent less than the errors of the regression analysis. Temporal variability of the discharge of a conservative trace metal can also result in a deflection in a trace metal-salinity plot. Results from the four samples collected from the West Duwamish Waterway were used to calculate the transport of metals out of the West Waterway. By comparing the transport of metals out of the West Duwamish Waterway with the transport of metals out of Elliott Bay, the combined significance of the plumes from the East Duwamish Waterway, the Harbor Island shipyards, the Denny Way CSO and the Seattle waterfront can be assessed.

Aluminum

Since most of the aluminum in marine particulate matter occurs as aluminosilicate (Sackett and Arrhenius, 1962), the Al concentrations in the suspended matter can be used to estimate the aluminosilicate percentages in the suspended matter ($Al \times 12$). Moreover, the Al/trace metal ratio can reveal if the metal sources are other than normal geological (sediment) ones, since aluminum is not normally a contaminant. The variations of the distributions of particulate Al in Elliott Bay are due to seasonal changes in input of suspended materials into surface waters and variations in bottom currents in Puget Sound which effect the resuspension and transport of bottom sediments into the bay. The highest concentrations of particulate Al in surface waters (250-850 mg/L), originate from the Duwamish River and the Denny Way CSO (Fig. II.26). Al-rich particulate matter is observed in the northern half of the bay and outward into the main basin of Puget Sound, providing evidence for out-of-bay transport of aluminosilicate material in near-surface waters. Below the surface, particulate Al concentrations decreased to a minimum at 20-40 meters followed by a gradual increase to the bottom. The increase in concentration of aluminosilicate materials in near-bottom waters is probably the result of advective transport of material into the bay from the main basin since the bottom currents are too slow to resuspend bottom sediments (Section II.1.3.1.).

Iron

In both April 1985 and January 1986, plumes of dissolved Fe originating from the West Duwamish Waterway and the Seattle waterfront can be seen (Figs. II.27a-b). In January 1986,

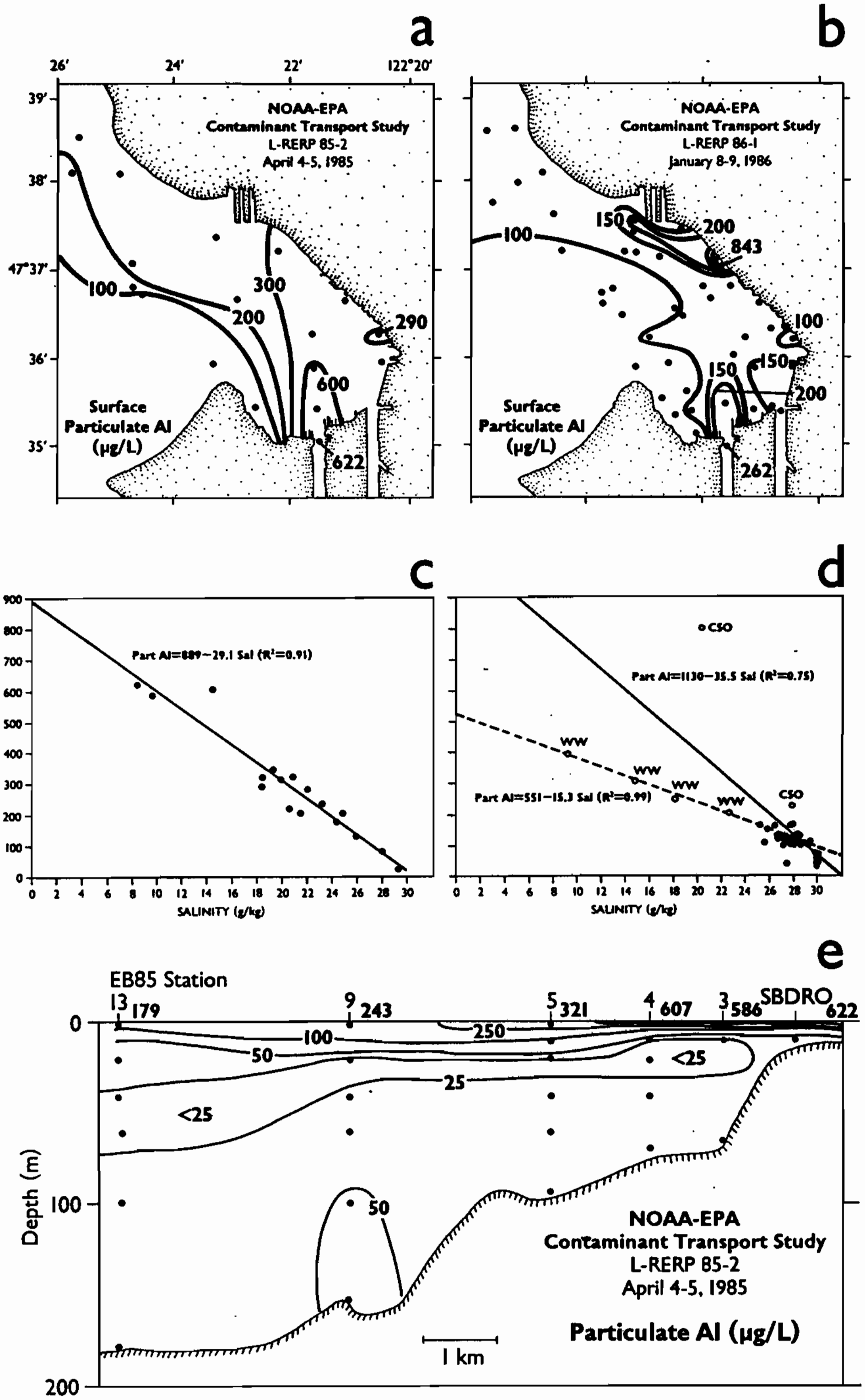


Figure II.26. Surface distribution of particulate Al in Elliott Bay during April 1985 (a) and January 1986 (b). Particulate Al vs. salinity plots for April 1985 (c) and January 1986 (d). Results of regression analysis of samples in Elliott Bay are presented as solid lines. Samples in the plumes of the West Duwamish Waterway (WW) and the Denny Way CSO (CSO) are noted as open circles and are not used in the regression analysis. For the January 1986 regression, only samples collected on the day that the CSO discharged were used in the regression analysis. A regression of the samples collected in the West Duwamish Waterway is presented as a dashed line (---). In the vertical transect in Elliott Bay during April 1985 (e), the bold values below and to the right of the station number are the concentrations from surface samples (<1 m) collected by small boat.

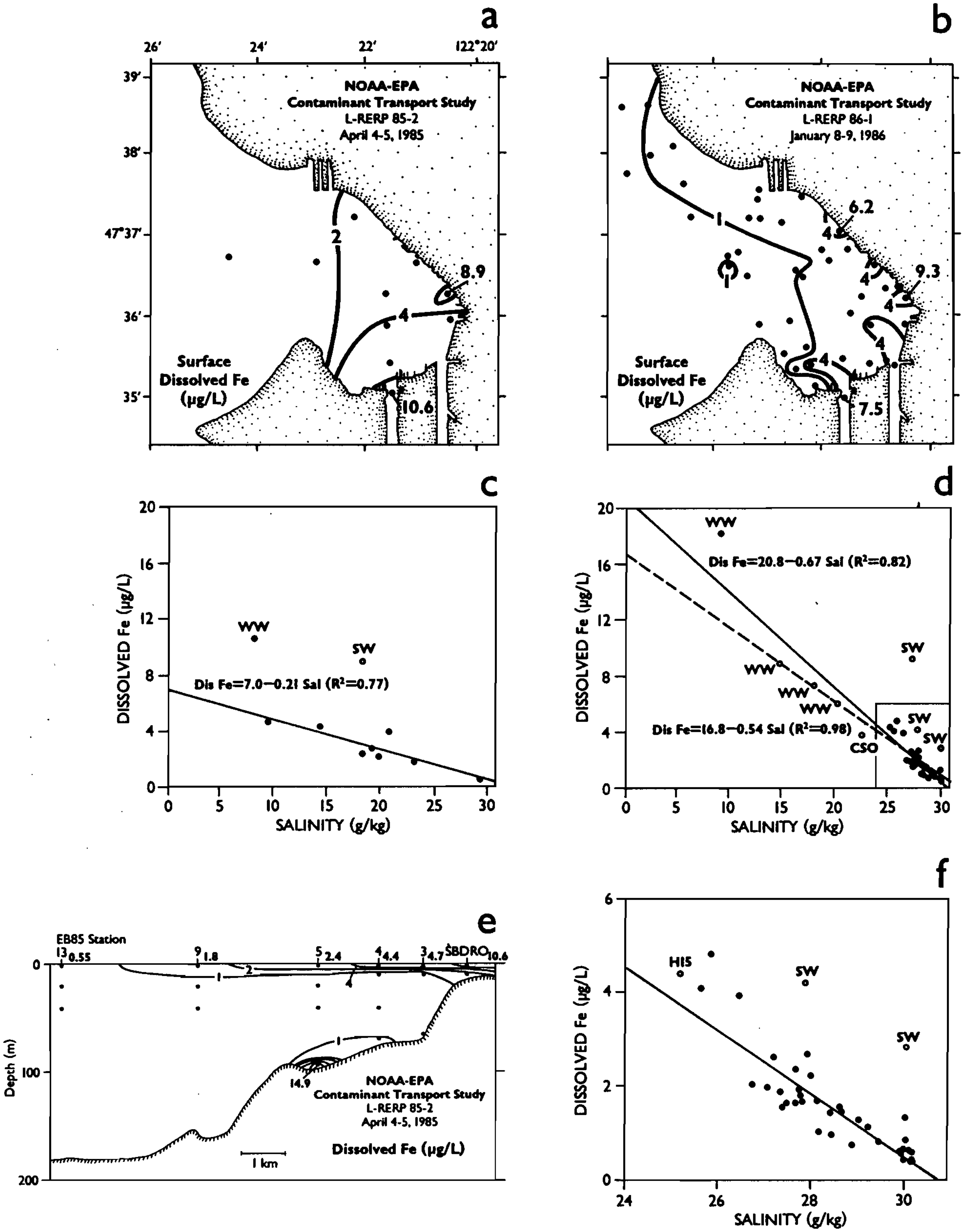


Figure II.27. Surface distribution of dissolved Fe in Elliott Bay during April 1985 and January 1986. Dissolved Fe vs. salinity plots for April 1985 and January 1986. Regression analysis of samples in Elliott Bay are given by the solid line. Samples in the plumes of the West Duwamish Waterway (WW), Denny Way CSO (CSO), Harbor Island shipyards (HIS) and the Seattle Waterfront (SW) are noted and were not used in the regression analysis. A regression analysis of the samples collected in the West Duwamish Waterway is given by the dashed line (---). Vertical transect in Elliott Bay during April 1985 (Figure 2e). The bold values below and to the right of the station number are the values for the surface (<1 m) samples taken by small boat. Figure f is an expansion of the lower right insert of d.

an additional plume can be seen originating from the East Duwamish Waterway. The salinity plots (Figs. II.27c-d) reveal that during both sampling periods the lowest salinity sample had dissolved Fe concentrations above the mixing line. This indicates that dissolved Fe from the Duwamish River is being removed from solution in the low salinity region of the estuary. This phenomenon has been reported by Boyle *et al.* (1977), Paulson and Feely (1985) and many others. The change in the y-intercept of the line used to calculate transport out of the West Duwamish Waterway vs. the y-intercept of the line used to calculate transport out of Elliott Bay (Fig. II.27d) indicates that sources from the Seattle waterfront are causing a slight increase in the amount of dissolved Fe being transported from Elliott Bay (Table II.6). The mid-depth dissolved Fe concentration was less than 1 µg/L (Fig. II.27e). The high concentration near the bottom of station EB85-5 is anomalous. Since dissolved Mn and Pb are higher at this location, the sediments might be chemically reduced.

Approximately 99% of the Fe in surface and subsurface waters of Elliott Bay is particulate. Particulate Fe concentrations in surface waters are highest near the mouth of the Duwamish River and along the Seattle waterfront (Fig. II.28a,b). The particulate Fe versus salinity plot (Fig. II.28c) for April, 1985 surface waters is nearly linear, suggesting very little sedimentation of particulate Fe from the surface plume. This interpretation is consistent with the results of the suspended matter and salinity measurements discussed previously. In January, the Denny Way CSO was a significant source of particulate Fe to the surface waters. A strong south-to-north gradient of particulate Fe is evident in the outer bay, indicating that the prevailing cyclonic motion of the surface currents transport particulate Fe-bearing substances out of the bay along the northern half of the bay. The particulate Fe versus salinity plot for January, 1986 (Fig. II.28d) is influenced by the additional input from the Denny Way CSO. Thus, the calculated transport of particulate Fe from Elliott Bay is about 20% higher than the transport out of the West Duwamish Waterway (Table II.7).

The vertical transect of particulate Fe (Fig. II.28e) indicates a very narrow surface plume in the upper 10 meters of the water column. Below this depth, particulate Fe concentrations decrease steadily to the bottom except for station 9 where there is some evidence for resuspended sediments in the bottom 50-70 meters of the water column.

Manganese

Dissolved Mn plumes originating from the West Duwamish Waterway can be seen during both sampling periods (Fig. II.29a,b) while an additional plume from the East Duwamish Waterway is evident during the January 1986 period. The change in the y-intercept of the line used to calculate transport out of the West Duwamish Waterway vs. the line used to calculate transport out of Elliott Bay (Fig. II.29c,d) indicate that sources within the East Duwamish Waterway are causing a slight increase in the supply and transport of dissolved Mn out of Elliott Bay

Table II.6. Transport of Dissolved Trace Metals

Transport	April 1985	January 1986	
	From Elliott Bay	From W. Duwamish W.	From Elliott Bay
Water (m^3/sec)	96.0	30.2	30.2
Fe (g/sec)	0.67 ±0.09	0.51(80%)[2] ±0.04	0.63 ±0.06
Mn (g/sec)	3.8 ±0.1	1.7(77%) 0.1	2.2 ±0.1±0.2
Cu (g/sec)	0.077 ±0.008	0.036(32%) ±0.003	0.11 ±0.01
Zn (g/sec)	0.57 ±0.05	0.41(46%) ±0.04	0.89 ±0.09
Pb (g/sec)	0.0048 ±0.0003	–	–
Ni (g/sec)	0.065 ±0.005	0.036(63%) ±0.004	0.057 0.006
Cd (g/sec)	–	–	–

1) Error based on error of the y-intercept calculation from regression analysis.

2) Values in parentheses are the West Duwamish Waterway's contribution to the total flux out of Elliott Bay.

Table II.7 Flux of total suspended matter and particulate metals out of Elliott Bay (g/sec)

	April 1985	January 1986	
	From Elliott bay	From W. Duwamish W.	From Elliott Bay
Flow (m^3/sec)	96.0	30.0	30.0
Total Suspended Matter	960.0	200.0	310.0
Al	85.0 ± 5.0	17.0 (50%)[2] ± 1.0	34.0 ± 1.0
Fe	99.0 ± 5.0	24.0(82%) ± 1.0	29.0 ± 3.0
Mn	2.0 0.1	0.018 ± 0.001	
Cu	0.14 0.01	0.014(24%) ± 0.003	0.0581 ±0.051
Zn	0.19 ± 0.01	0.064(46%) 0.003	0.14 ±0.020
Pb	0.086 ± 0.009	0.044(29%) 0.004	0.021 0.003
Ni	0.053 ±0.003	0.010(29%) ± 0.001	0.035 0.005

Errors based on one s of the error in the y-intercept of the regression analysis.

1 Based upon the flux of particulate Fe and a Cu/Fe ratio of 0.0017 ± 0.0015.
2 Values in parentheses are the West Duwamish Waterway's contribution to the total flux out of Elliott Bay.

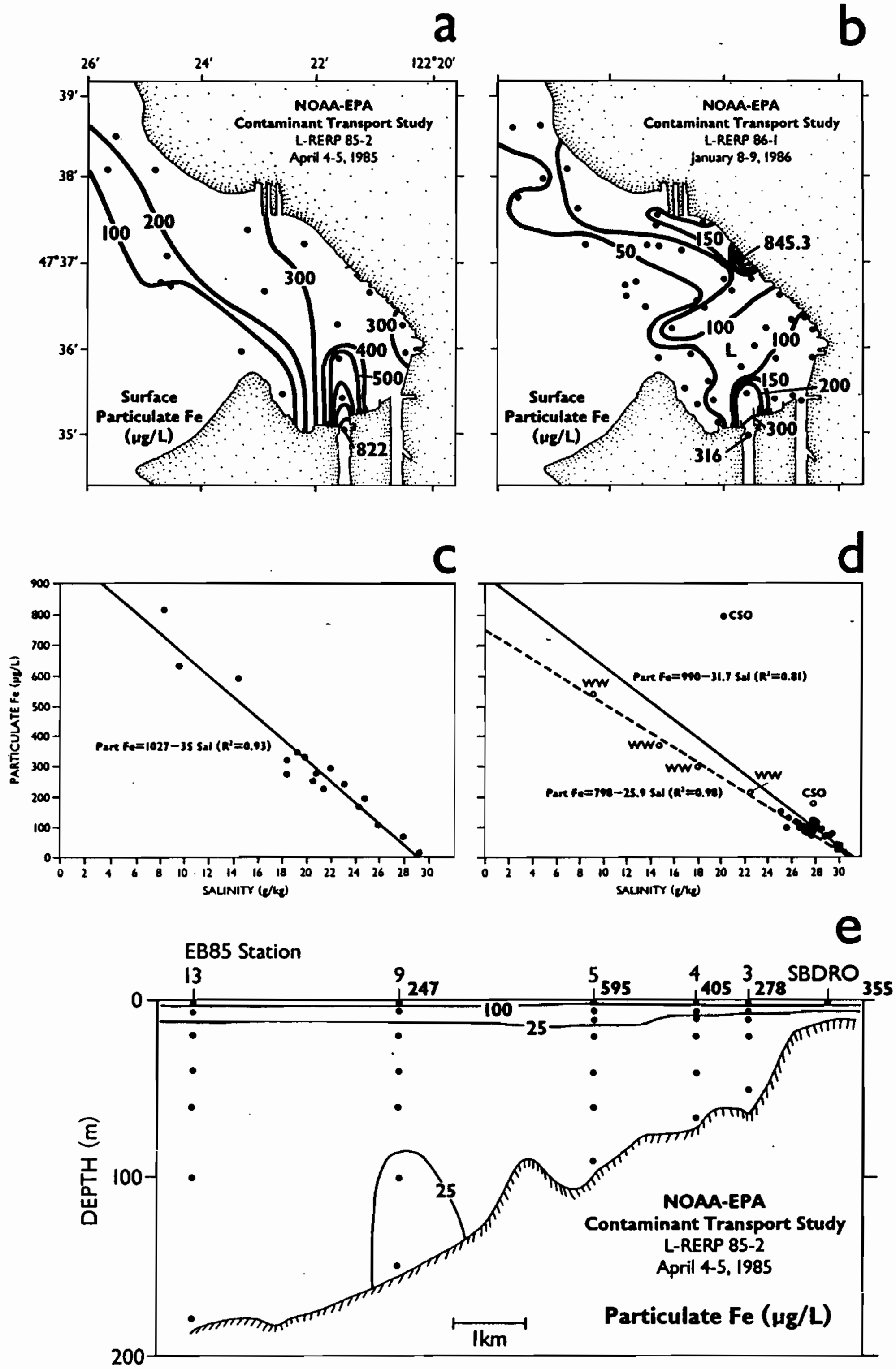


Figure II.28. Surface distribution of particulate Fe in Elliott Bay during April 1985 (a) and January 1986 (b). Particulate Fe vs. salinity plots for April 1985 (c) and January 1986 (d). Results of regression analysis of samples in Elliott Bay are presented as solid lines. Samples in the plumes of the West Duwamish Waterway (WW) and the Denny Way CSO (CSO) are noted as open circles and are not used in the regression analysis. For the January 1986 regression, only samples collected on the day that the CSO discharged were used in the regression analysis. A regression of the samples collected in the West Duwamish Waterway is presented as a dashed line (---). In the vertical transect in Elliott Bay during April 1985 (e), the bold values below and to the right of the station number are the concentrations from surface samples (<1 m) collected by small boat.

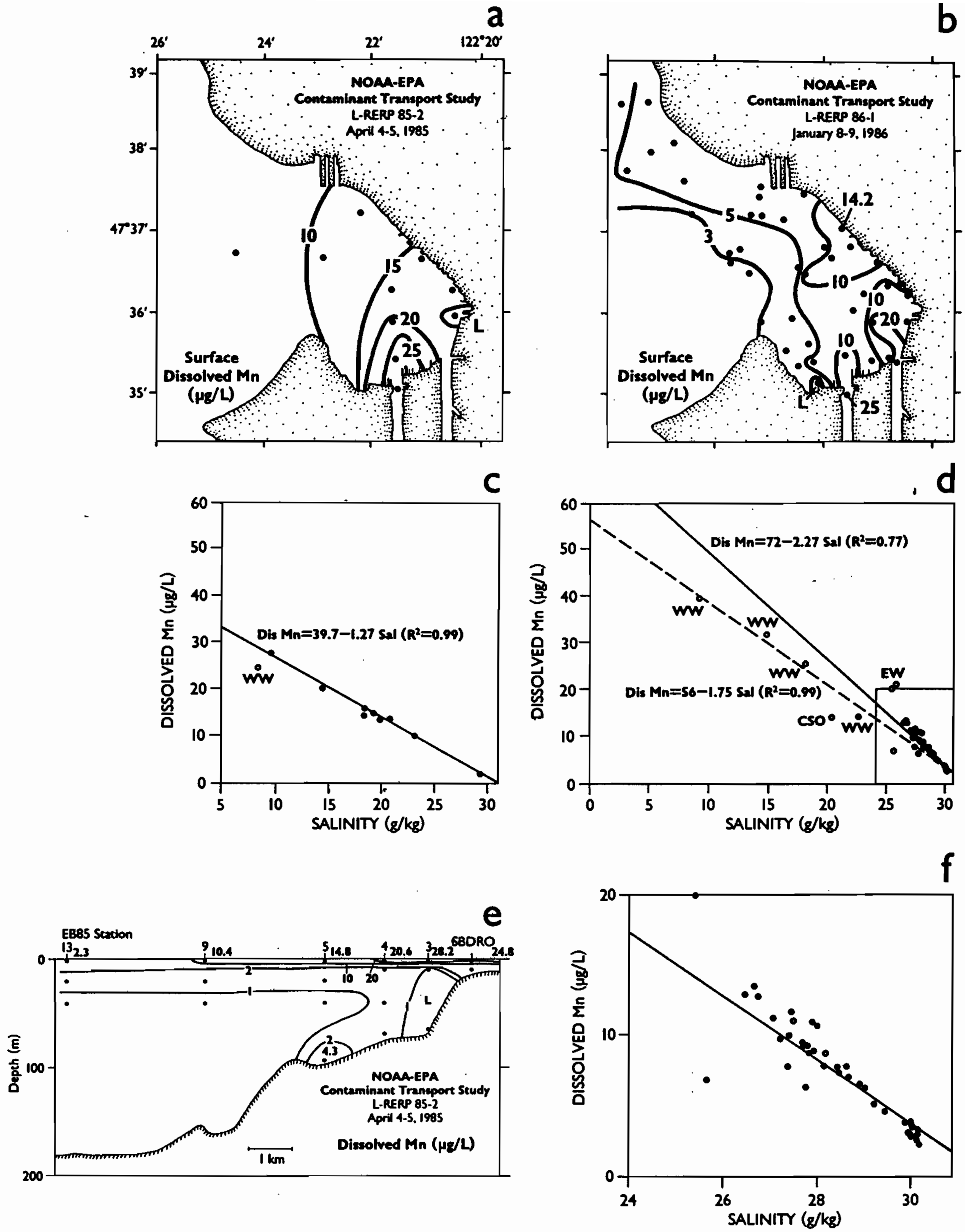


Figure II.29. Surface distribution of dissolved Mn in Elliott Bay during April 1985 (a) and January 1986 (b). Dissolved Mn vs. salinity plots for April 1985 (c) and January 1986 (d). Results of regression analysis of samples in Elliott Bay are presented as solid lines. Samples in the plumes of the West Duwamish Waterway (WW), the East Duwamish Waterway (EW) and the Denny Way CSO (CSO) are noted as open circles and are not used in the regression analysis. A regression of the samples collected in the West Duwamish Waterway is presented as a dashed line (---). In the vertical transect in Elliott Bay during April 1985 (e), the bold values below and to the right of the station number are the concentrations from surface samples (<1 m) collected by small boat. Figure f is an expansion of the lower right insert of d.

(Table II.6). The vertical transect indicates that dissolved Mn at mid-depth ranges between <1 and 2 μg/L (Fig. II.29c). The vertical transect indicates that dissolved Mn was added to the water column from sedimentary sources near station EB85-5, possibly as a result of reducing conditions in the sediments (see discussion on Iron).

Particulate Mn plumes from the Duwamish River are evident during both the April 1985 and January 1986 sampling periods (Figs. II.30a,b). The Denny Way CSO was also a significant source of particulate Mn in January. Manganese was roughly equally partitioned between dissolved and particulate phases in the water column. The vertical transect (Fig. II.30e) indicates evidence for a strong vertical gradient of particulate Mn in the water column with a minimum at about 30-40 meters. The enrichment of particulate Mn in the bottom 30-60 meters of the water column is probably due to the scavenging of manganese released from sediments (Feely *et al.*, 1983).

Copper

The areal distribution patterns reveal a small plume originating from the Seattle waterfront in April 1985 (Fig. II.31a) while the vertical transect (Fig. II.31e) shows a mid-plume surface layer enrichment in dissolved Cu. Larger and more significant plumes originating from the Harbor Island shipyards and Denny Way CSO were seen in January 1986 (Fig. II.31b). Concentrations of 5900 and 5000 ng/L were found in the Denny Way CSO and the Harbor Island shipyard plumes, respectively. The large increase in the y-intercept for the line used to calculate transport out of Elliott Bay in comparison to the y-intercept for the line used to calculate transport out of West Duwamish Waterway (Fig. II.31d) indicates that the Denny Way CSO and Harbor Island shipyards are tripling the transport of dissolved Cu out of Elliott Bay (Table II.6). The large areal extent of the Harbor Island shipyard plume suggests that this source is much more significant than the CSO. The 1985 vertical transect (Fig. II.31e) indicates that mid-depth dissolved Cu concentration ranged between 300 and 400 ng/L.

The particulate Cu distributions were very similar to the dissolved distributions, although the mean concentrations in the particulate phase (100 ng/L) were significantly lower than Cu concentrations in the dissolved fraction (Figs. II.32a-b). In January, the Harbor Island shipyards and Denny Way CSO were also major sources for particulate Cu to the surface waters of Elliott Bay. The calculated transport of particulate Cu from the West Duwamish Waterway in January was 10 times less than the calculated transport from Elliott Bay in April (Table II.7). The vertical transect reveals that the surface plume is the major source of particulate Cu in the bay (Fig. II.32e). There is a slight enrichment of particulate Cu in the near-bottom waters of the outer bay, due either to advection of main basin suspended material or to local resuspension of bottom sediments. Enrichment of Cu and other trace metals directly north of Harbor Island is probably related to surface runoff during heavy rainfall.

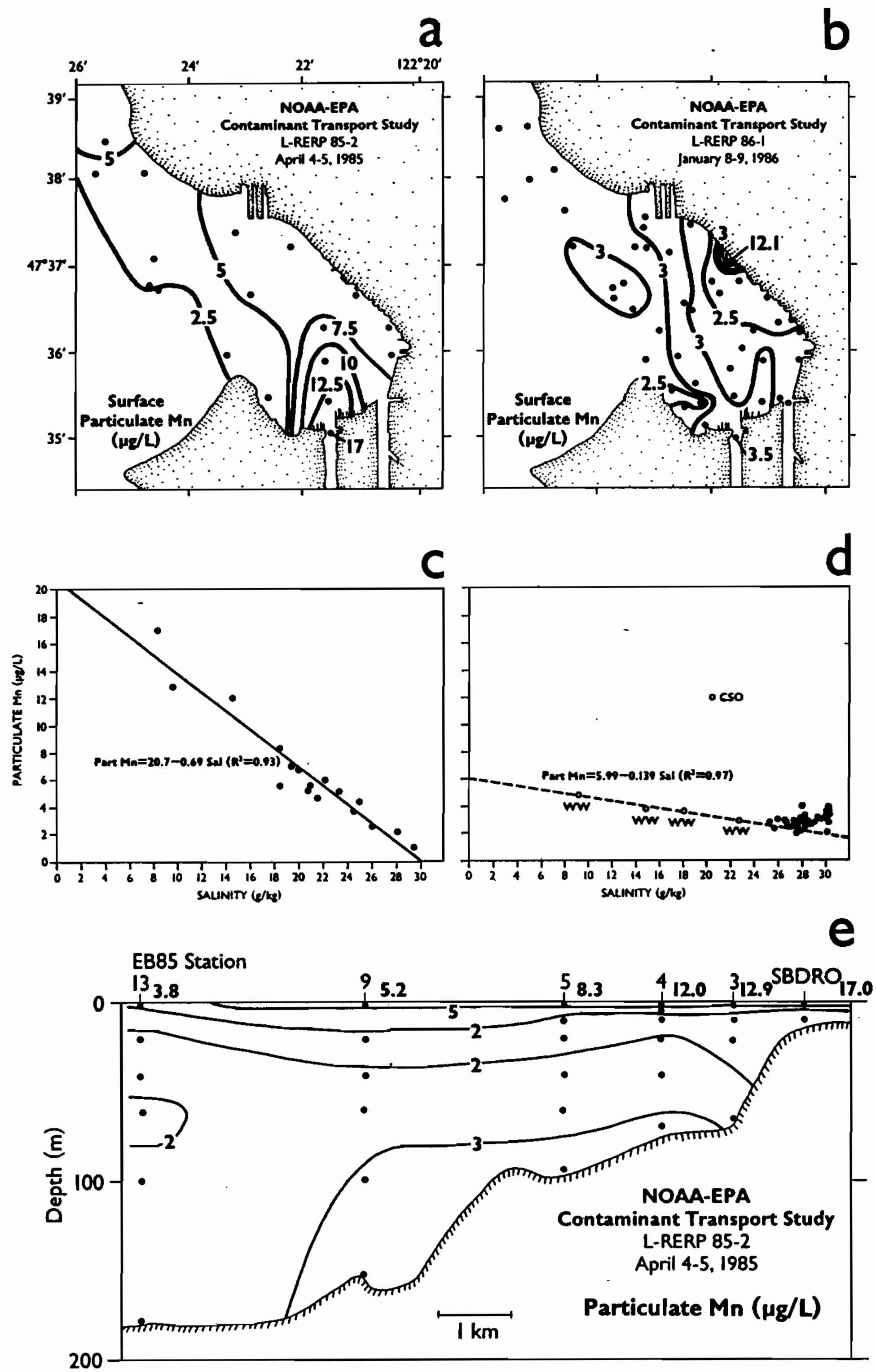


Figure II.30. Surface distribution of particulate Mn in Elliott Bay during April 1985 (a) and January 1986 (b). Particulate Mn vs. salinity plots for April 1985 (c) and January 1986 (d). The results of the regression analysis of samples collected in Elliott Bay during April 1986 is presented as solid line. Samples in the plumes of the West Duwamish Waterway (WW) and the Denny Way CSO (CSO) are noted as open circles. A line with an adequate regression coefficient could not be fitted to the Elliott Bay data for January, 1986 samples. A regression of the samples collected in the West Duwamish Waterway is presented as a dashed line (---). In the vertical transect in Elliott Bay during April 1985 (e), the bold values below and to the right of the station number are the concentrations from surface samples (<1 m) collected by small boat.

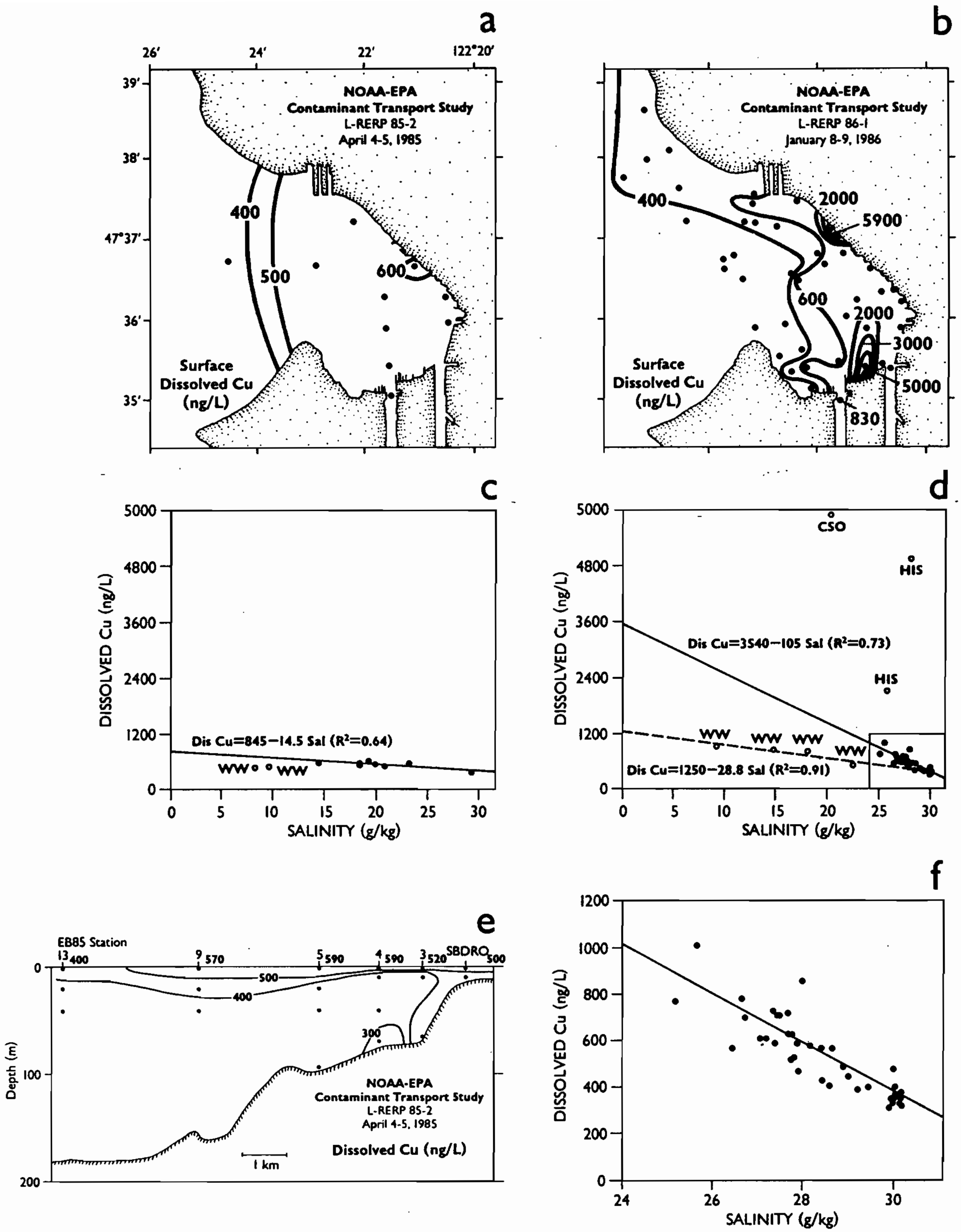


Figure II.31. Surface distribution of dissolved Cu in Elliott Bay during April 1985 (a) and January 1986 (b). Dissolved Cu vs. salinity plots for April 1985 (c) and January 1986 (d). Results of regression analysis of samples in Elliott Bay are presented as solid lines. Samples in the plumes of the West Duwamish Waterway (WW), the Harbor Island shipyards (HIS) and the Denny Way CSO (CSO) are noted as open circles and are not used in the regression analysis. A regression of the samples collected in the West Duwamish Waterway is presented as a dashed line (---). In the vertical transect in Elliott Bay during April 1985 (e), the bold values below and to the right of the station number are the concentrations from surface samples (<1 m) collected by small boat. Figure f is an expansion of the lower right insert of d.

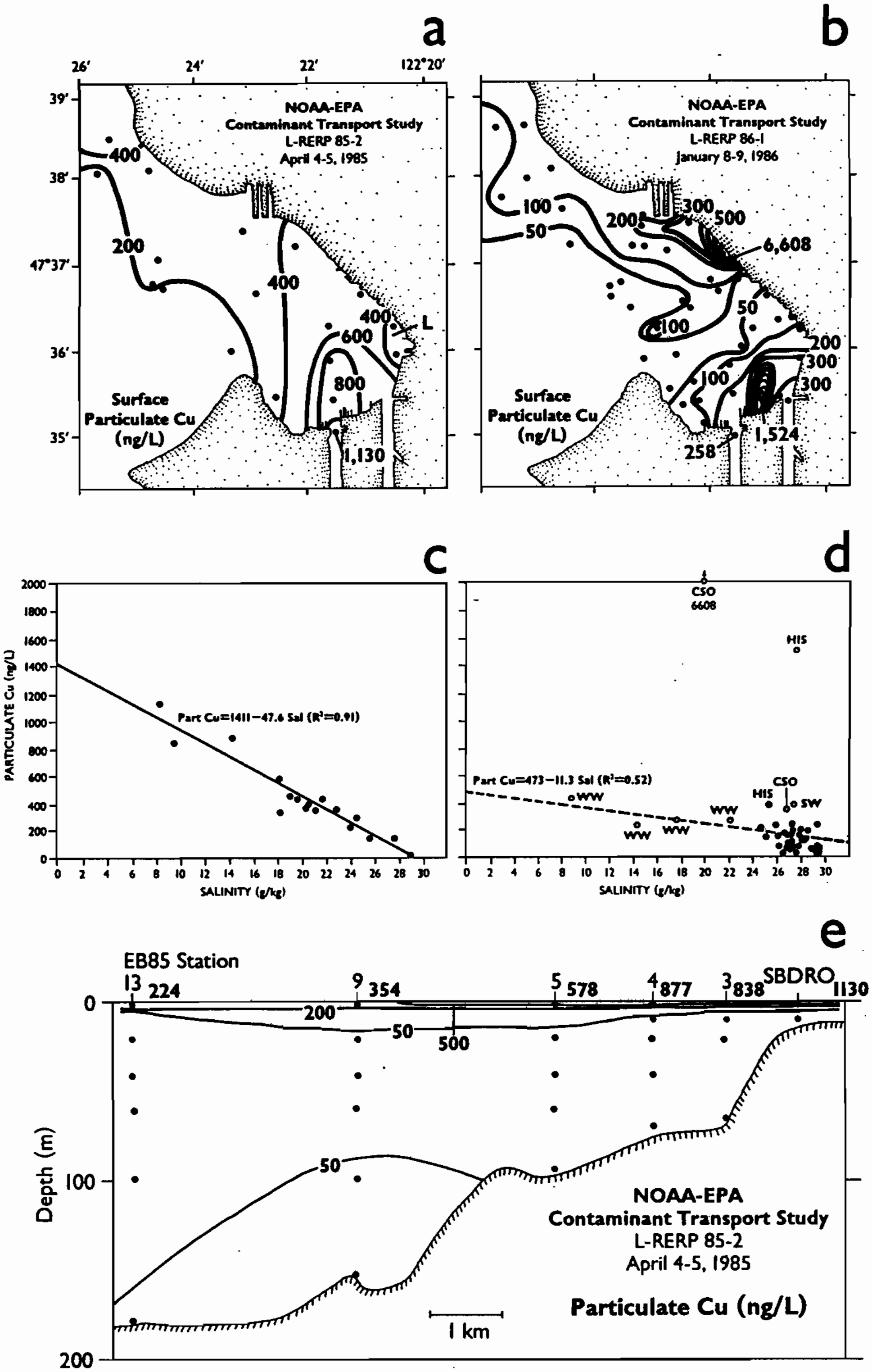


Figure II.32. Surface distribution of particulate Cu in Elliott Bay during April 1985 (a) and January 1986 (b). Particulate Cu vs. salinity plots for April 1985 (c) and January 1986 (d). The results of the regression analysis of samples collected in Elliott Bay during April 1986 is presented as solid line. Samples in the plumes of the West Duwamish Waterway (WW), the Denny Way CSO (CSO), the Harbor Island shipyards (HIS) and the Seattle waterfront are noted as open circles. A line with an adequate regression coefficient could not be fitted to the Elliott Bay data for January 1986 samples. A regression of the samples collected in the West Duwamish Waterway is presented as a dashed line (---). In the vertical transect in Elliott Bay during April 1985 (e), the bold values below and to the right of the station number are the concentrations from surface samples (<1 m) collected by small boat.

Zinc

Like Cu, Zn is a relatively soluble metal and can be expected to appear as a result of surface runoff as well as from point sources with high particulate loadings. The surface distributions of dissolved Zn were similar to those of dissolved Cu for both sampling periods. A plume from the Seattle waterfront is evident in April 1985, as well as high in concentration at the same station off the head of the West Duwamish Waterway (Fig. II.33a). In January 1986, larger and more significant plumes can be seen off the Denny Way CSO and the Harbor Island shipyards (Fig. II.33b) with dissolved concentrations of 33,000 and 20,500 ng/L, respectively. The change in the y-intercept of the line used to calculate transport out of Elliott Bay relative to the y-intercept for the line used to calculate transport out of the West Duwamish Waterway (Fig. II.33d) suggests that the Harbor Island shipyards and the Denny Way CSO have increased the transport of dissolved Zn from Elliott Bay by a factor of 2.5 (Table II.6). The vertical transect indicates that dissolved Zn concentrations between 500 and 1000 ng/L were found at mid-depth in Elliott Bay.

Although lower in absolute concentration, the trends of particulate Zn concentrations are very similar to those of dissolved Zn distributions (Figs. II.34a-b). In April 1985, the highest concentration was observed in the West Duwamish Waterway. In January 1986, larger plumes of particulate Zn were observed off the Denny Way CSO and the Harbor Island shipyards where concentrations as high as 14,500 ng/L were observed. The particulate Zn versus salinity plots (Figs. II.34c-d) reflect these sources in the solid line. The mass transport calculations suggest that the CSO and Harbor Island are doubling the transport of particulate Zn out of Elliott Bay relative to the transport out of the West Duwamish Waterway (Table II.7). The vertical transect (Fig. II.34e) indicates very high enrichments in the surface plume followed by rapid decreases in particulate Zn concentrations in subsurface waters. There is also evidence for a weak maximum at about 40 m in the inner bay which is probably the result of Zn scavenging onto newly-formed Mn oxyhydroxide coatings on the particles (Feely *et al.*, 1983).

Lead

In both sampling periods, the dissolved Pb concentration at the head of the West Duwamish Waterway was between 40 and 50 ng/L (Figs. II.35a-b). The Pb-salinity plots for April 1985 (Fig. II.35c) show a constant decrease in the dissolved Pb concentration with salinity suggesting that there were no other significant inputs with the possible exception of a small plume near the Denny Way CSO even though it had not been discharging for over a week, i.e., there was diffusion of Pb from the most concentrated sources. In January 1986, a more significant plume having a dissolved Pb concentration of 2570 mg/L can be seen originating from the Denny Way CSO (Fig. II.35b). Smaller plumes can be seen off the Seattle waterfront near the King Street CSO, and off the Harbor Island shipyards. A regression line having a r^2 of greater

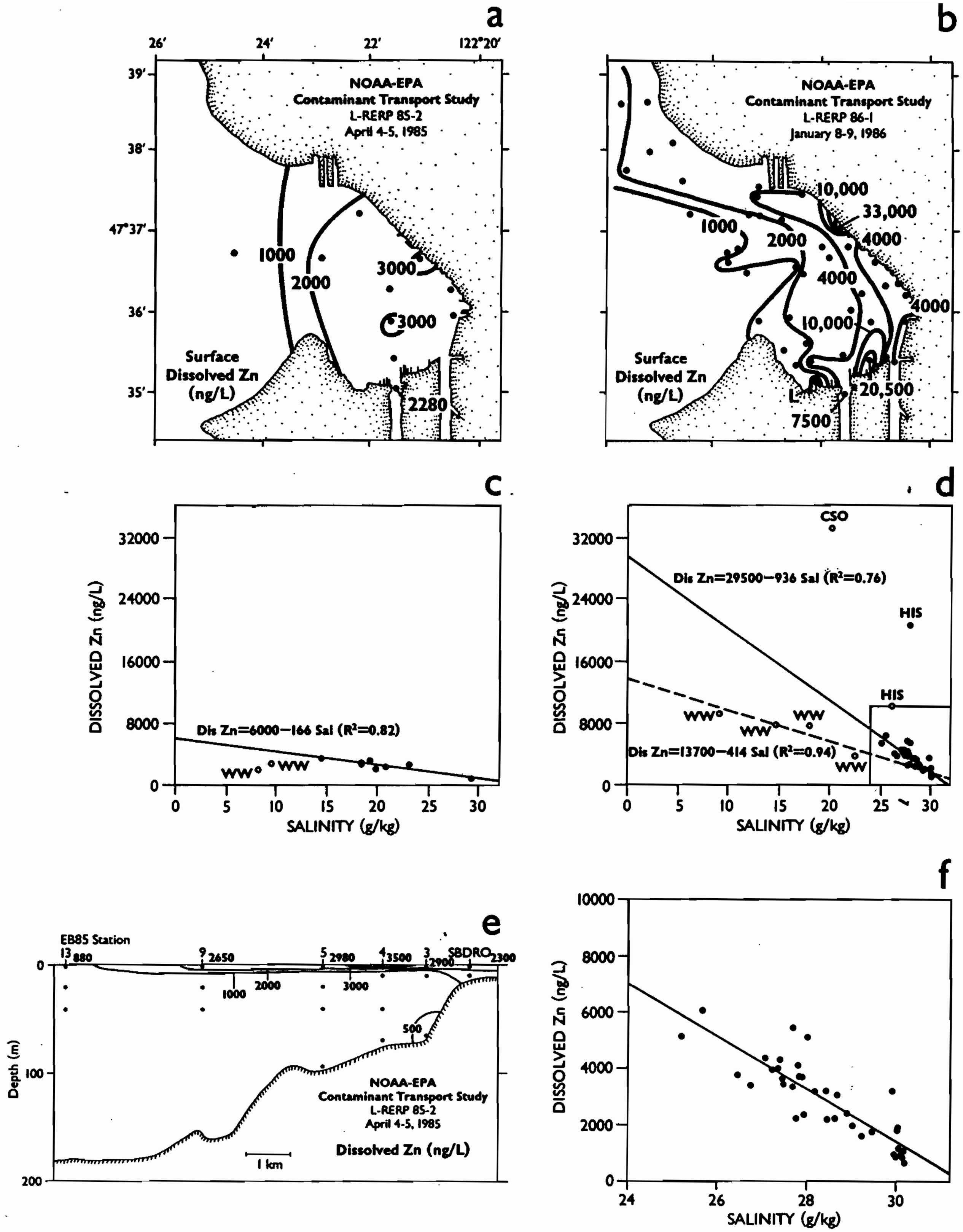


Figure II.33. Surface distribution of dissolved Zn in Elliott Bay during April 1985 (a) and January 1986 (b). Dissolved Zn vs. salinity plots for April 1985 (c) and January 1986 (d). Results of the regression analyses of samples in Elliott Bay are presented as solid lines. Samples in the plumes of the West Duwamish Waterway (WW), the Harbor Island shipyards (HIS) and the Denny Way CSO (CSO) are noted as open circles and are not used in the regression analysis. A regression of the samples collected in the West Duwamish Waterway is presented as a dashed line (---). In the vertical transect in Elliott Bay during April 1985 (e), the bold values below and to the right of the station number are the concentrations from surface samples (<1 m) collected by small boat. Figure f is an expansion of the lower right insert of d.

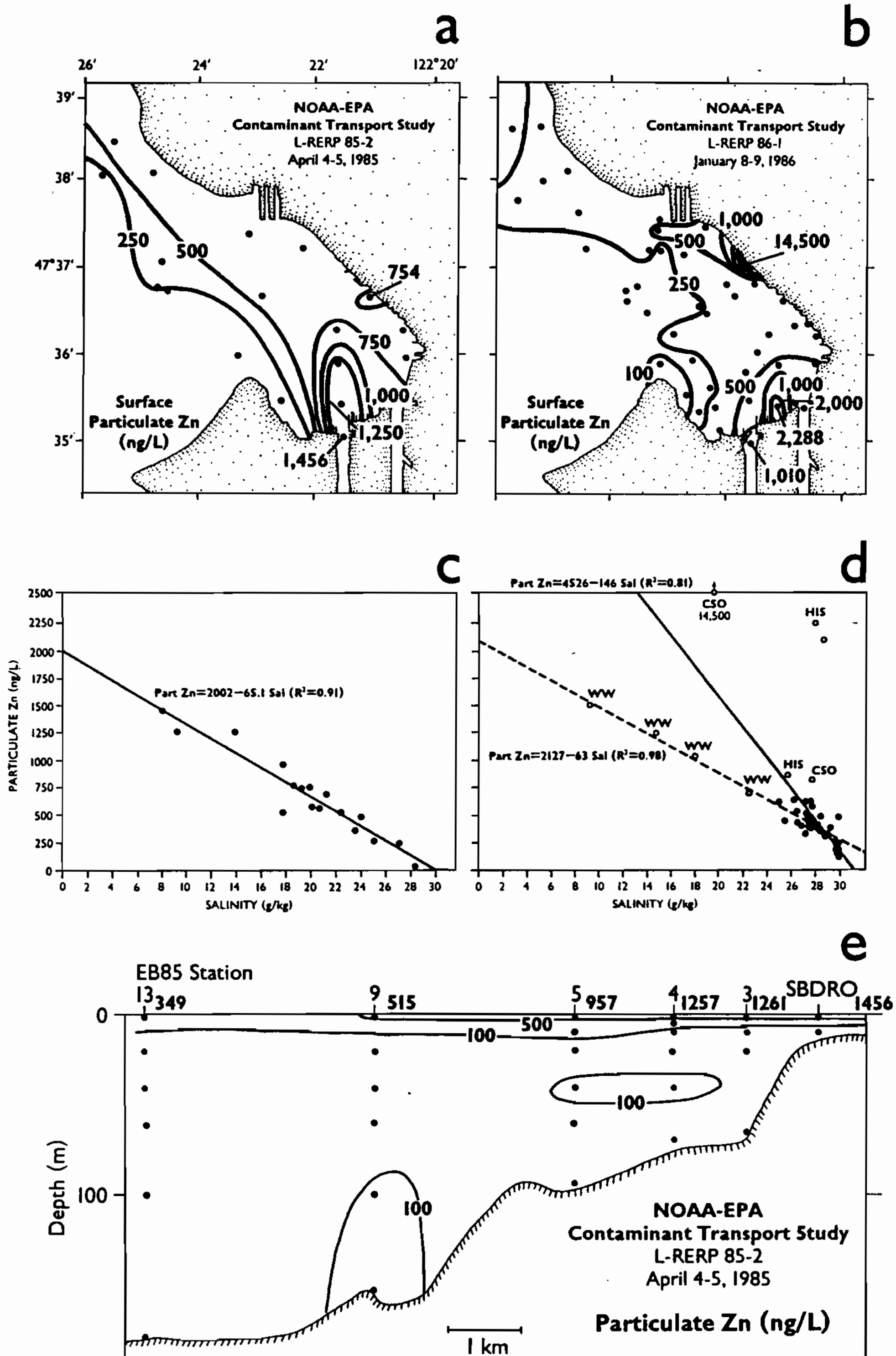


Figure II.34. Surface distribution of particulate Zn in Elliott Bay during April 1985 (a) and January 1986 (b). Particulate Zn vs. salinity plots for April 1985 (c) and January 1986 (d). Results of the regression analyses of samples in Elliott Bay are presented as solid lines. Samples in the plumes of the West Duwamish Waterway (WW), Denny Way CSO (CSO) and the Harbor Island shipyards (HIS) are noted as open circles and are not used in the regression analysis. For the January 1986 regression, only samples collected on the day that the CSO discharged were used in the regression analysis. A regression of the samples collected in the West Duwamish Waterway is presented as a dashed line (---). In the vertical transect in Elliott Bay during April 1985 (e), the bold values below and to the right of the station number are the concentrations from surface samples (<1 m) collected by small boat.

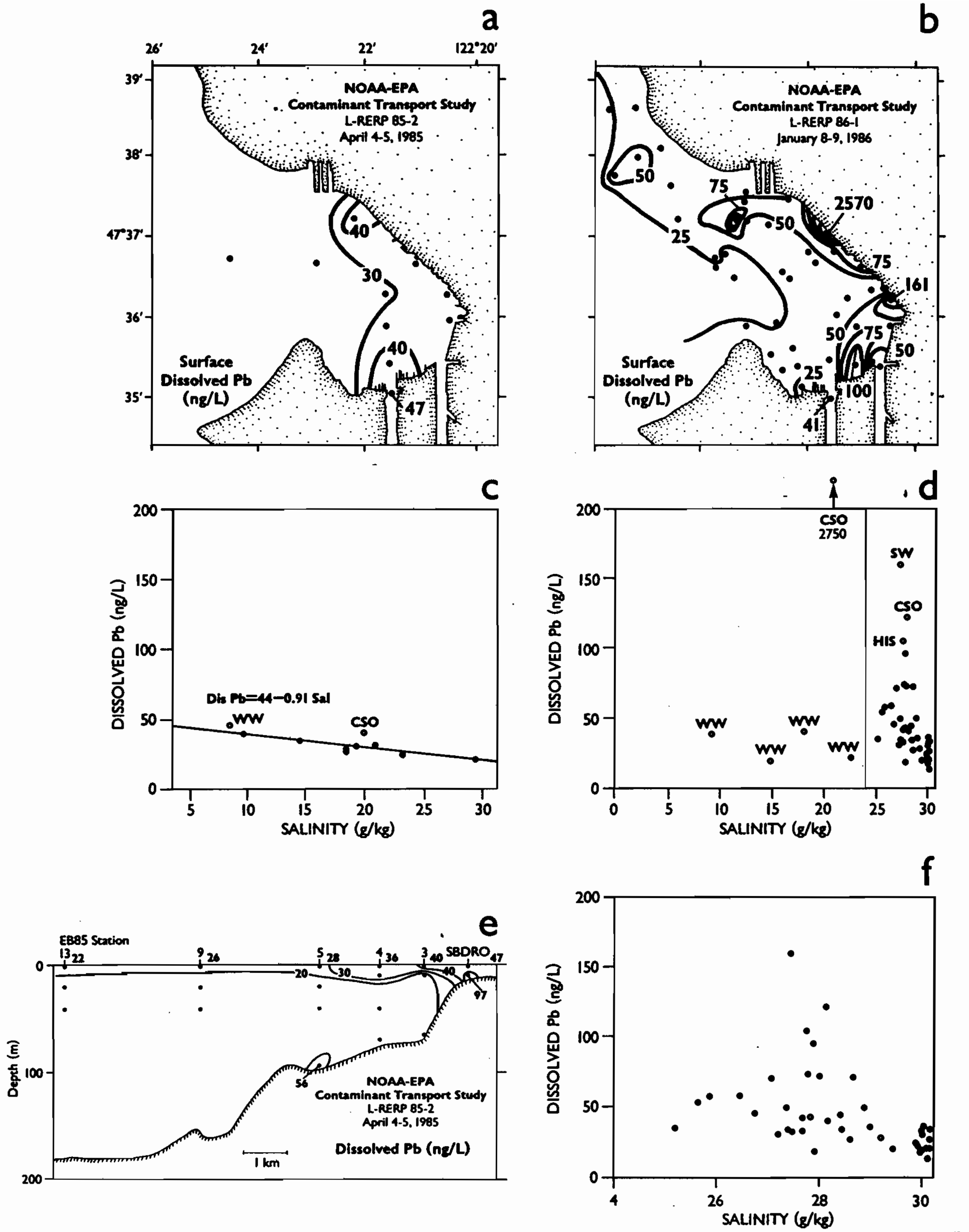


Figure II.35. Surface distribution of dissolved Pb in Elliott Bay during April 1985 (a) and January 1986 (b). Dissolved Pb vs. salinity plots for April 1985 (c) and January 1986 (d). Samples in the plumes of the West Duwamish Waterway (WW), the Harbor Island shipyards (HIS), the Seattle waterfront (SW) and the Denny Way CSO (CSO) are noted as open circles. Lines with regression coefficients >0.5 could not be fitted to the data for January, 1986 for samples collected from either the West Duwamish Waterway or Elliott Bay. In the vertical transect in Elliott Bay during April 1985 (e), the bold values below and to the right of the station number are the concentrations from surface samples (<1 m) collected by small boat. Figure f is an expansion of the right insert of d.

than 0.5 could not be drawn through either the Elliott Bay or West Duwamish Waterway data (Fig. II.35d), indicating a multiplicity of sources, including possibly, atmospheric deposition. The transect indicates that mid-depth water in Elliott Bay had dissolved Pb concentrations less than 20 ng/L (Fig. II.35e). The bottom samples at stations EB85-5 and EB85-SBDR0 show enrichments in dissolved Pb. The enrichment at EB85-SBDR0 may be due to diffusion of dissolved Pb out of the highly contaminated sediments of the West Duwamish Waterway.

Particulate Pb concentrations in Elliott Bay are generally 4-11 times the dissolved Pb concentrations (Figs. II.36a-b). Major sources for particulate Pb include the Duwamish River, Harbor Island, the Seattle waterfront and the Denny Way CSO. In January particulate Pb concentrations near the Denny Way CSO exceeded 10,000 ng/L. The plume from the outfall was observed to flow along the northern shore past Pier 91. Beyond Pier 91, particulate Pb concentrations in the surface waters exceeded or equaled 250 ng/L westward around Magnolia Bluff. These results provide clear evidence for particulate Pb transport into the main basin of Puget Sound from Elliott Bay. The mass transport of particulate Pb out of Elliott Bay is more than three times the transport out of the West Duwamish Waterway, indicating the significance of other sources (Table II.7). The transect (Fig. II.36e) indicates that most of the particulate Pb transport out of the bay is associated with the surface plume. Beneath the surface, particulate Pb concentrations decrease to values below 50 ng/L. There is a zone of higher particulate Pb concentrations in near-bottom waters of the outer bay which is due either to locally resuspended sediments or advection from the main basin. Both dissolved and particulate Pb appear to be excellent tracers of surface water movement.

Nickel

The surface distribution of dissolved Ni for April 1985 reveals only a decreasing gradient from east to west the plume (Fig. II.37a). The Ni vs. salinity plot (Fig. II.37c) shows a slight increase in dissolved Ni with distance away from the head of the West Duwamish waterway indicating the presence of another source of dissolved Ni. In January 1986, plumes can be seen which originate from the Denny Way CSO and from a combination of sources; from the East and West Duwamish Waterways and Harbor Island shipyards (Fig. II.37b). Sources other than those from the West Duwamish Waterway increase the transport of dissolved Ni out of Elliott Bay by 60% (Table II.6). Dissolved Ni concentrations less than 400 ng/L were found at mid-depth in Elliott Bay.

Particulate Ni concentrations were generally about 20-60% of the dissolved concentrations (Fig. II.38a-b). High values were observed at the mouth of the Duwamish River in April and January and seaward of the Denny Way CSO in January. The highest concentrations (>1000 ng/L) were observed in the immediate vicinity of the outfall in January. The concentration gradients of particulate Ni indicate flow to the northwest along the northern shore. The

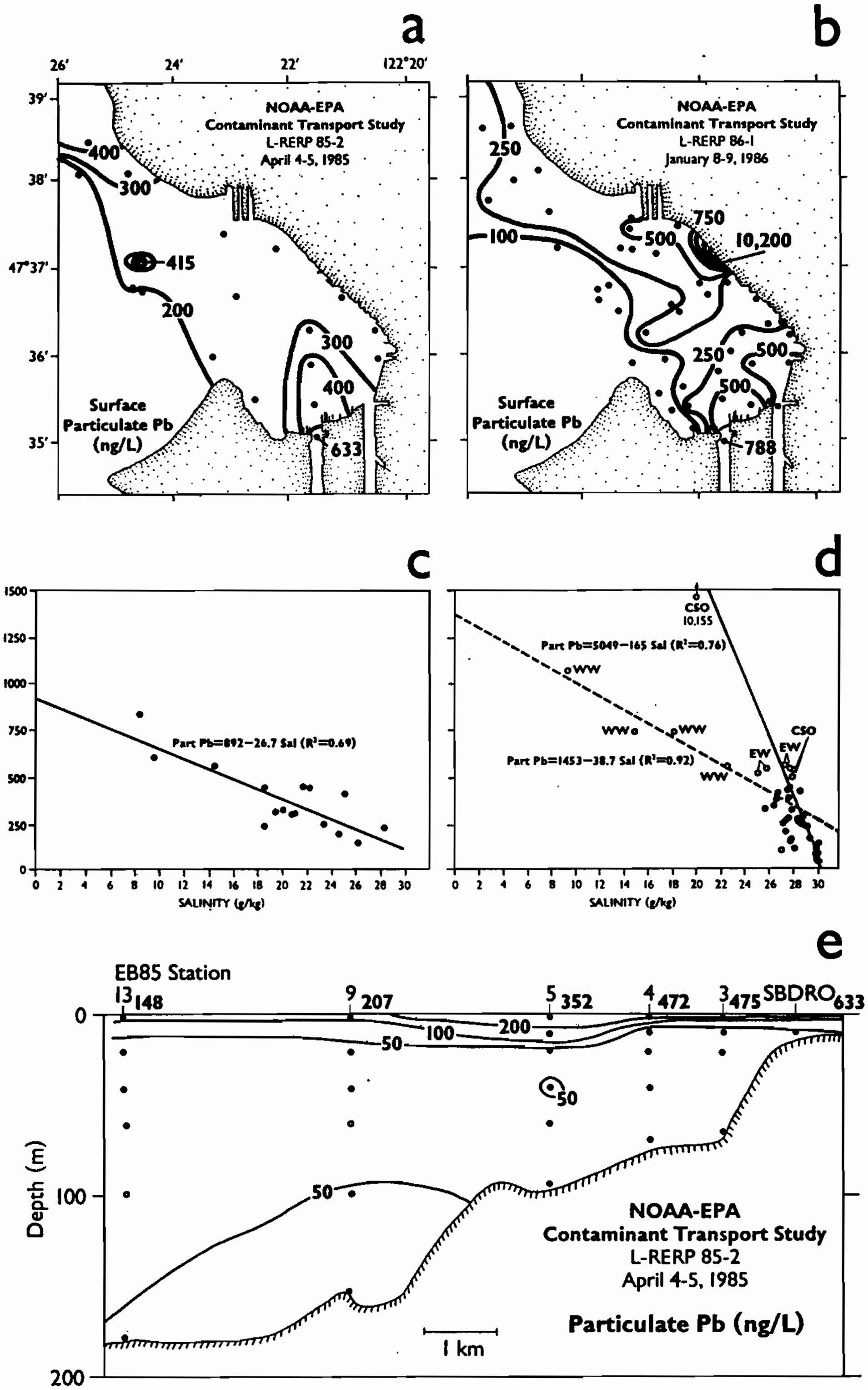


Figure II.36. Surface distribution of particulate Pb in Elliott Bay during April 1985 (a) and January 1986 (b). Particulate Pb vs. salinity plots for April 1985 (c) and January 1986 (d). Results of regression analysis of samples in Elliott Bay are presented as solid lines. Samples in the plumes of the West Duwamish Waterway (WW), the East Duwamish Waterway (EW) and the Denny Way CSO (CSO) are noted as open circles and are not used in the regression analysis. For the January 1986 regression, only samples collected on the day that the CSO discharged were used in the regression analysis. A regression of the samples collected in the West Duwamish Waterway is presented as a dashed line (---). In the vertical transect in Elliott Bay during April 1985 (e), the bold values below and to the right of the station number are the concentrations from surface samples (<1 m) collected by small boat.

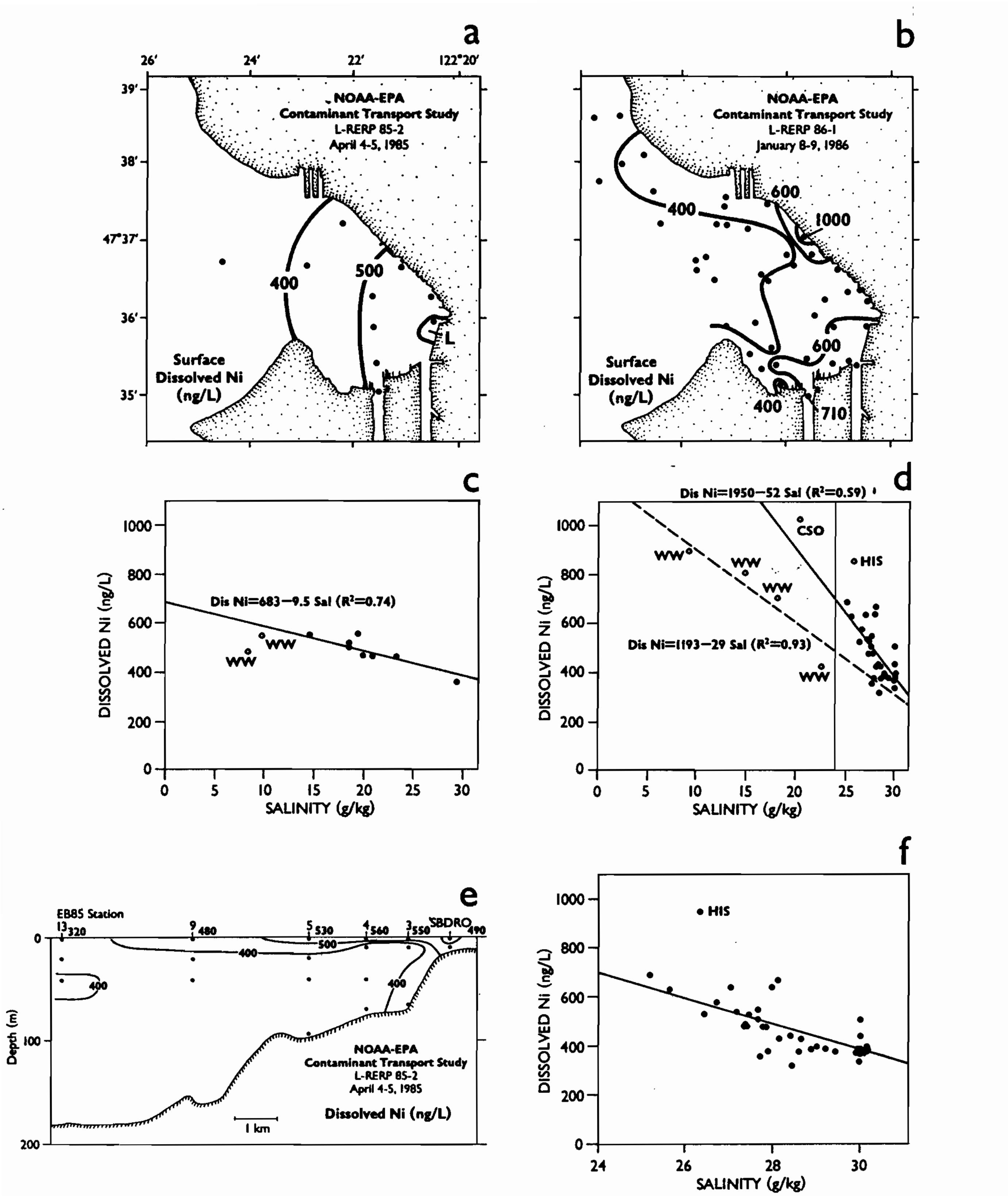


Figure II.37. Surface distribution of dissolved Ni in Elliott Bay during April 1985 (a) and January 1986 (b). Dissolved Ni vs. salinity plots for April 1985 (c) and January 1986 (d). Results of regression analysis of samples in Elliott Bay are presented as solid lines. Samples in the plumes of the West Duwamish Waterway (WW), the Harbor Island shipyards (HIS) and the Denny Way CSO (CSO) are noted as open circles and are not used in the regression analysis. A regression of the samples collected in the West Duwamish Waterway is presented as a dashed line (---). In the vertical transect in Elliott Bay during April 1985 (e), the bold values below and to the right of the station number are the concentrations from surface samples (<1 m) collected by small boat. Figure f is an expansion of the lower right insert of d.

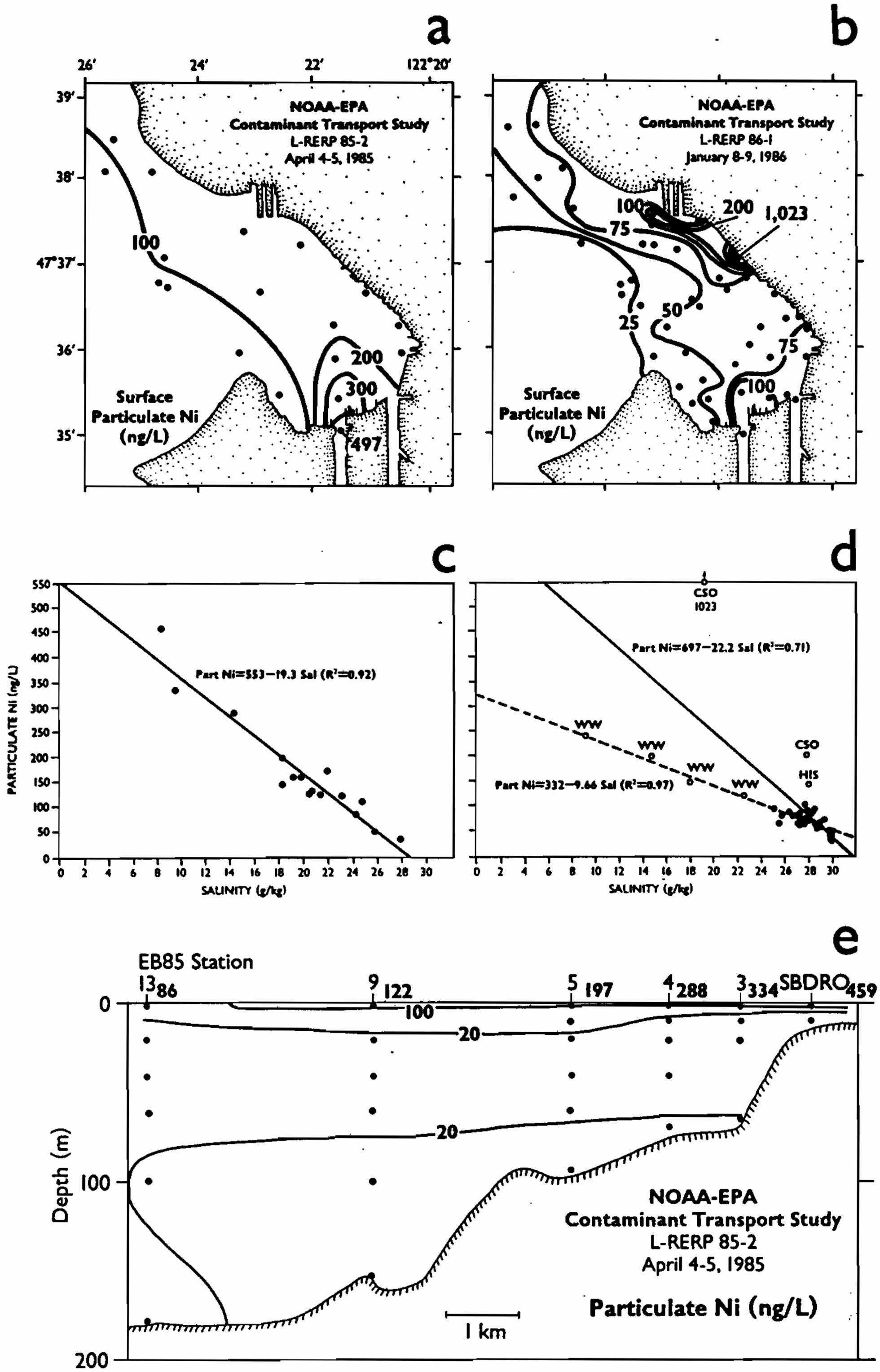


Figure II.38. Surface distribution of particulate Ni in Elliott Bay during April 1985 (a) and January 1986 (b). Particulate Ni vs. salinity plots for April 1985 (c) and January 1986 (d). Results of the regression analyses of samples in Elliott Bay are presented as solid lines. Samples in the plumes of the West Duwamish Waterway (WW), the Harbor Island shipyards (HIS) and the Denny Way CSO (CSO) are noted as open circles and are not used in the regression analysis. For the January 1986 regression, only samples collected on the day that the CSO discharged were used in the regression analysis. A regression of the samples collected in the West Duwamish Waterway is presented as a dashed line (---). In the vertical transect in Elliott Bay during April 1985 (e), the bold values below and to the right of the station number are the concentrations from surface samples (<1 m) collected by small boat.

particulate Ni transport out of Elliott Bay is twice the transport from the West Duwamish Waterway (Table II.7). In subsurface waters particulate Ni concentrations reach a minimum (<20 ng/L) between 20 m and 60 m and increase slightly near the bottom (Fig. II.38e).

Chromium

Particulate Cr concentrations in Elliott Bay ranged from 20 to 1444 ng/L (Fig. II.39). High concentrations were observed at the mouth of the Duwamish River in April and January and seaward of the Denny Way CSO in January. The highest concentrations (> 1440 ng/L) were observed in the immediate vicinity of the CSO outfall in January. The concentration gradients of particulate Cr suggest that most of the particulate Cr is transported to the northwest along the northern shore. In subsurface waters particulate Cr concentrations reach a minimum between 20 m and 60 m and increase slightly near the bottom (Fig. II.36a).

Cadmium

Unlike the other metals shown thus far, dissolved Cd concentrations in the West Duwamish Waterway were lower than those in Elliott Bay (Figs. II.40a-b). The ocean constitutes a much larger mass source of Cd than do human inputs. Although the Cd vs. salinity plot for April 1985 shows a increase in dissolved Cd with salinity, a regression line having a r^2 greater than 0.5 could not be drawn (Fig. II.40c). Plumes originating from the Denny Way CSO and the Harbor Island shipyards can be seen in the surface distribution for January 1986 (Fig. II.40b). Dissolved Cd concentrations greater than 75 ng/L were found at mid-depth in Elliott Bay (Since 90% or more of Cd is in the dissolved form we chose to measure only that form).

Temporal Changes in the Concentrations of Cu, Zn and Pb in the Upper Layer of Elliott Bay.

Samples collected from Elliott Bay during 1980 and 1981 showed high concentrations of dissolved Cu, Zn and Pb relative to other areas in Puget Sound (Paulson and Feely 1985). Since 1981, local, state and federal agencies have initiated pollution abatement programs in the Duwamish Waterway and Harbor Island area. In order to evaluate the effects that these programs might have had on the water quality of Elliott Bay, a comparison was made between the data collected in 1985 and 1986 and data collected in 1980 and 1981 (Figs. II.41-II.42). Concentrations of dissolved Cu in 1985 and 1986 were slightly lower than samples collected in 1980 and much lower than those collected in 1981. In contrast, little change in dissolved Zn can be seen between samples collected in 1981 and 1985. The most dramatic decrease can be seen in the dissolved Pb data. The concentrations of samples collected off the head of the West Duwamish Waterway in 1985 and 1986 are lower by an order of magnitude or more relative to samples collected in 1981.

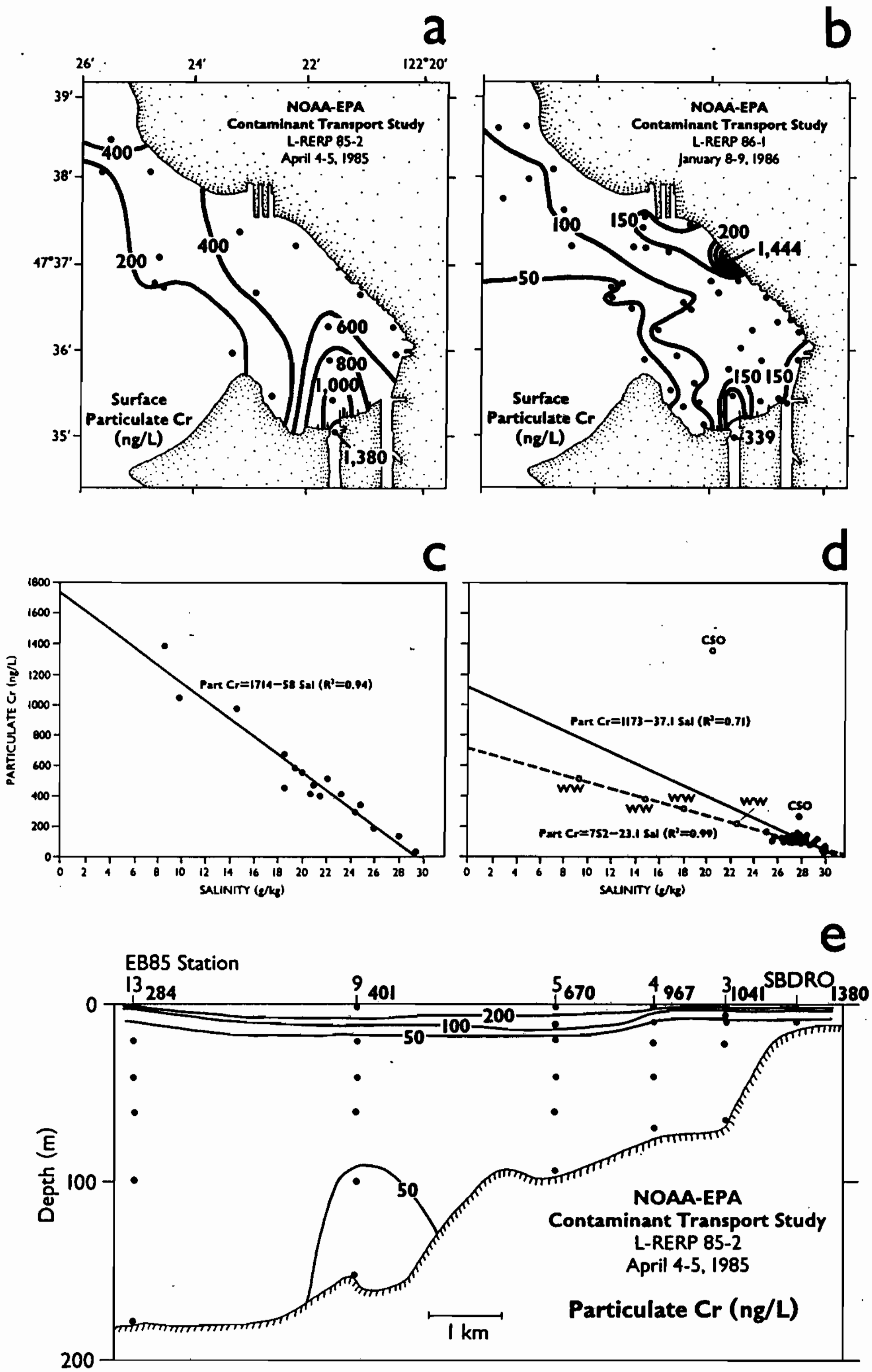


Figure II.39. Surface distribution of particulate Cr in Elliott Bay during April 1985 (a) and January 1986 (b). Particulate Cr vs. salinity plots for April 1985 (c) and January 1986 (d). Results of the regression analyses of samples in Elliott Bay are presented as solid lines. Samples in the plumes of the West Duwamish Waterway (WW), the Harbor Island shipyards (HIS) and the Denny Way CSO (CSO) are noted as open circles and are not used in the regression analysis. For the January 1986 regression, only samples collected on the day that the CSO discharged were used in the regression analysis. A regression of the samples collected in the West Duwamish Waterway is presented as a dashed line (---). In the vertical transect in Elliott Bay during April 1985 (e), the bold values below and to the right of the station number are the concentrations from surface samples (<1 m) collected by small boat.

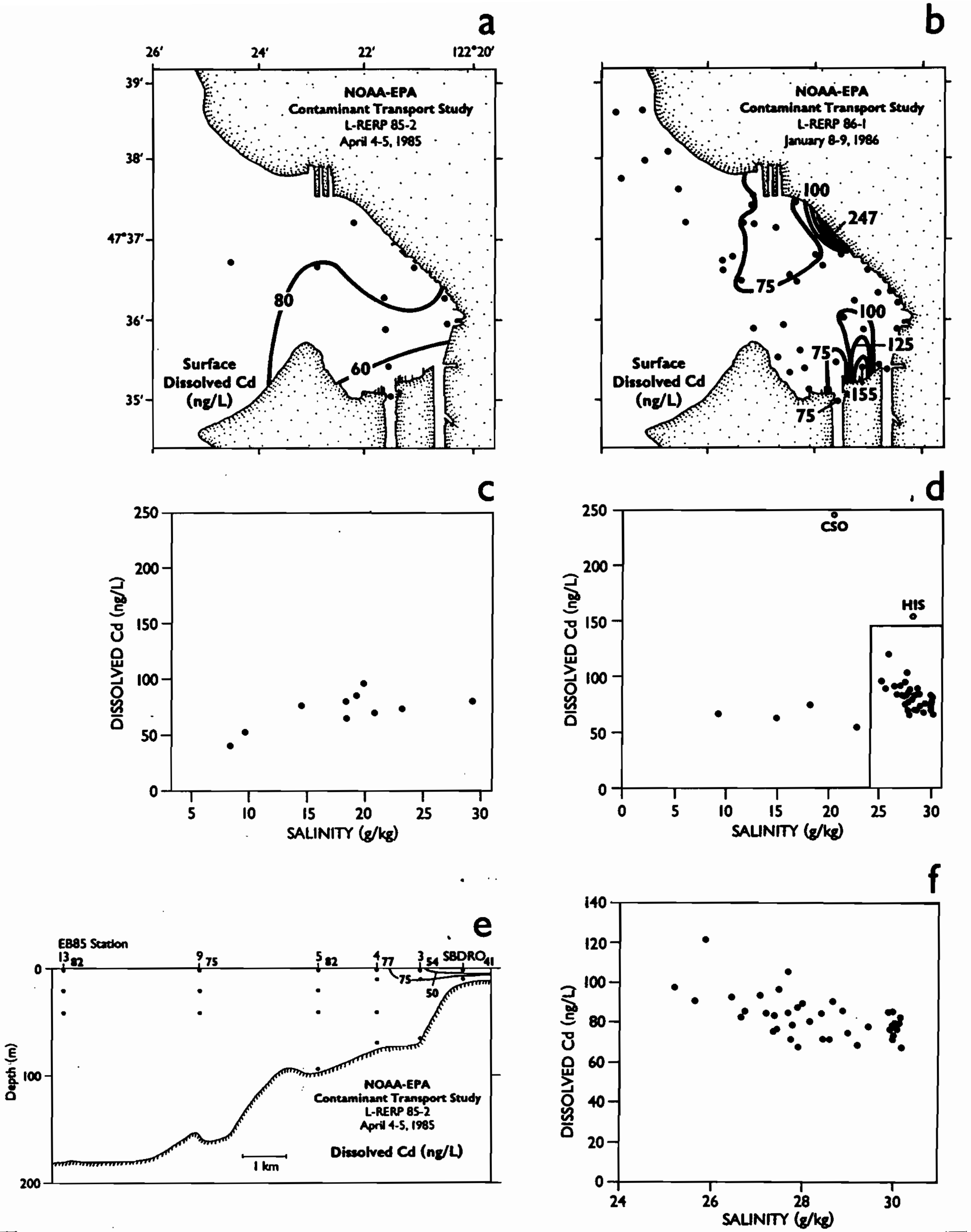


Figure II.40. Surface distribution of dissolved Cd in Elliott Bay during April 1985 (a) and January 1986 (b). Dissolved Cd vs. salinity plots for April 1985 (c) and January 1986 (d). Samples in the plumes of the Denny Way CSO (CSO) and the Harbor Island shipyards (HIS) are noted as open circles. Lines with adequate regression coefficients could not be fitted to any data set. In the vertical transect in Elliott Bay during April 1985 (e), the bold values below and to the right of the station number are the concentrations from surface samples (<1 m) collected by small boat. Figure f is an expansion of the lower right insert of d.

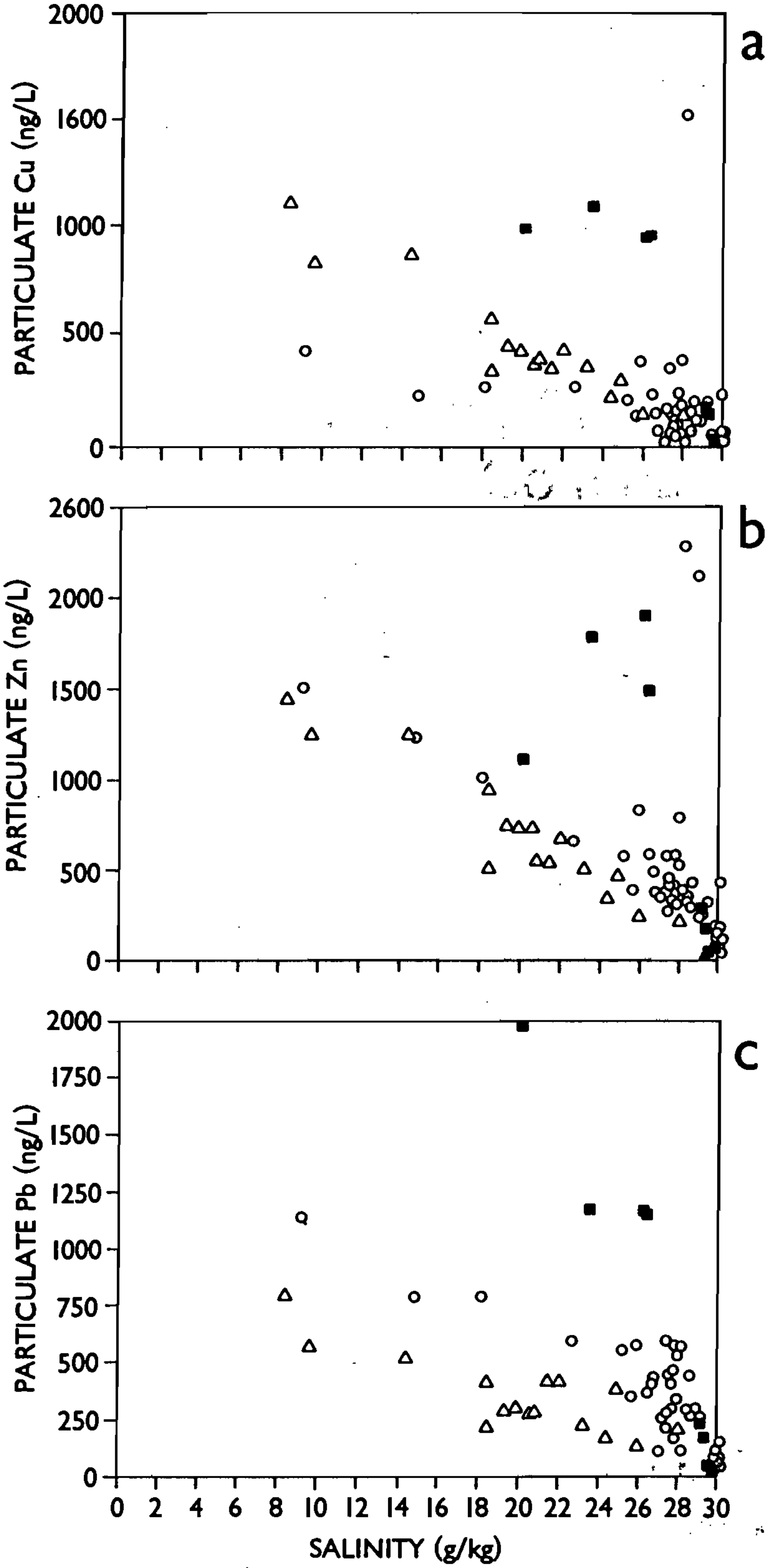


Figure II.41. Regressions of salinity and dissolved trace metals in the upper layer of Elliott Bay. Dissolved Cu (a and d), Zn (b and e) and Pb (c and f) during 1980 (▲), 1981 (■), 1985 (△) and 1986 (O). Figs. d, e and f are enlargements of the high salinity regions of a, b and c, respectively.

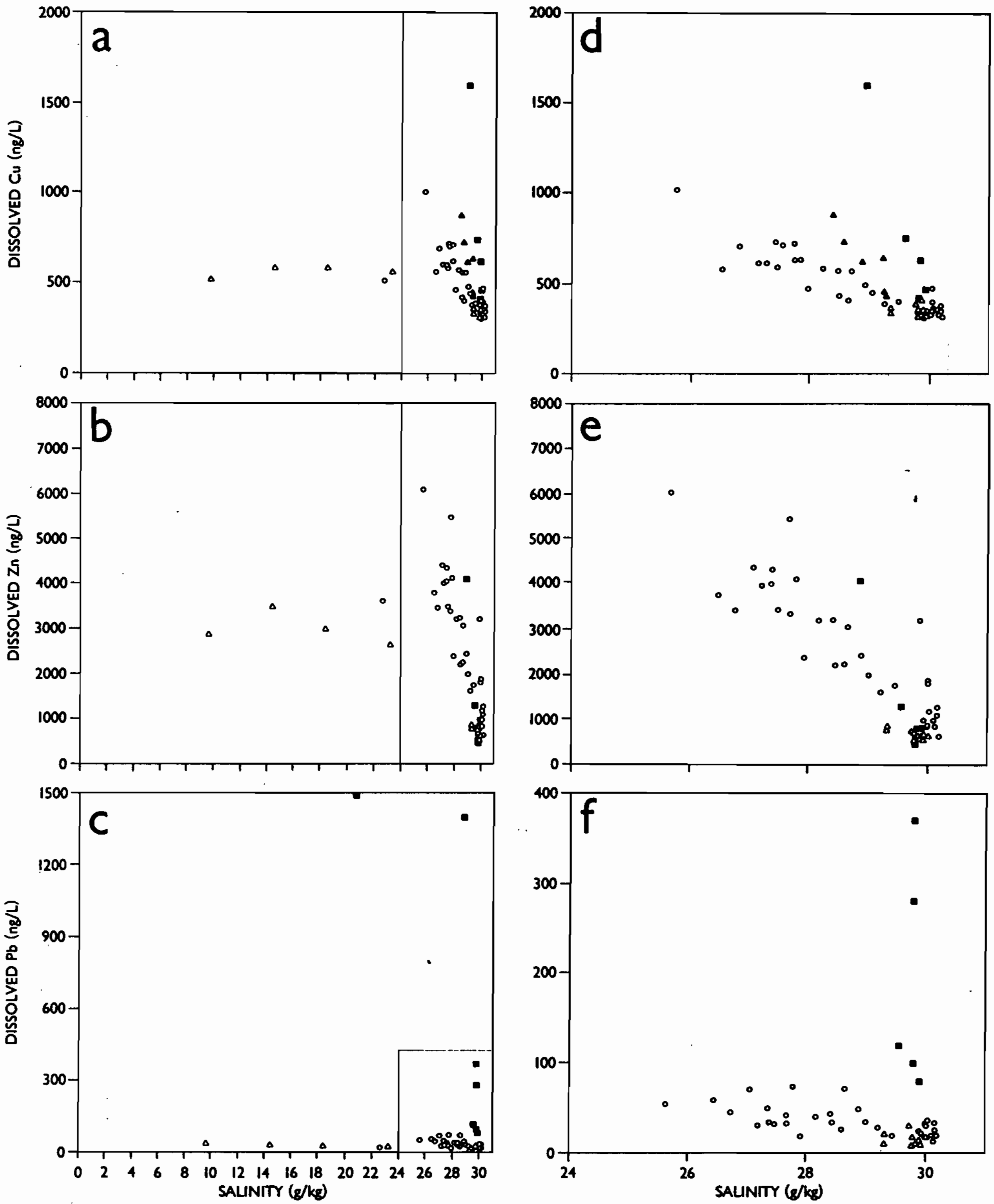


Figure II.42. Figure II.58. Regressions of salinity and particulate trace metals in the upper layer of Elliott Bay. Particulate Cu (a), Zn (b) and Pb (c) during 1981 (■), 1985 (△) and 1986 (○).

Particulate Cu and Zn concentrations showed no decrease during the interval. Particulate Pb concentrations have increased (Fig. II.42); probably due to the higher flow rates during 1985 and 1986 sampling period since the transport of particulate Pb is similar (Table II.8).

Dissolved trace metals being transported from Elliott Bay originate from quantifiable sources upstream of the Duwamish Waterway (Green River water and Renton Sewage Treatment Plant effluent) and non-quantifiable sources in the Waterway or on Elliott Bay. Since the concentration of dissolved trace metals is not a function of flow rate (Curl *et al.*, 1982), the transport of dissolved trace metals from the Green River will increase proportionately with flow rate. If the amount of dissolved trace metals discharged into the Waterway or from the Elliott Bay shoreline is constant and not a function of flow rate, increased flow from the Green River will tend to dilute these discharges. Therefore, it is possible that the lower concentrations seen in 1985 and 1986 compared to the concentrations found in 1980 and 1981 are a result of higher flow rates which occurred during the recent sampling. In order to distinguish between the effects of flow rate and temporal changes in the anthropogenic input on the transport of dissolved metals from Elliott Bay, we attempted to subtract the inputs of Green River water and Renton Sewage Treatment Plant effluent from the apparent transport of dissolved trace metals from Elliott Bay (Table II.8). These calculated values are attributable to discharges from Duwamish Waterway and Elliott Bay sources. From this analysis, it can be seen that the decreased dissolved Pb concentrations found in 1985 are not due to effects of river flow but are due to decreased inputs of dissolved Pb from sources downstream of the turning basin. This analysis indicates that the discharge of dissolved Cu downstream of the turning basin has also (decreased by a factor of about 5). In contrast, little change in the discharge of dissolved Zn was found.

Could the existing pollution abatement programs have caused such a large decrease in the transport of dissolved Pb? METRO reports (Harper-Owes, 1983; Gamponia *et al.*, 1986) have determined that storm water systems draining the site of the Harbor Island secondary lead smelter have been responsible for high concentrations of Pb in the sediments and water column of the West Duwamish Waterway. The Duwamish Industrial Non-Point Source Investigation has found total Pb concentrations between 1,400,000 and 2,300,000 ng/L in storm water from this drain (J. Shahan, METRO, pers. com.). Twenty-two (22%) of the total Pb from this storm drain was in the dissolved form (Harper-Owes, 1983). Since dissolved chloride ions in seawater can solubilize lead from sediments, particulate lead in these storm drains could also contribute to the dissolved Pb load once they were introduced into the saline waters of the West Duwamish Waterway. Between the earlier sampling period in Elliott Bay (1981) and the present investigation (1985-1986), the secondary lead smelter ceased smelting operations (1984), the storm drains were cleansed of their residual sediments (1984) and parking lots in the vicinity of the secondary lead smelter were paved in 1983 to control fugitive dust. Because of the extremely large source

Table II.8. Apparent Dissolved Inputs Downstream of the Turning Basin

	April, 1980	August, 1981	April, 1985	January, 1986
Flow (m^3/sec)	17	9.2	90	30
Dissolved Cu (g/sec)	0.21 (0.23,0.01,0.01)	0.36 (0.38,0.01,0.01)	0.011 (0.077,0.056,0.01)	0.08 (0.11,0.02,0.01)
Particulate Cu (g/sec)		? (0.034,?,0.001)	? (0.14,?,0.001)	? (0.058,?,0.001)
Dissolved Zn (g/sec)		1.0 (1.1,0.01,0.04)	0.43 (0.57,0.10,0.04)	0.82 (0.89,0.03,0.04)
Particulate Zn (g/sec)		? (0.12,?,0.004)	? (0.19,?,0.004)	? (0.14,?,0.004)
Dissolved Pb (g/sec)		0.42 (0.42,0.001,0.01)	0.0 (0.0048,0.002,0.01	------ ------
Particulate Pb (g/sec)		? (0.055,?,0.01)	? (0.086,?,0.01)	? (0.151,?,0.01)

The calculation used to calculate the apparent flux downstream of the turning basin is shown in the parenthesis (a,b,c) where a is the apparent flux of dissolved metals from Elliott Bay; b is the flux of dissolved trace metals in Green River water (average concentration 620, 1100 and 20 ng/P for dissolved Cu, Zn and Pb, respectively) and c is the dissolved trace metal flux from the Renton Sewage Treatment Plant.

of dissolved lead associated with post smelter operations, these removal and control measures could explain the dramatic decrease in the concentration of dissolved Pb in Elliott Bay.

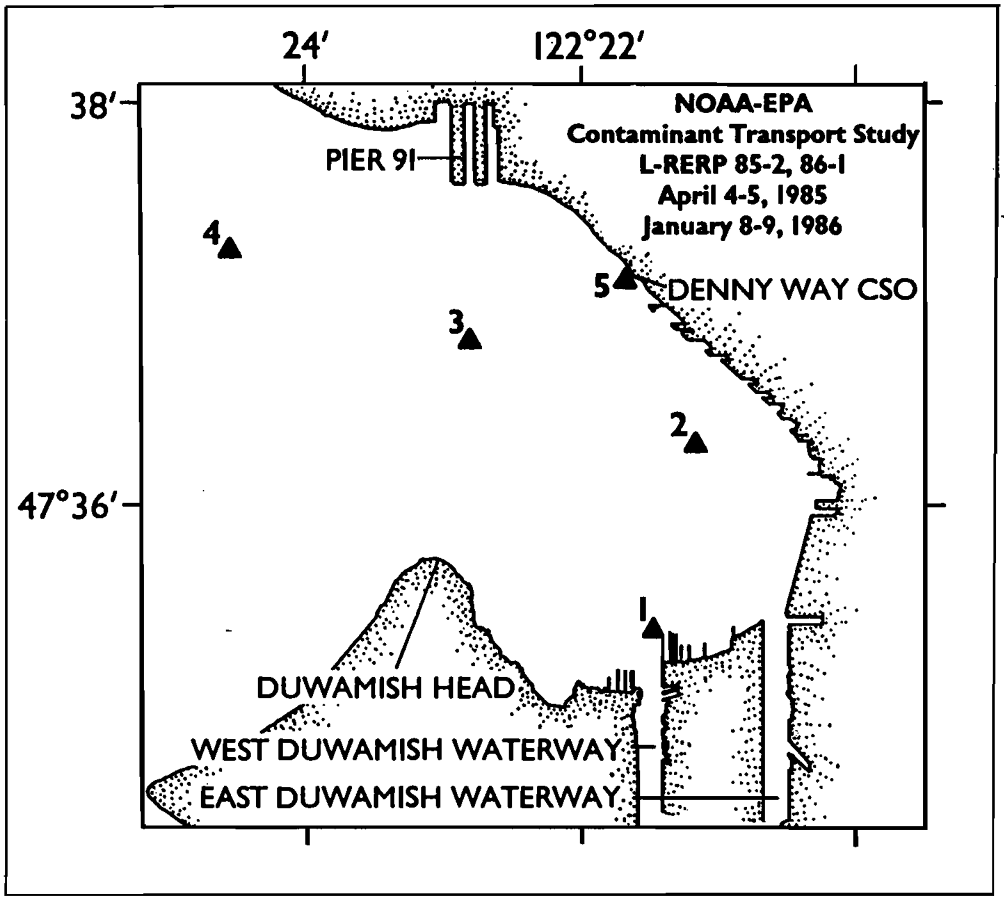
The concentrations of particulate metals in 1985 and 1986 were also lower than those found in 1981 (Fig. II.42). However, these decreases seem to be more related to flow rate effects since the transports of particulate Cu, Zn and Pb from Elliott Bay were higher during the high flow periods of 1985 and 1986 relative to the lower flow periods of 1981 (Table II.8). Since total suspended matter concentration varies with river flow rate, an analysis to separate flow rate effects from temporal changes in the discharge of particulate tract metals can not be made. The concentrations of Pb on the suspended matter also provide evidence for flow rate effects. Although the particulates in the storm sewer draining the secondary smelter contained 20-40% Pb by weight, they are diluted by less concentrated riverine particulates both in the water column and in the sediments of the Duwamish Waterway. Pb concentrations in the sediments near the discharge point of this sewer had concentrations as high as 13,000 ppm, indicating that some of the particulate Pb discharged by the storm drain settled nearby. The degree of dilution that the particulates from the storm drain will attain in the water column will depend on the overall suspended load. The increase in suspended load (from 3 mg/l in 1981 to 4 mg/l in 1986) is partly responsible for the decrease in the particulate Pb concentrations on suspended matter (490 ppm in 1981 vs. 220 ppm in 1986). Since the Duwamish Waterway contributed only about 30% of the particulate Pb flux into Elliott Bay (Table II.8) in January, 1986; variations in the particulate Pb flux from other sources along Elliott Bay probably obscure any decrease as a result of pollution abatement programs. These other sources include atmospheric deposition from automobile exhaust, which should decrease dramatically over the next few years.

II.1.5.2. Toxic Organics

Poly Aromatic Hydrocarbons (PAH)

The concentration of PAH entering Elliott Bay from the surface waters of the Duwamish River in April of 1985 was quite low (1 μg/g) (Fig. II.43). This concentration is similar to that found in the relatively pristine Admiralty Inlet in 1980 (Bates *et al.*, 1987). Suspended particulates from the near bottom waters, however, showed levels of PAH four times higher than the highest concentrations measured on suspended or settling particulates from the main basin (Bates *et al.*, 1987). The surface concentrations in Elliott Bay were high both along the waterfront (5.2 μg/g at station 2) and off Pier 90 (5.2 μg/g at station 3), suggesting sources in these areas. The PAH concentration was lower at station 4 located at the outer edge of Elliott Bay. The concentration decreased slightly with depth at station 4 and was similar to concentrations measured in central Puget Sound off Meadow Point (Bates *et al.*, 1984). The concentration of PAH on settling particulates at station 3 also decreased with depth in the water column from 4.4 μg/g

PAH CONCENTRATIONS IN ELLIOTT BAY



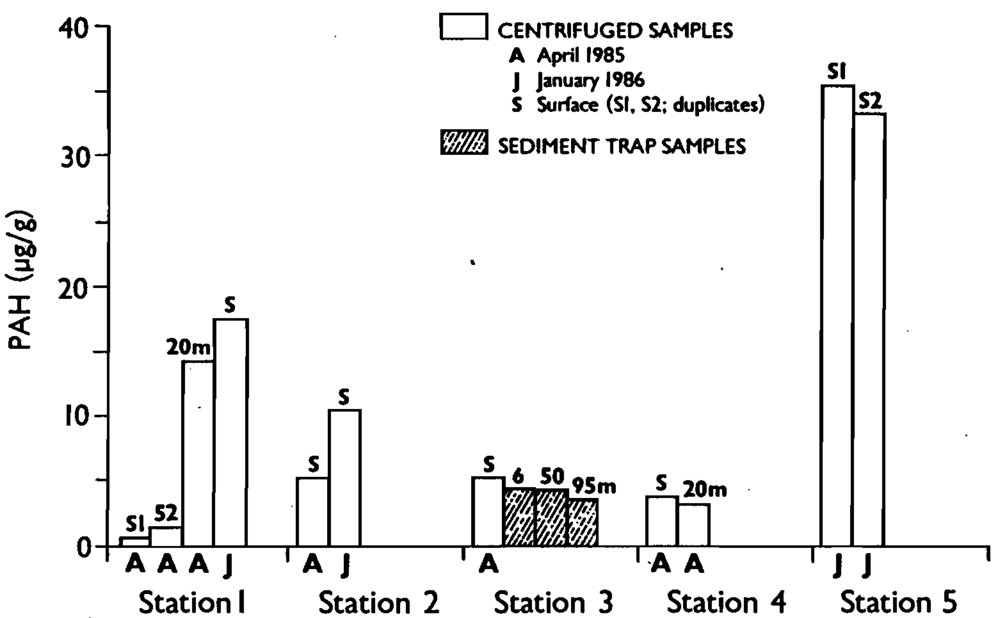


Figure II.43. PAH station locations and concentrations in Elliott Bay. Suspended particulates were collected by centrifuge (open bars) in April 1985 and January 1986 at the surface and, in some cases, at 20 m depth. Settling particulates were collected by sediment trap (hatched bars) during March to June 1985.

at 6 m to 3.7 µg/g at 95 m. These concentrations are similar to those obtained in the bottom sediments in this region (Romberg *et al.*, 1984).

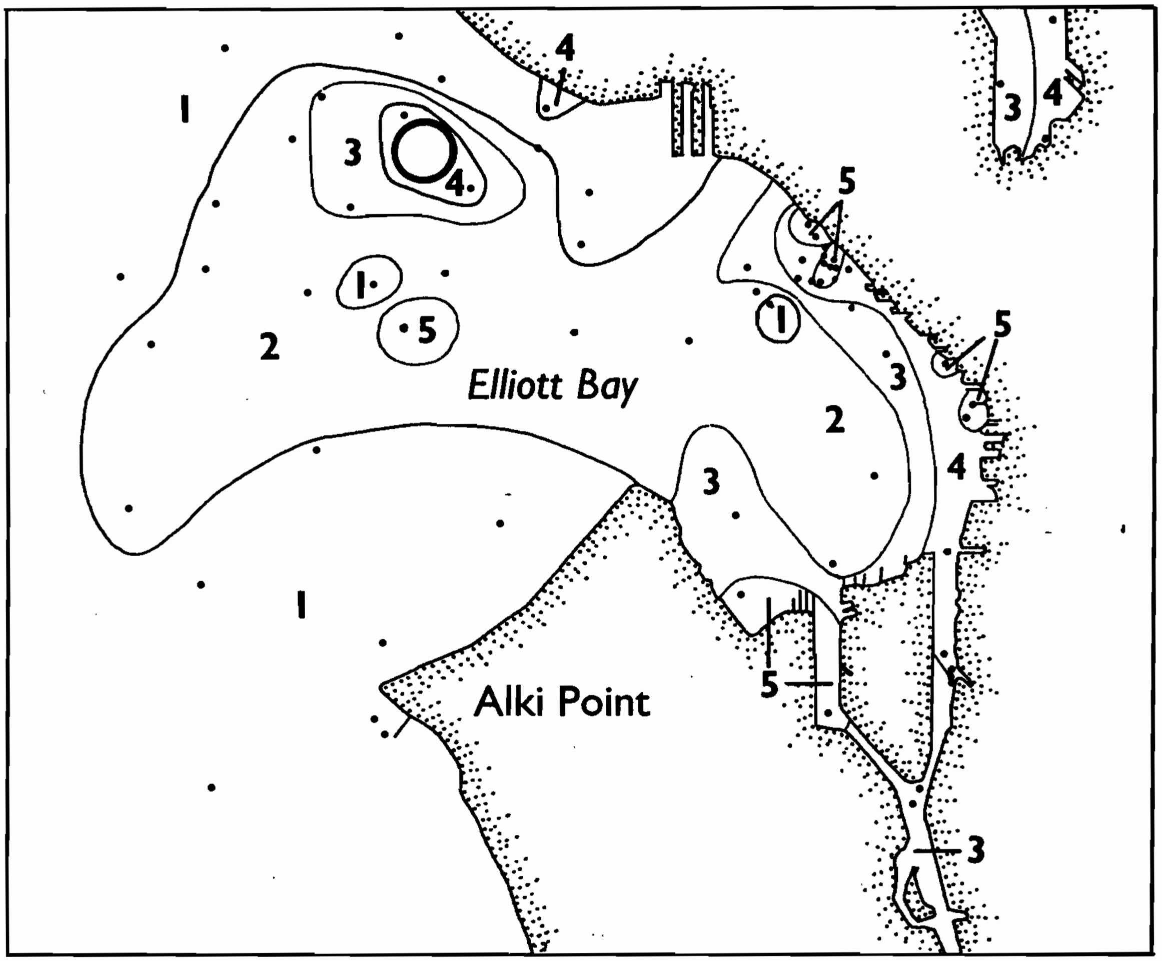
PAH concentrations for all Elliott Bay surface samples taken in January 1986 were much higher than those of April 1985, reflecting the higher urban runoff. Extremely high concentrations were found off the Denny Way CSO site (35 µg/g at station 5) and at the mouth of the Duwamish River (18 µg/g at station 1). PAH levels along the waterfront were (Sta. 2) somewhat lower, but twice as high as those found in April 1985 (11 vs. 5.2 µg/g).

PAH distributions in the sediments of Elliott Bay decrease in a seaward direction from 3.0 µg/g off the mouth of the river to 1.5 µg/g at the outer edge of Elliott Bay (Bates *et al.*, 1987, Fig. II.44.). These sediment data and the high level of PAH in the suspended particulates from the bottom waters at station 1 (14 µg/g) indicate that the Duwamish River is an important source of PAH to Elliott Bay. Hamilton *et al.* (1983) have shown that during low flow conditions particulate hydrocarbons in the surface waters of the lower Duwamish River are deposited in the fine-grained sediments of the river bed. These sediments are resuspended in the salt wedge and transported upstream with the tidal flow. Although the majority of the particles are sedimented in the river bed, necessitating periodic dredging, it is likely that some fraction of these PAH-laden particles are discharged directly to Elliott Bay. This would produce the seaward decrease in PAH distribution observed in Elliott Bay (Fig. II.44) (Bates *et al.*, 1987; Romberg *et al.*, 1984).

The elevated concentrations of PAH in surface waters at stations 2 and 3 relative to station 1 (5 vs. 1 µg/g) in April 1985 indicate that the West Waterway of the Duwamish River is not the major source of PAH to surface waters in Elliott Bay during this period. The East Waterway is a source of particulate matter to Elliott Bay (see vertical distribution of SPM (Fig. II.16.) transect E-E') and is likely contributing some PAH in the same way as is the West Waterway. In the absence of rainfall, PAH sources such as industrial discharges, creosote pilings (Lake *et al.*, 1979), and aeolian combustion products might contribute to elevated concentrations in Elliott Bay. For two days prior to our sampling in April there had been measurable rainfall in the area and trace rainfall on the two sampling days (NOAA NWS, 1985, 1986). Storm drains along the waterfront collect and discharge urban runoff directly into Elliott Bay for all rainfall events. The vertical distribution of suspended particulate matter (Fig. II.17) indicates particle sources for several locations where storm drains are known to exist (Evans-Hamilton, 1986), for example Pier 89. No discharge data are available for these storm drains, but increased particle concentrations suggest the possibility of urban discharges which would elevate the PAH levels in these areas. High concentrations of PAH in the sediments along the waterfront (Fig. II.44) support the claim that this area is a contributor of PAH to Elliott Bay.

The PAH concentrations on suspended, settling, and sedimented particulates at station 3 support a downward flux of PAH from the surface waters to the bottom sediments. However, the

Contour map of **High Molecular Weight or Combustion PAH** concentrations in surface sediment grab samples collected from Elliott Bay (Dots represent data points.)



HIGH PAHs
(ng/g dry weight)

RANGE SCALE
1 = <3000
2 = 3000 - 6000
3 = 6000 - 12,000
4 = 12,000 - 24,000
5 = >24,000

○ Disposal Area

Figure II.44. PAH in sediments of Elliott Bay (After Romberg *et al.*, 1984; Bates *et al.*, 1987).

particulate flux from the surface waters to the bottom sediments is a small part of the total particulate transport out of Elliott Bay (Baker *et al.*, 1983). The decreasing concentration of PAH from station 3 to 4 could result from dilution, although the paucity of data make it impossible to correlate this dilution with the increasing salinity.

The PAH concentrations on suspended particulates in the surface waters of Elliott Bay in January 1986 were much higher than those measured in April 1985. The concentration measured in the surface waters at the mouth of the Duwamish River in January of 1986 was very high (18 µg/g). This high concentration is most likely due to effluent from the combined sewer overflows and storm drains discharging into the West Waterway. The Harbor CSO is known to have discharged 160,000 gallons of effluent into the West Waterway during our January 1986 sampling period (L. Wharton, METRO, personal communication). The volume of discharge for METRO CSOs is monitored, but no PAH concentration information is available. PAH concentrations in CSO discharges would be largely dependent on the fraction of urban runoff, since this is supposed to be the major source of PAH to CSO discharges. If we use a low PAH loading factor for urban runoff of 0.4 mg/L (Tetra Tech, 1986), a PAH concentration of 0.1 ng/L can be estimated in the West Waterway surface waters for this CSO event. All urban runoff collected by the 12 storm drains from the mouth of the West Waterway to the southern end of Harbor Island discharges directly into the West Waterway (J. Talbot, City of Seattle, personal communication). There is no monitoring of these discharges, so volumetric and PAH concentration data for our sampling period are not available. Pollutant loading of urban effluents is difficult to assess. It depends on local land use, traffic volume, road surface type, rainfall duration and storm intensity, and can vary by as much as two orders of magnitude (Zawlocki, 1981). We can, however, make some estimates based on drainage area and an average PAH loading factor. The 7 major storm drains in this area collect rainfall from 1569 acres (Tetra Tech, 1986). PAH concentrations of 9.4 ng/L and 52 ng/L at the mouth of the West Waterway were estimated for this storm event using low and high PAH loading factors, respectively (Appendix XIV). Although these estimated concentrations neglect PAH contributions from other local or upstream sources, our concentration of 47 ng PAH/L measured at the mouth of the West Waterway (Station 1) agrees quite well.

Extremely high concentrations were measured near the Denny Way CSO (34 µg/g). High concentrations of PAH in the surface sediments in the region of the CSO (Romberg *et al.*, 1984) indicate that at least some of the CSO effluent is being deposited in the nearby bottom sediments. These data substantiate the claim that the waterfront can be a major contributor of PAH to Elliott Bay. Pollutant loading for a particular CSO event depends upon amount of rainfall and number of days since rainfall last occurred (Barrick, 1982). It also changes during the course of a CSO event and does not correlate well with flow or total suspended solids (Eganhouse and Kaplan, 1981). Annual CSO discharges to Elliott Bay can vary by as much as an order of magnitude, making estimates of total annual PAH discharge to Elliott Bay difficult.

Chlorinated Hydrocarbons

The concentrations of polychlorinated biphenyls measured in this study were in all cases near or below the limit of quantification. DDT and its breakdown products DDD and DDE were in all cases below our detection limits (Appendices XI-XIII). This suggests that the present input of chlorinated hydrocarbons to these embayments is quite low. This is not surprising since the use of PCB has been largely curtailed since 1976 (Cairns and Siegmund, 1981) and DDT use was prohibited in 1972. Concentrations of certain PCB isomers in surface waters were approximately ten times greater in January 1986 than in April 1985; at both times however concentrations were still extremely low (<90 ng/g). PCB was been measured in the Duwamish River in high concentrations in 1974 following the spill from an electrical transformer (Hafferty *et al.*, 1977). Sediment from five storm drains discharging to the Duwamish River were also found to have high concentrations (100,000 ng/g) of PCB (Tetra Tech, 1986). Combined sewer overflow and storm drain collection basins apparently can trap some of their particulate load for considerable periods of time. Small amounts of particulate PCB can then be discharged years after their deposition when high flow conditions scour the pipes. The dramatic effect of cleaning these pipes is suggested elsewhere in this report (p. 123) by the reduction in Elliott Bay lead concentrations following cleanup of discharge pipes near a lead smelter on Harbor Island. Chlorinated hydrocarbons are still present in the bottom sediments of Elliott Bay. Their distribution in the sediments suggests sources from the Duwamish River, the dredge spoil site at Four Mile Rock, and the CSO at Denny Way (Romberg *et al.*, 1984).

II.1.5.3. Summary

The West Duwamish Waterway, Harbor Island and Denny Way CSO sites were always enriched over Elliott Bay mid-depth concentrations, with the exception of Cd (Table II.9.). Sources from the West Duwamish Waterway dominated the distributions of dissolved and particulate trace metals during the high river flow period of April, 1985. The plume from the West Duwamish Waterway was confined to a very thin surface layer (<2 m). This feature enhanced the transport of particulate matter out of Elliott Bay. Plots of salinity versus dissolved and particulate trace metals suggest that toxic trace metals are essentially conservative within Elliott Bay during this period. This would suggest that the majority of metals which emanate from the Duwamish Waterway enter the main basin of Puget Sound without much loss. Comparisons between horizontal fluxes and vertical flux indicate that less than 3% of the particulate matter in the surface lens was lost from the water column due to settling (Table II.10).

Table II.9. Enrichments of Trace Metals in surface plumes in Elliott Bay.

Element	mid-depth Conc.	Enrichments[1] (Relative to mid-depth) April 1985 W. Duwamish Waterway	January 1986 W. Duwamish Waterway	Harbour Is. Shipyards	Denny Way CSO
Fe	0.4 μg/L	27.5	44.5	3.2	14.3
Mn	1.15 μg/L	20.5	33.2	7.8	12.3
Cu	360 mg/L	0.38	1.6	12.9	16.4
Zn	640 mg/L	2.56	13.4	31.0	50.5
Pb	15 mg/L	2.1	1.6	7.1	170
Ni	380 mg/L	0.28	1.4	1.8	1.7
Cd	80 mg/L	-0.49	-0.2	0.9	2.1

[1] Enrichments are multipliers, indicating how much more concentrated a surface sample is compared to the mid-depth sample.

Table II.10: Horizontal and Vertical Flux of suspended matter and particulate trace metals in Elliott Bay during April 1985.

Parameter	Horizontal Flux (gm/sec)	Vertical Flux (gm/sec)	Vertical Flux / Horizontal Flux (%)
Suspended Matter	960.0	34.0	3.5
Mn	2.0	0.016	0.8
Cu	0.14	0.0011	0.8
Pb	0.086	0.0021	2.4

Table II.11. Order-of-magnitude calculation of the flux of trace metals from the Denny Way CSO during the January 8th storm.

Element	Dissolved			Particulate		
	F_{CSO}	F_{CSO}/F_{EB}	$F_{SCO}/(F_{EB}-F_{DW})$	F_{CSO}	F_{CSO}/F_{EB}	$F_{CSO}/(F_{EB}-F_{DW})$
	gm/sec	%	%	gm/sec	%	%
Al				1.5	4	9
Fe	0.01	2	9	1.5	10	30
Mn	0.03	1	6	0.02	--	--
Cu	0.01	9	14	0.01	17	23
Zn	0.06	7	13	0.03	21	39
Pb	0.005	--	--	0.02	13	20
Ni	0.002	4	10	0.002	6	8

where F_{CSO}, F_{EB} and F_{DW} are the fluxes from the CSO, out of Elliott Bay and out of the Duwamish Waterway. Numerical values are given for the CSO only. F_{EB}-F_{DW} represents the flux of metals into Elliot Bay from unquantified shoreline sources. $F_{CSO}/(F_{EB}-F_{DW})$ represents the portion of this flux which the CSO would have contributed if the average concentration of the CSO effluent was equal to the CSO effluent concentration when station S1 was sampled.

The surface distribution of particulate PAH in April, 1985 was distinctly different from the distribution of trace metals. The highest concentration of PAH was found along the Seattle Waterfront; the Duwamish Waterway was not a major source of PAH at this time.

The distributions of particulate and dissolved trace metals were strongly affected by combined sewer overflow events during January, 1986. In addition, plumes of particulate and dissolved Cu and Zn were discovered north of the shipyards on Harbor Island. Calculations indicate that transport of Cu, Zn and Pb out of Elliott Bay was enhanced 2 to 3 times compared to that transported out of the West Duwamish Waterway.

The Denny CSO and West Duwamish Waterway were the major sources of PAH in the January, 1986 sampling period. The levels are extremely high and are probably due largely to particulate PAH washed off the city streets by rain. PCB concentrations were also higher in January, suggesting scouring of storm drain and CSO pipes containing PCB deposited in previous years.

These observations indicate that there are significant sources of contaminants from many sources along Elliott Bay's shores. The quantification of these sources requires both concentration and flow data. Although precise estimates of contaminant fluxes from the Denny Way CSO can not be made, the availability of CSO flow data allows one to perform an order-of-magnitude estimate. Assuming that samples S1 and J1 were one-third CSO effluent and two-thirds seawater based on their salinity, an assumed CSO effluent concentration can be calculated. By multiplying this assumed effluent concentration by the average CSO flow for the duration of the overflow event (0.6 m^3/sec), an order-of-magnitude estimate of the CSO contaminant flux was made and is shown in Table II.11.

These order-of-magnitude estimates can be compared to the fluxes of metals out of the Duwamish Waterway (F_{DW}) and Elliott Bay (F_{EB}). Assuming conservative behavior in Elliott Bay, the flux of metals from Elliott Bay shoreline sources was calculated by subtracting the flux of metals out of the West Duwamish Waterway (F_{DW}) from the flux out of Elliott Bay (F_{EB}). Table II.11 indicates that the Denny Way CSO might contribute 2 to 9% of the dissolved flux of a metal out of Elliott Bay or 6 to 14% of the dissolved flux of a metal from shoreline sources. The possible particulate contribution of a metal from the Denny Way CSO ranged between 4% and 21% of the flux out of Elliott Bay. The particulate flux from the CSO could constitute between 9% and 39% of the total shoreline source. Since some metals such as particulate Pb exhibit higher fluxes in the initial stages of a storm (Dally *et al.*, 1983), the calculated flux based on one sample collected during the later stages of the event may be less than the actual flux. From this order-of-magnitude estimate, it seems that the particulate trace metal contribution from the CSO is more significant than the dissolved contribution and that there are other significant shoreline sources. The surface distribution patterns of the trace metals suggest that the CSO and other shoreline sources at the north end of Harbor Island were significant inputs to Elliott Bay during January, 1986. The higher levels of contaminants in the "hot spot" directly west of the Denny Way CSO (Romberg *et al.*, 1984; Bates *et al.*, 1987) results from rapid sedimentation of particulates from the effluent. However, there is little indication that contaminants from "hot spots", or elsewhere in Elliott Bay, are resuspended, remobilized or transported out of the Bay.

II.2. COMMENCEMENT BAY

Two moorings, one surface and one subsurface, were centrally located in the mouth of Commencement Bay to measure currents and water properties at 1, 4, and 152 m in a water depth of 158 m (Table II.1 and Fig. II.45). This location was selected because previous water property observations indicated near surface flow meandering back and forth across the entrance and because the location was an old dump site of interest. Observations of currents and shipboard CTD's were obtained over a 21 day period. The CTD observations were made over a few tidal conditions (Table II.2). The general statistics of the moored instruments are in Table II.3.

II.2.1. Hydrographic Setting

Puyallup River

The Puyallup River begins at the confluence of the Puyallup and Tacoma Glaciers on Mount Rainier and flows approximately 46 miles to Commencement Bay. The river and its principal tributaries (White, Carbon, and Mowich River) drain approximately 60% of the slopes of Mount Rainier. Two flow maxima are present during a normal year; high rainfall in winter produces a December/January peak and snowmelt runoff produces a larger peak in June. The river flows through forested and agricultural land to the USGS gauging station near Puyallup. The last 6.6 miles are through urban and industrial areas. Clear and Clark Creeks enter the river beyond the Puyallup gauging station but contribute less than 2% of the total river flow (Puget Sound Task Force, 1970).

Mean monthly flow in April 1985 was 133% of the 10-year monthly average. For the two days of our sampling the flow was 128% of the 10-year average at a flow rate average of 87 m^3/s (Fig. II.46).

II.2.2. Physical Oceanography

II.2.2.1. Salinity

Distributions of surface salinity are presented in Fig. II.47. As in Elliott Bay, there is a very shallow surface brackish layer, salinity below the upper few meters is characteristic of the source waters of the main basin. The major effects of freshening are not obvious below 4 m. The surface salinity distributions at high tide show weak horizontal gradients, with slightly less saline water in the northern half of the bay. During ebb the salinity distribution shows much stronger horizontal gradients, and the plume of fresh water from the Puyallup River exits through

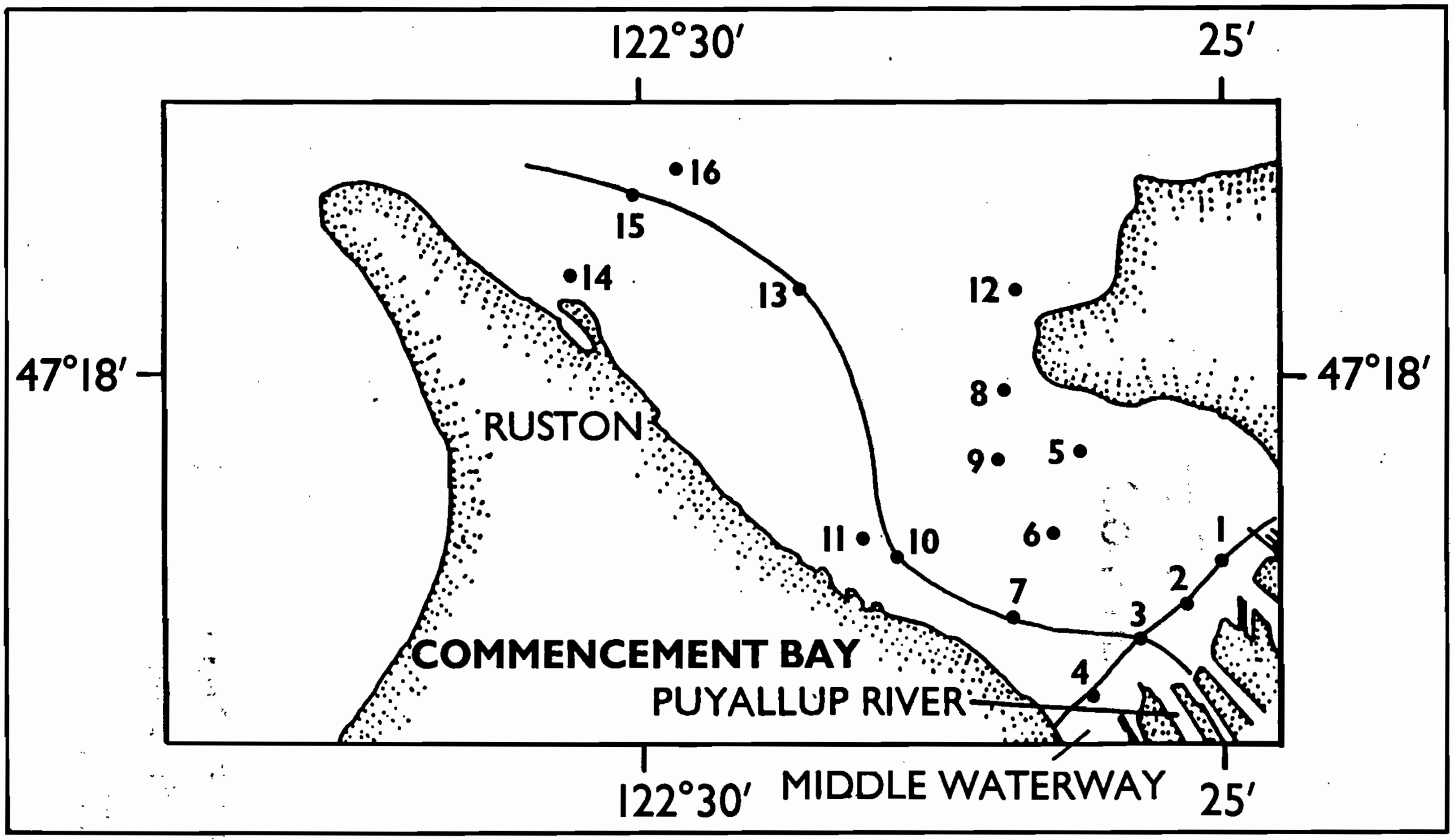


Figure II.45. Location of stations and moorings in Commencement Bay. The station names are derived by adding the prefix 'CB85-' to the station number shown in the figure. The vertical transect across the heads of the waterways is composed of stations CB85-1 to CB85-4. The transect into outer Commencement Bay is composed of stations CB85-3, CB85-7, -10, -13 and -15.

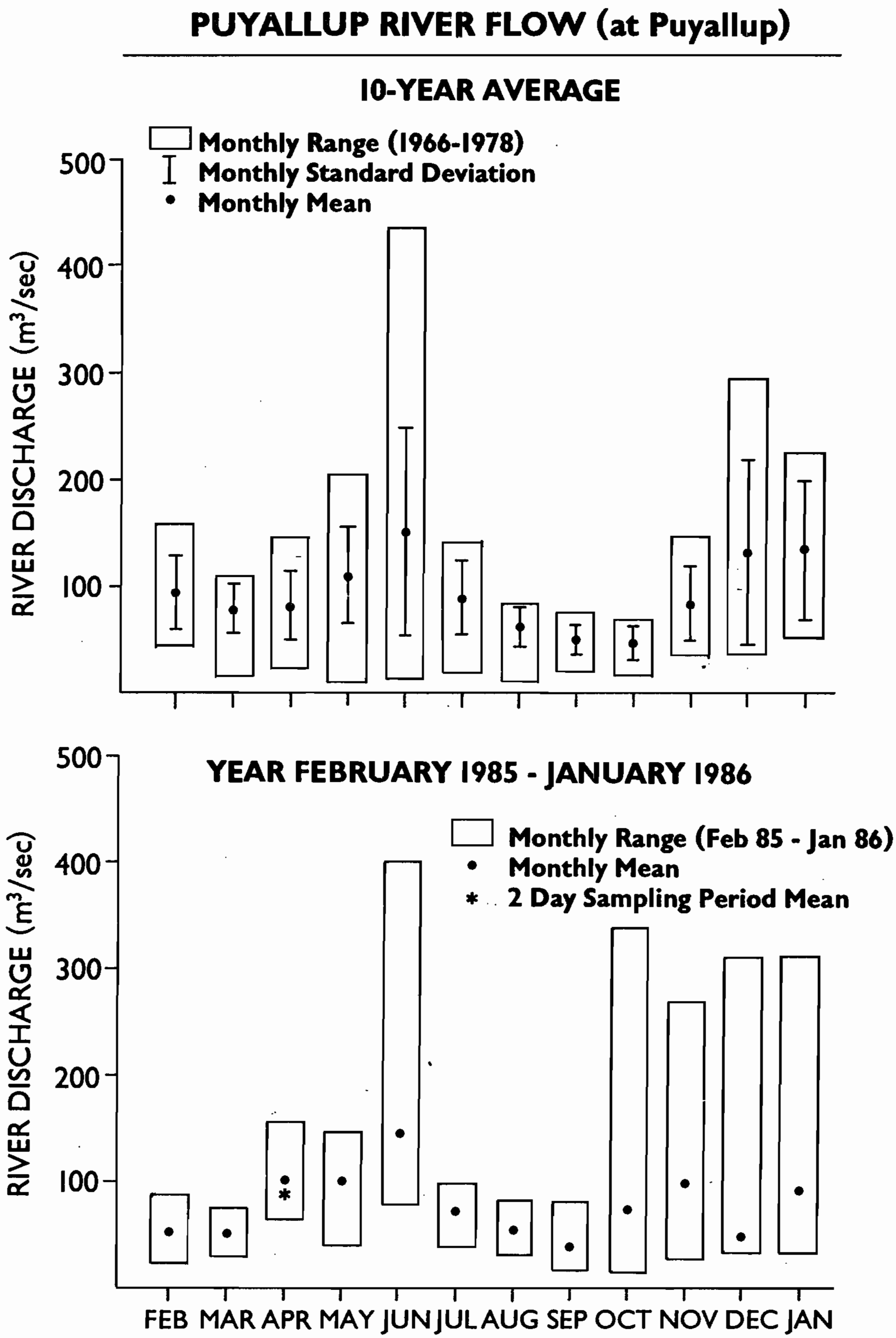


Figure II.46. Discharge of the Puyallup River (Upper Figure). Monthly means, range and standard deviation for the period 1966-1978. Monthly means (Lower Figure) and range for the period February 1985 - January 1986.

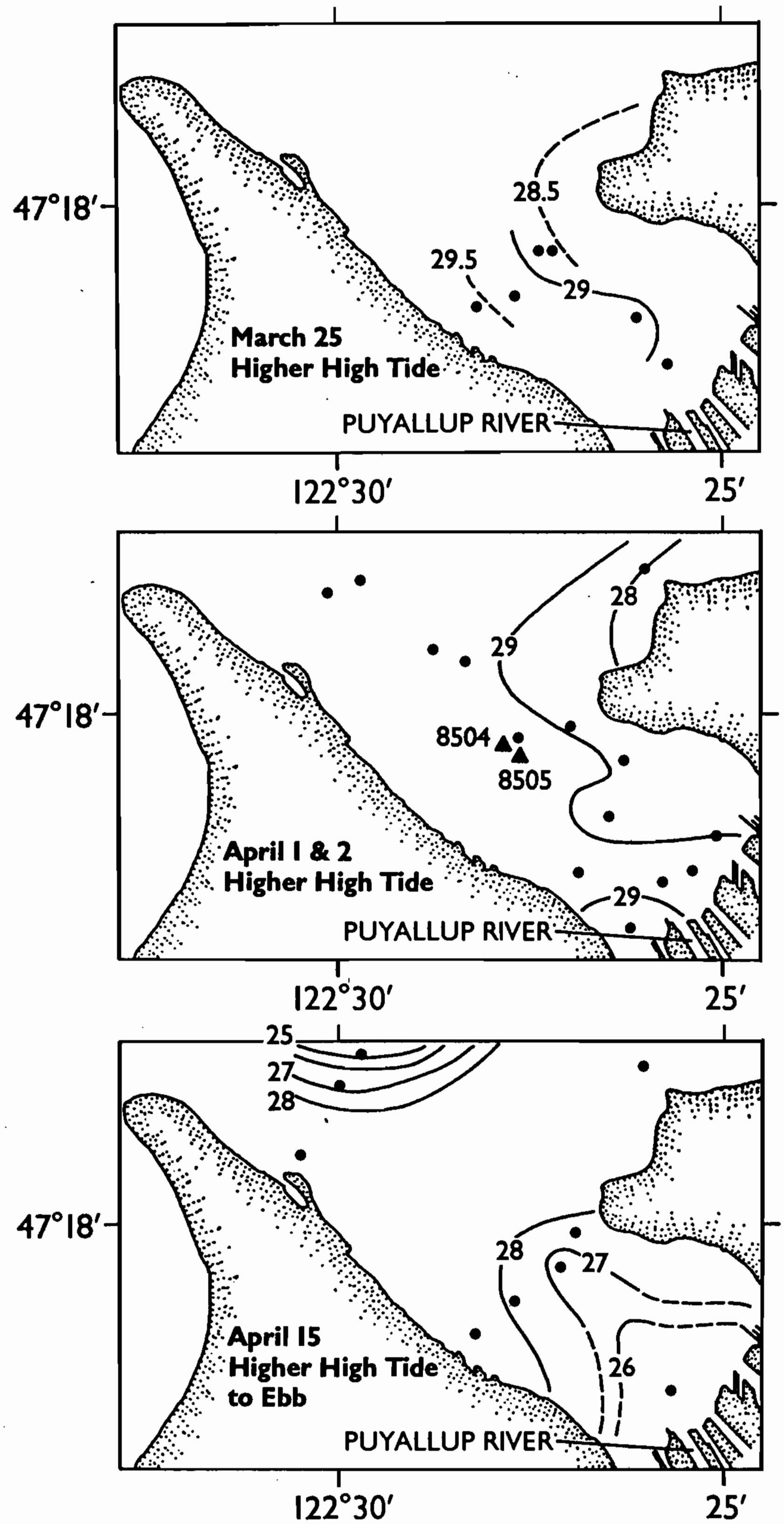


Figure II.47. Distribution of surface salinity in Commencement Bay, March and April 1985.

the center of the bay. There is an indication of freshened water coming through Dalco Passage or from the Narrows.

Salinities measured by the moored instruments show the most variation in the surface layer (Fig. II.48). The 1 and 4 m observations indicate how the extremely thin the layer of fresher water is, much like that in Elliott Bay. The mean difference is 1.8 ppt with a large variance. There is a trend toward larger differences through the record, with larger decreases in surface salinity centered on 3 and 14 April probably due to increased river outflow (see Fig. II.46). The Duwamish River has peak flows at about those times. The patchiness of the fresher water plume also is seen in the salinity difference series going from almost no difference to large differences. The difference has variation which does not seem tidal; three peaks/lows are observed on some days. The salinity gradient is small over the rest of the water column, increasing by only 1 ppt in 150 m. There is an increase in bottom salinity in early April. The increase is probably the result of a bottom water intrusion propagating along the main basin.

II.2.2.2. Currents

The maximum currents at the 4 m and the 152 m level are larger than currents at similar depths in Elliott Bay (Fig. II.49). The flow is tidal with a dominant semi-diurnal component. The cross bay components indicate a non-zero mean. The low frequency flow (tides removed) also clearly displays this cross bay component (Fig. II.50), indicating flow at an angle to the entrance section. Note that there also are uncoupled, alternating periods of inflow and outflow. The progressive vector diagrams, however, indicate that the net circulation or transport is extremely small (Fig. II.51). The vector mean flow values are lower than in Elliott Bay (Fig. II.3.) but the variance is much greater, particularly at surface, suggesting wind dominated events. The apparent cross-bay flow at the surface may be a result of different axis of flow during flood and ebb currents and may not be real. The relatively short records in Commencement Bay make definitive interpretation difficult. Water from the Puyallup River mouth would have taken two days to reach Reston during this period. Near bottom water would have taken 18 days to traverse the same distance. Nonetheless, it is clear from the coarser bottom sediments in Commencement Bay that tidal resuspension allows fine particles to diffuse out of the bay even if advection is very slow.

II.2.3. Particulate Matter Transport

II.2.3.1. SPM - April 1985

The vertical distribution of suspended particulates in Commencement Bay during April 1-2, 1985 is shown in Figure II.52.

The highest concentration measured of suspended particulates in Commencement during April 1-2, 1985 was 2 mg/L at Station 7 near the bottom. In general, SPM concentrations are

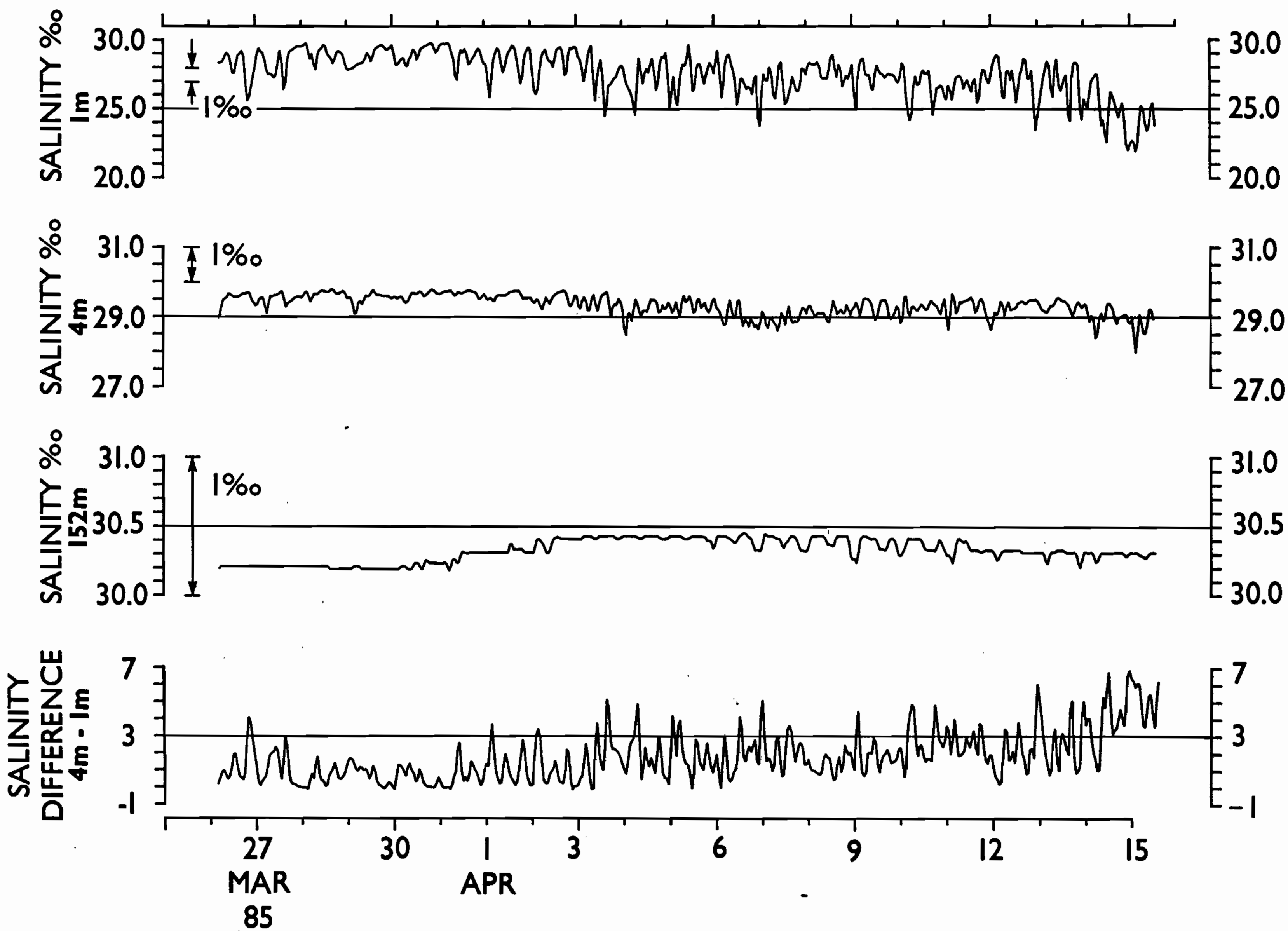


Figure II.48. Time series of salinity and salinity difference (4 m minus 1 m) in Commencement Bay. The salinity ranges vary and are scaled to the maximum and minimum values of the records.

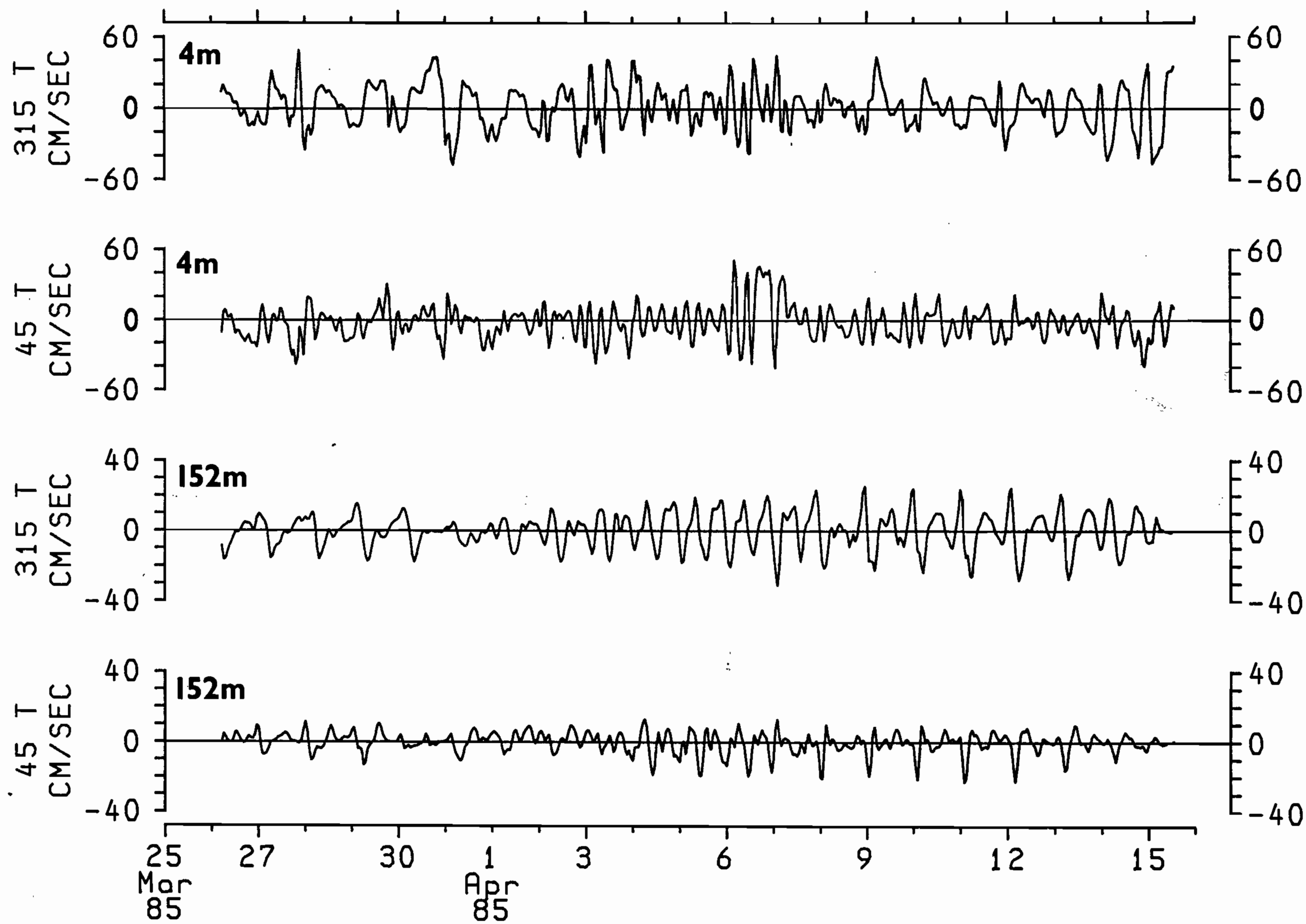


Figure II.49. Time series of currents relative to the axis (315°) of Commencement Bay. The speed scales vary according to the range of currents observed.

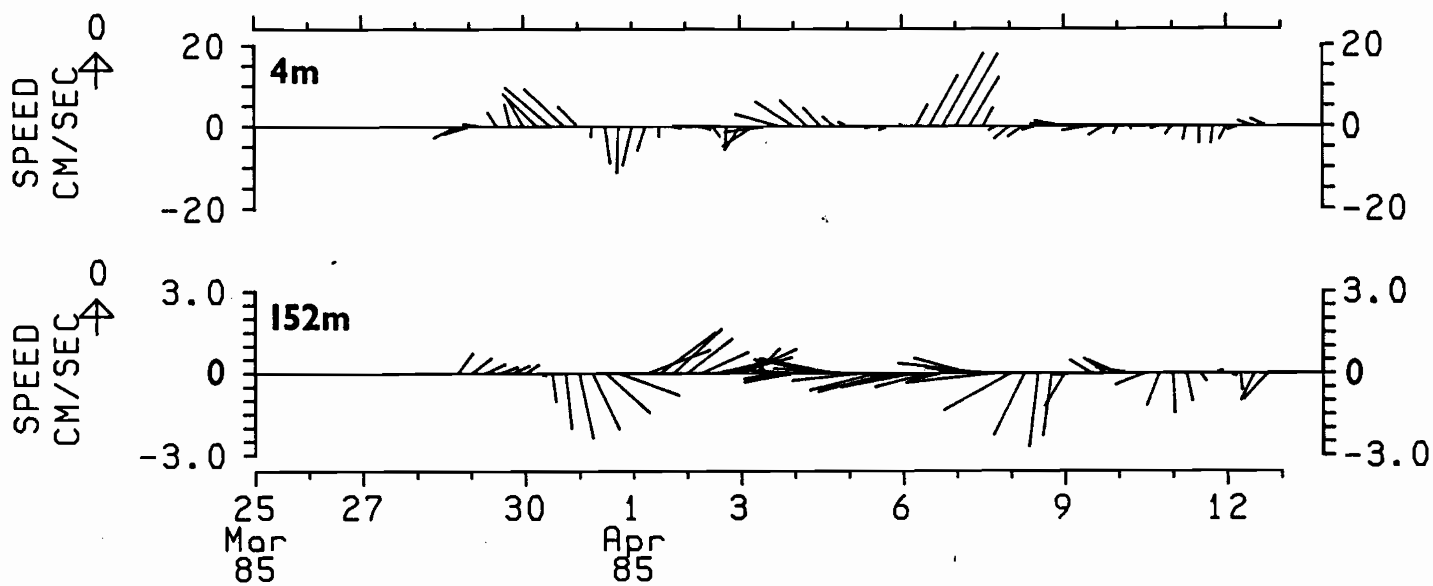


Figure II.50. Vector time series of low frequency currents in Commencement Bay. The vectors are relative to north and scaled to observed minimums and maximums at 4 and 152 m.

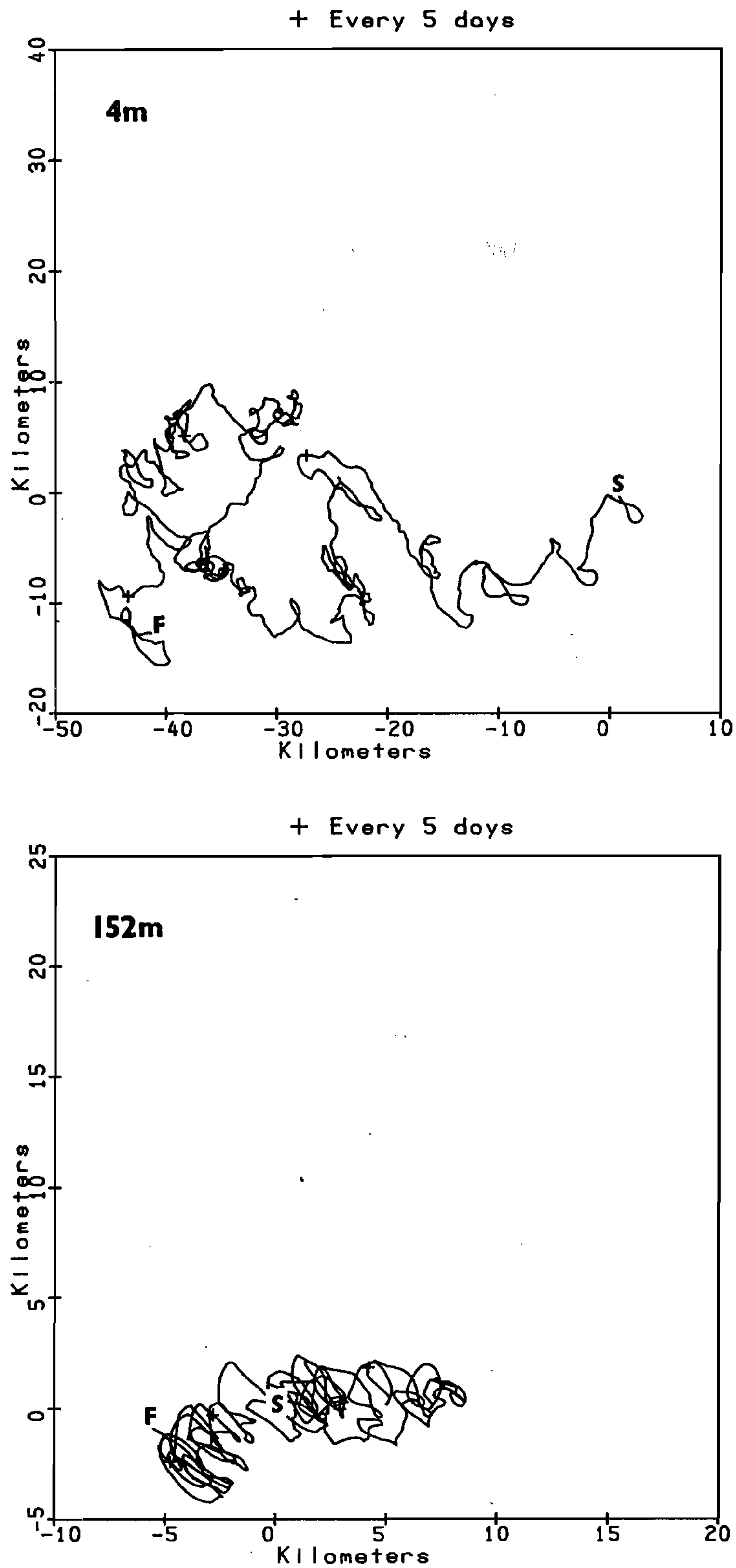


Figure II.51. Progressive vector diagrams of currents in Commencement Bay, April 1985. The scale differences reflect the differences in current magnitude.

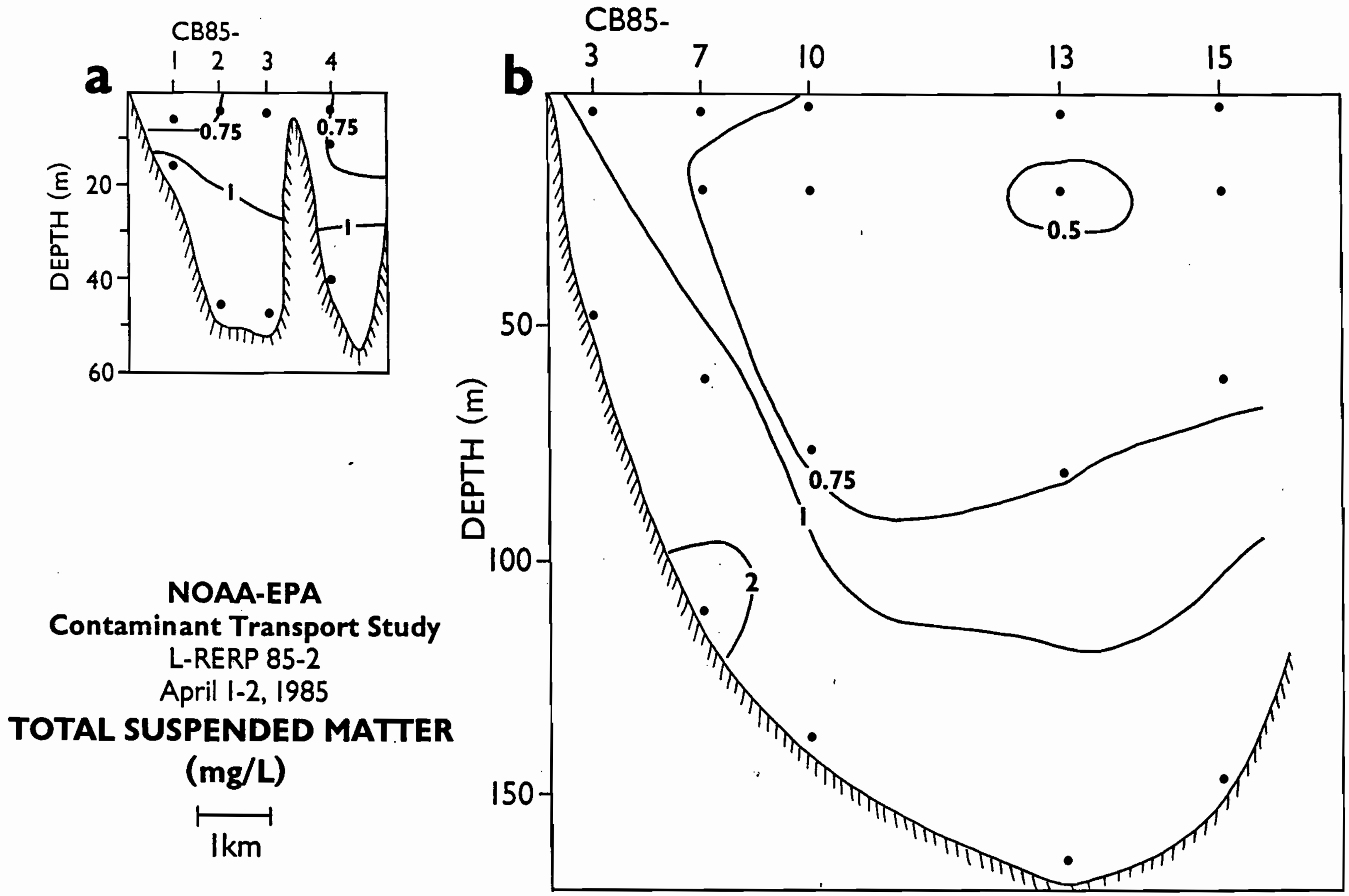


Figure II.52. Vertical Transects of Total Suspended Matter in Commencement Bay. The transect across the heads of the waterways is shown in Fig. a while the transect that extends into outer Commencement Bay is shown in Fig. b.

highest near the mouth of the Puyallup River where they increase with depth (from 1 mg/L at the surface to 2 mg/L at 125 m). The surface concentrations decrease with distance from the river mouth to ~0.6 mg/L in the outer bay surface and intermediate water (Section b).

A relatively turbid bottom layer about 50 m thick of rather uniform SPM concentration (~1.5 mg/L) due to tidal sediment resuspension was found from the Puyallup river mouth throughout the axis of the bay to its confluence with the main basin of Puget Sound.

SPM concentrations along the waterfront of the port facility (Stations 1-4; Section a) were lower at the surface (0.75 mg/L) than at depth (~1.0 mg/L). The SPM was distributed uniformly horizontally.

II.2.4. Trace Metals and Organics in Commencement Bay

II.2.4.1. Trace Metals

The sampling plan for Commencement Bay included a transect across the front of the industrial waterways as well as a transect from the Puyallup Waterway out into Commencement Bay (Fig. II.45). The data from this transect were collected in order to evaluate the sources of trace metals to Commencement Bay. Since all the samples from Commencement Bay were collected with General Oceanic Go-Flo™ sampling bottles, the vertical resolution of the data was less than that of the small boat sampling data from Elliott Bay. The samples in the surface plume of the Puyallup River (CB85-2 and CB85-3) had salinities of 22.65 and 26.04 g/kg, respectively. The surface particulate samples for the same stations were collected from slightly deeper depths and had salinities of 29.14 and 29.27 g/kg, respectively. These salinities indicate that contaminants discharged at the surface would be highly diluted with cleaner seawater by the time they were mixed down to the depths that were sampled. The lack of vertical resolution precluded the calculation of transport out of Commencement Bay by the method described for Elliott Bay.

Iron

The highest concentrations of dissolved Fe (7.6 μg/L) were found in the plume of the Puyallup River at stations CB85-2 and CB85-3 (Fig. II.53). Concentrations decreased with distance to the side of the plume and with distance out into Commencement Bay. Stations in front of other major waterways (CB85-1 and CB85-4) had dissolved Fe concentrations only slightly higher than concentrations in outer Commencement Bay water. There seemed to be a small secondary plume off the shores of Ruston. Dissolved Fe concentrations also decreased with depth; values as low as 0.25 μg/L were found at mid-depth in outer Commencement Bay.

Particulate Fe concentrations were four times higher than dissolved Fe concentrations in the Puyallup River plume and did not change dramatically to the sides of the plume nor out into the bay (Fig. II.53). In contrast, near-bottom particulate Fe concentrations were 100-300 higher

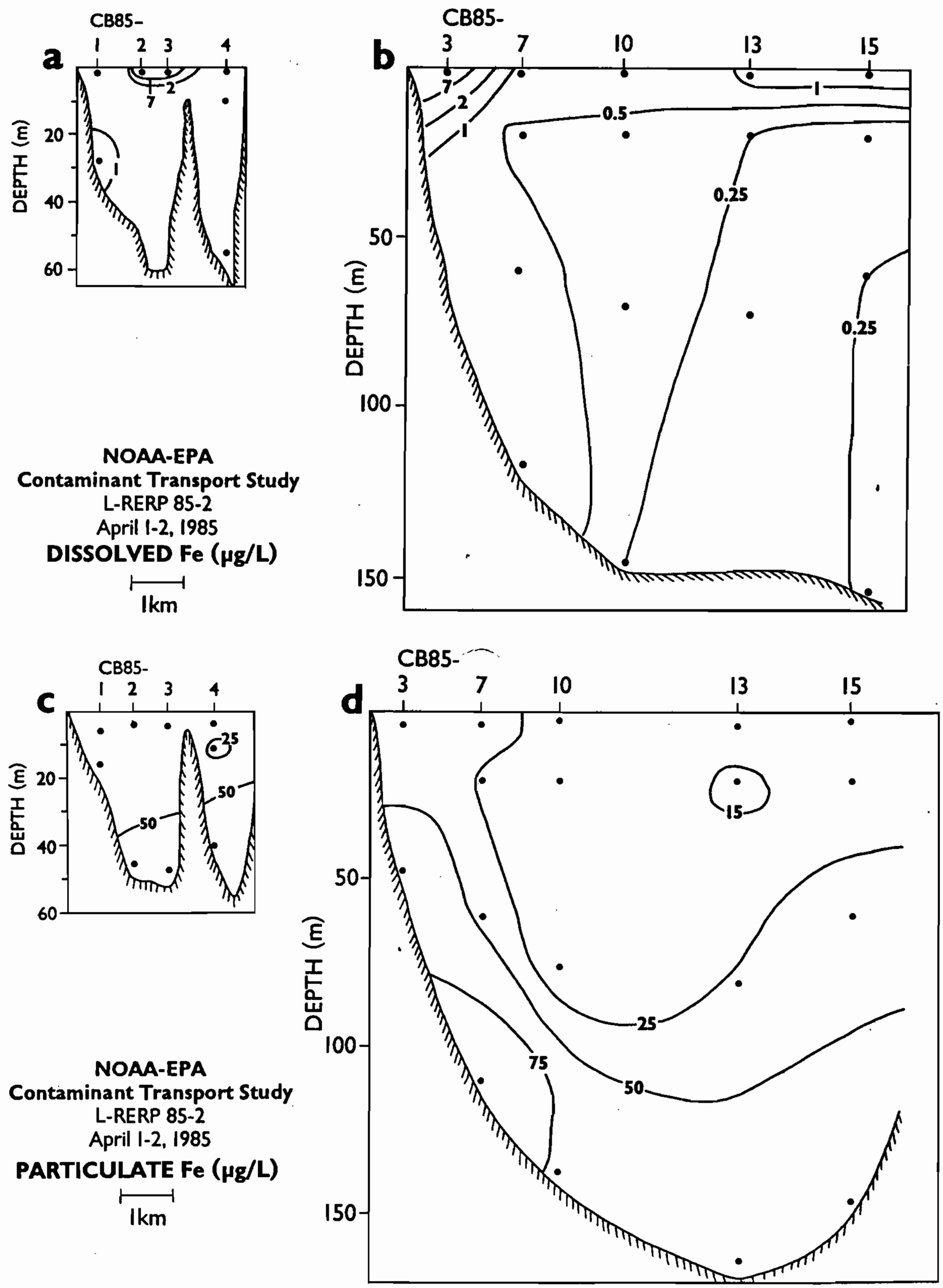


Figure II.53. Vertical transects of dissolved Fe (a and b) and particulate Fe (c and d) in Commencement Bay during April, 1985. Transects across the heads of the the waterways (a and c). Transects into outer Commencement Bay (b and d).

than the corresponding dissolved concentrations and were 3-4 times higher than particulate Fe concentrations in the mid-depth region of the water column.

Manganese

The plume of Puyallup River contained the highest concentrations of dissolved Mn (11.8 μg/L). Surface concentrations to the sides of the plume and in outer Commencement Bay ranged between 2.1 and 3.3 μg/L (Fig. II.54). The increase in dissolved Mn in the bottom waters is probably due to diffusion of Mn out of the sediments.

Particulate Mn concentrations in the Puyallup River plume were lower than the dissolved Mn concentrations by about a factor of 5. Concentrations decreased slightly to the sides of the Puyallup River plume and out into the Bay (Fig. II.54). Particulate Mn concentrations increased with depth to concentrations as high as 4.5 μg/L. In the near-bottom region, particulate Mn concentrations were generally between 0.5 and 1.0 times the dissolved Mn concentrations.

Copper

The highest concentrations of dissolved Cu (750 ng/L) were found in the Puyallup River plume and decreased to the sides of the plume and with distance into outer Commencement Bay (Fig. II.55). Concentration also decreased with depth to values less than 300 ng/L in the bottom waters of outer Commencement Bay.

The highest surface particulate Cu concentration (58 ng/L) was found at station CB85-4 (near the head of Middle Waterway) with concentrations decreasing to the northeast and out into the Bay (Fig. II.55). In the surface waters of Commencement Bay, particulate Cu concentrations were usually less than one-tenth of the dissolved Cu concentrations. A secondary particulate Cu plume was also observed off the shores of Ruston. Particulate Cu concentrations increased in the near-bottom nepheloid layer by a factor of about 3 relative to mid-depth concentrations. In the near-bottom region, dissolved Cu concentrations were greater than particulate Cu concentrations by factors ranging between 3 and 6.

Zinc

The highest dissolved Zn concentration of 2600 ng/L was found in the plume of the Puyallup River. Concentration decreased to 1100 ng/L to sides of the plume and out into the Bay (Fig. II.56). A secondary plume was evident off the shores of Ruston. Dissolved Zn concentrations decrease with depth to values less than 700 ng/L in the bottom waters of outer Commencement Bay.

The highest surface particulate Zn concentration (155 ng/L) was also found in the Puyallup River plume (Fig. II.56), although it was 10 times lower than the corresponding dissolved Zn concentration. The surface particulate Zn concentrations decreased both to the sides of the plume

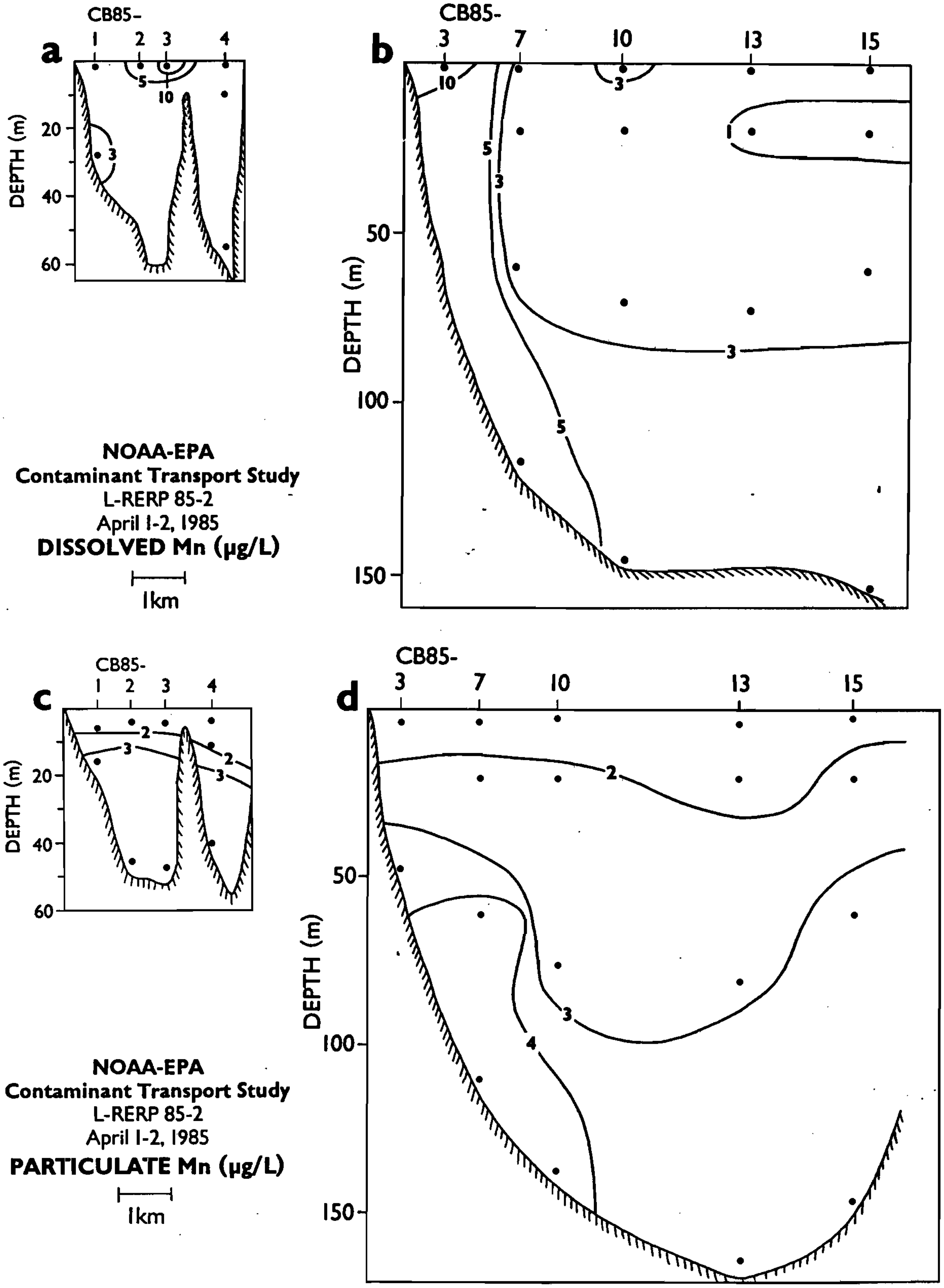


Figure II.54. Vertical transects of dissolved Mn (a and b) and particulate Mn (c and d) in Commencement Bay during April, 1985. Transects across the heads of the the waterways (a and c). Transects into outer Commencement Bay (b and d).

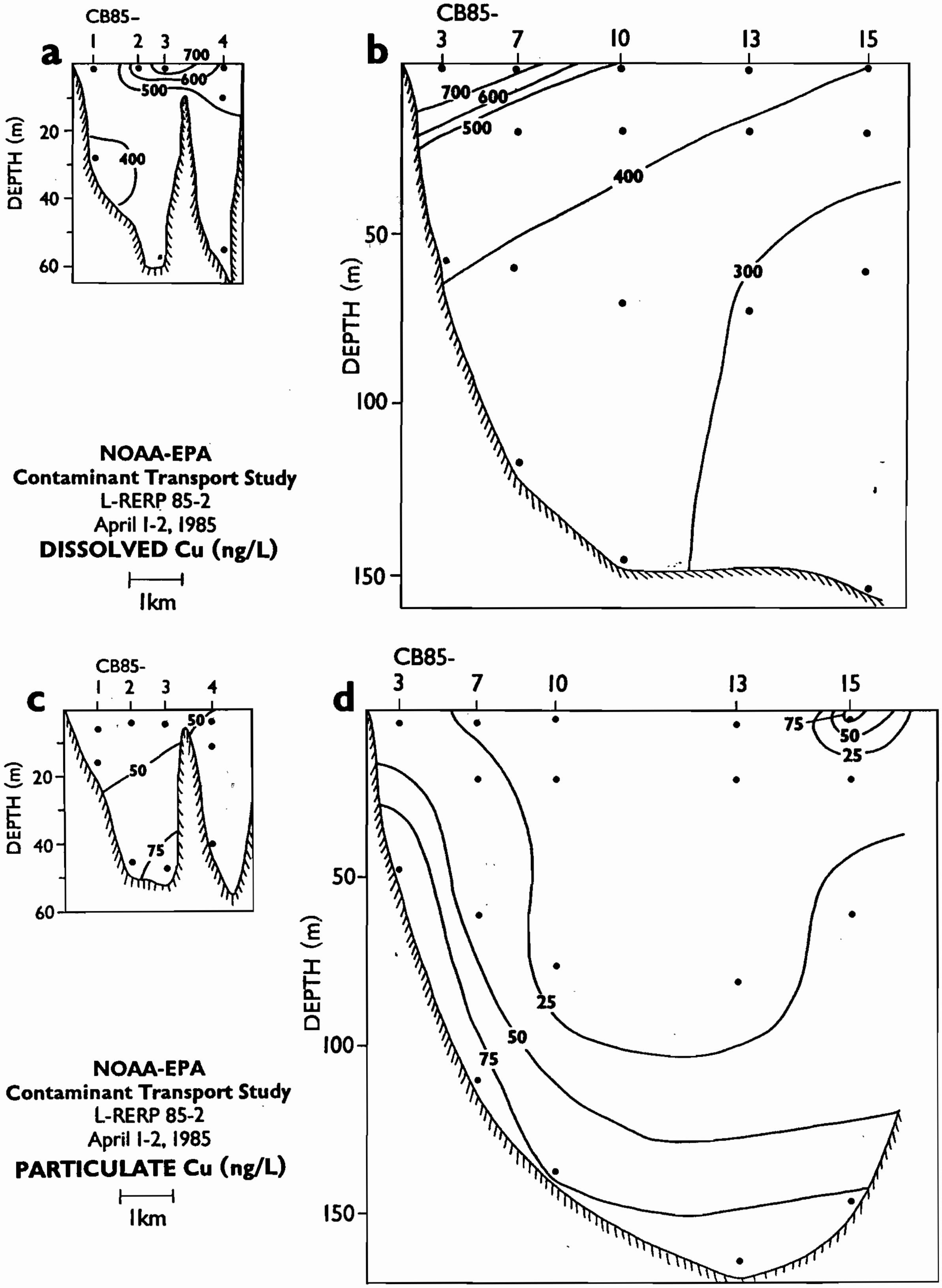


Figure II.55. Vertical transects of dissolved Cu (a and b) and particulate Cu (c and d) in Commencement Bay during April, 1985. Transects across the heads of the the waterways (a and c). Transects into outer Commencement Bay (b and d).

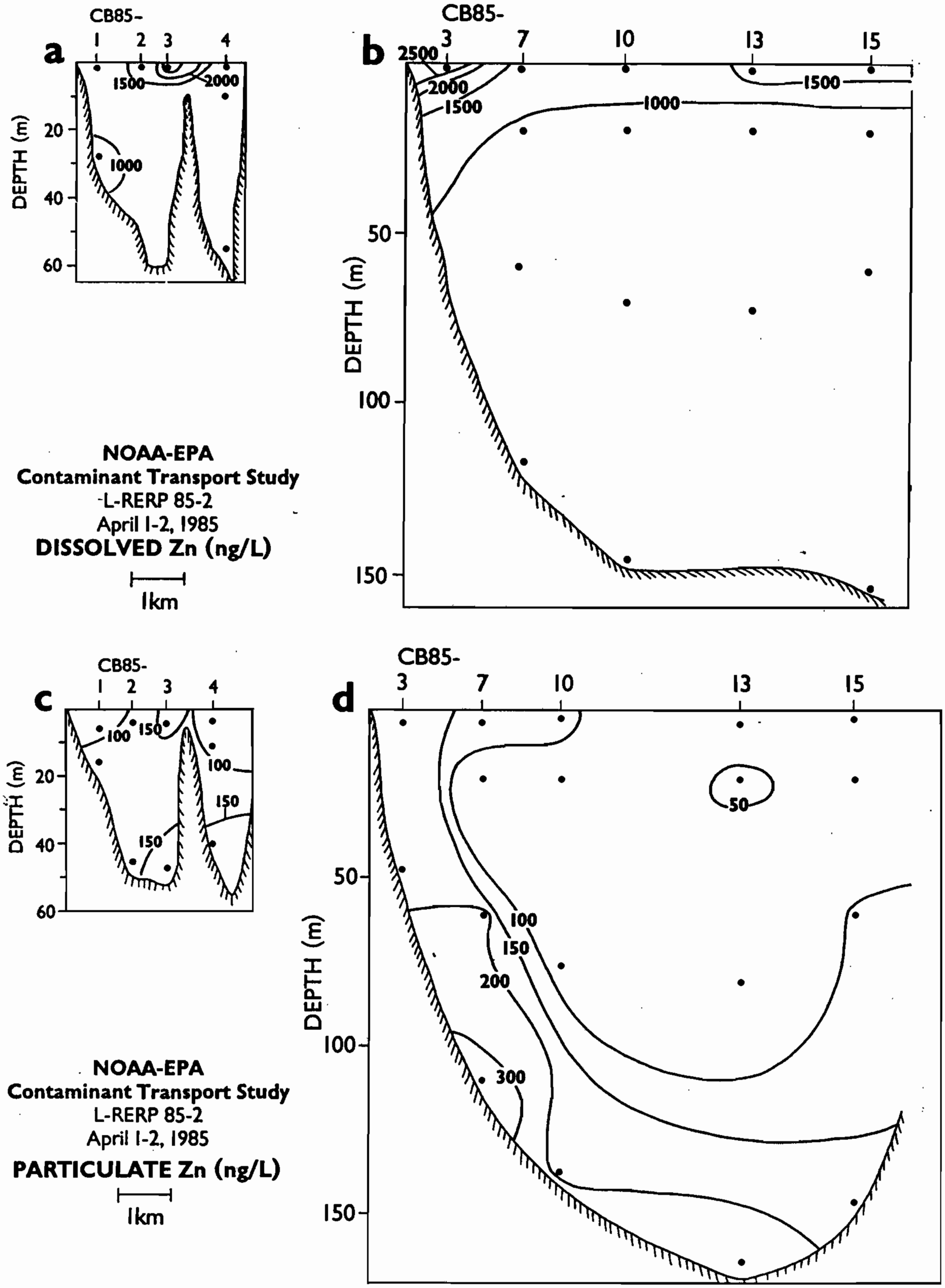


Figure II.56. Vertical transects of dissolved Zn (a and b) and particulate Zn (c and d) in Commencement Bay during April, 1985. Transects across the heads of the the waterways (a and c). Transects into outer Commencement Bay (b and d).

and out into the Bay. The particulate Zn concentrations increased with depth to values as high as 315 ng/L in the near-bottom nepheloid layer of outer Commencement Bay. In this region, the particulate Zn concentrations were between 0.25 and 0.5 times the corresponding dissolved Zn.

Lead

The highest concentration of dissolved Pb (80 ng/L) was found in the plume of the Puyallup River and values decreased to the side of the plume (Fig. II.57). Dissolved Pb concentrations also decreased with distance into the Bay. Dissolved Pb concentrations decreased with depth to values less than 10 ng/L in the bottom water of outer Commencement Bay.

The concentration of particulate Pb in the Puyallup River Plume was 202 ng/L (Fig. II.57) which was more than twice the dissolved Pb concentration. Although the particulate Pb concentrations in surface waters decreased to the side of the plume, the concentrations in front of the other waterways were greater than concentrations in the outer Bay. In outer Commencement Bay, the particulate Pb concentrations increase in the near-bottom nepheloid layer to values 2 to 4 times higher than mid-depth concentrations. The particulate Pb concentrations in the nepheloid layer were more than 5 times the corresponding dissolved Pb concentrations.

Nickel

The transect of dissolved Ni showed the least variation of the metals studied in Commencement Bay (Fig. II.58). Dissolved Ni only varied between 570 ng/L in the river plume and 390 ng/L in the bottom waters of outer Commencement Bay.

The particulate Ni concentration in the Puyallup River Plume was 25 ng/L (Fig. II.58) which was 20 times lower than the dissolved Ni concentrations. Surface particulate Ni concentrations decreased to the side of the plume and out into the Bay. The particulate Ni concentrations in the near-bottom layer were higher than mid-depth stations by factors ranging between 2 and 3. In the nepheloid layer, the dissolved Ni concentrations were still greater than the particulate Ni concentrations by factors greater than 5.

Cadmium

As in Elliott Bay, the lowest dissolved Cd concentration (75 ng/L) was found in the river plume (Fig. II.59). However, surface concentrations from other samples collected at the head of other waterways were slightly higher than the concentrations of offshore waters.

Chromium

The surface particulate Cr concentration in the Puyallup River plume (52 ng/L) was only slightly higher than concentrations in surface waters to the side of the plume and in outer

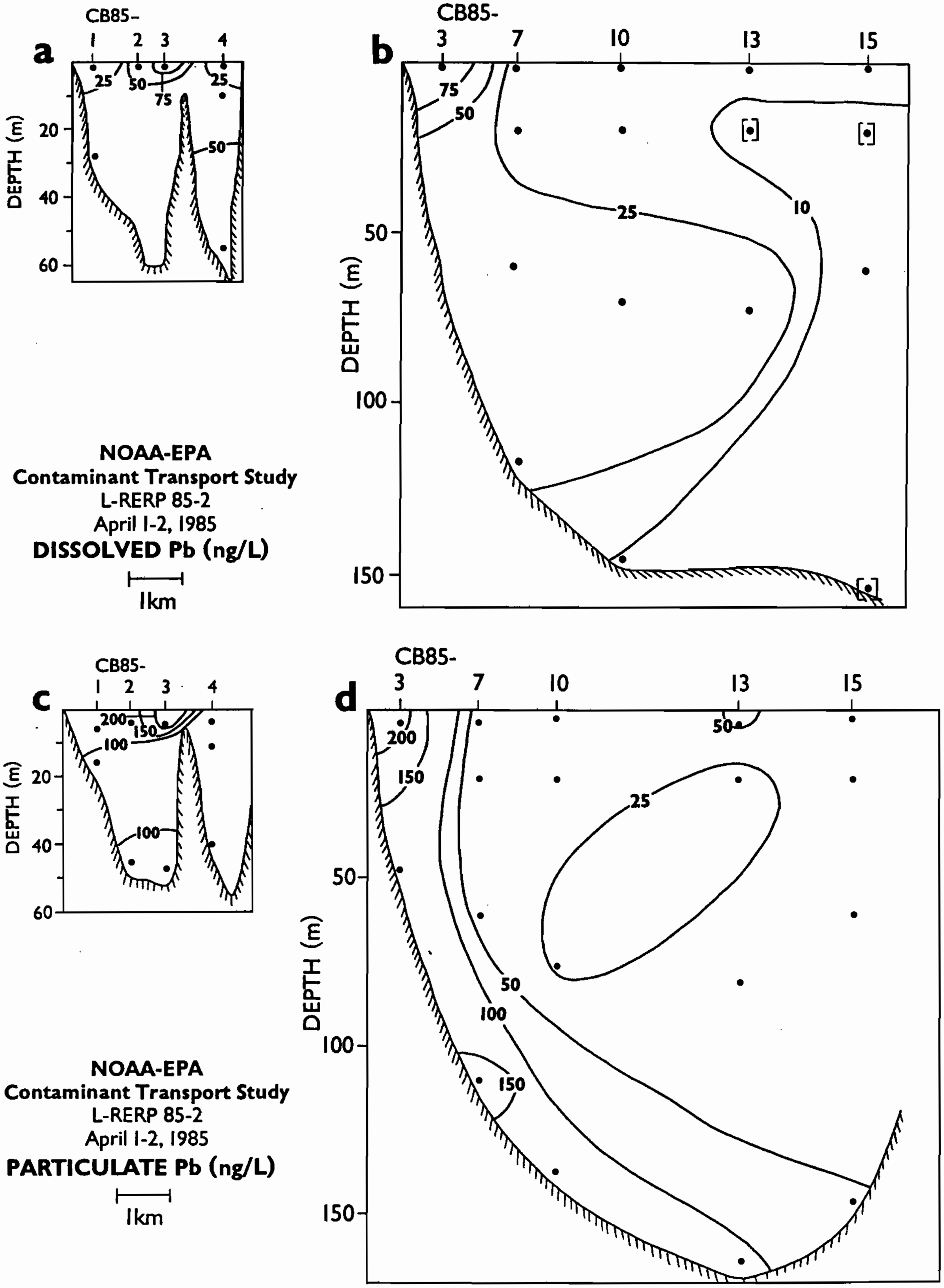


Figure II.57. Vertical transects of dissolved Pb (a and b) and particulate Pb (c and d) in Commencement Bay during April, 1985. Transects across the heads of the the waterways (a and c). Transects into outer Commencement Bay (b and d).

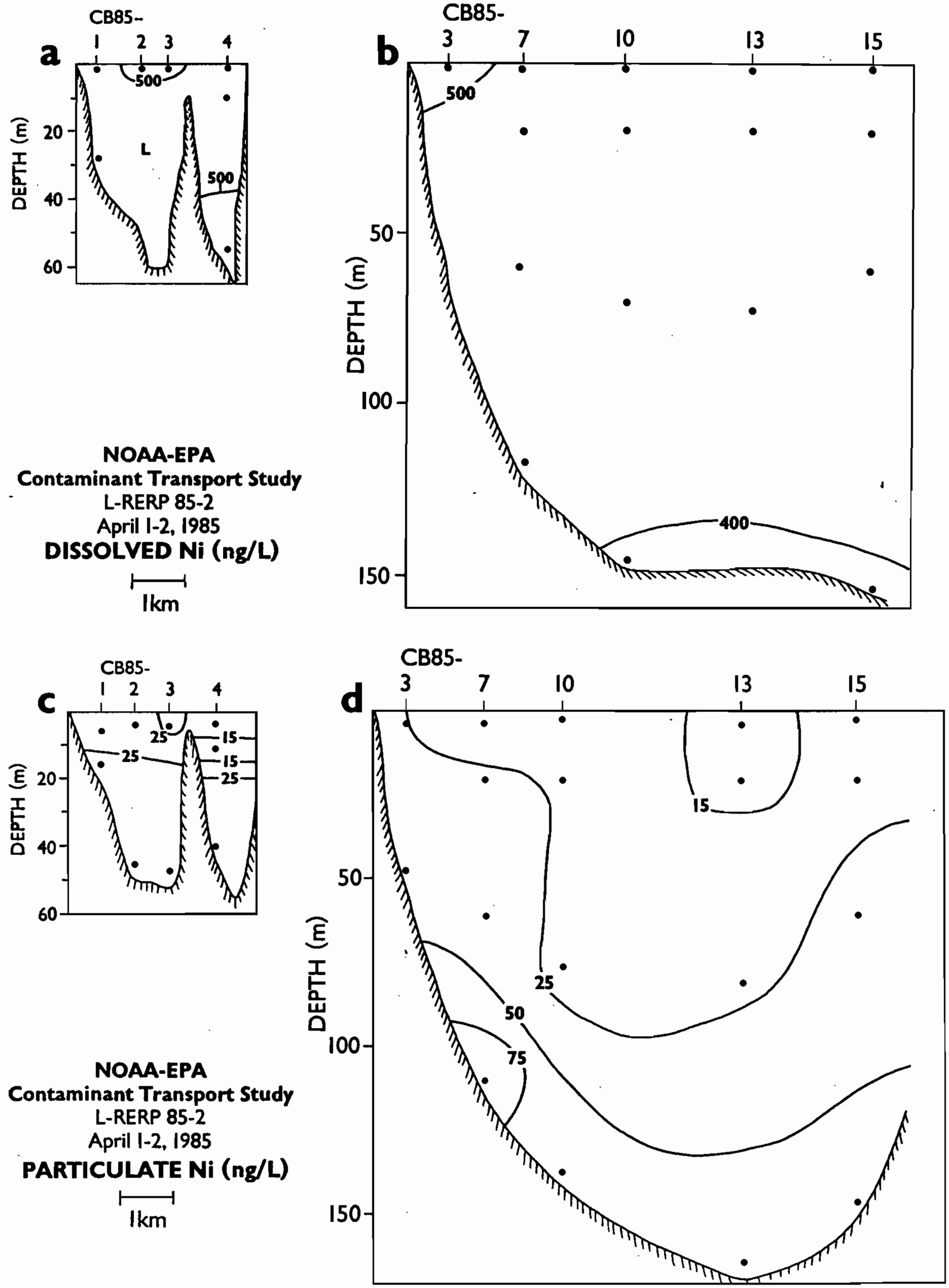


Figure II.58. Vertical transects of dissolved Ni (a and b) and particulate Ni (c and d) in Commencement Bay during April, 1985. Transects across the heads of the the waterways (a and c). Transects into outer Commencement Bay (b and d).

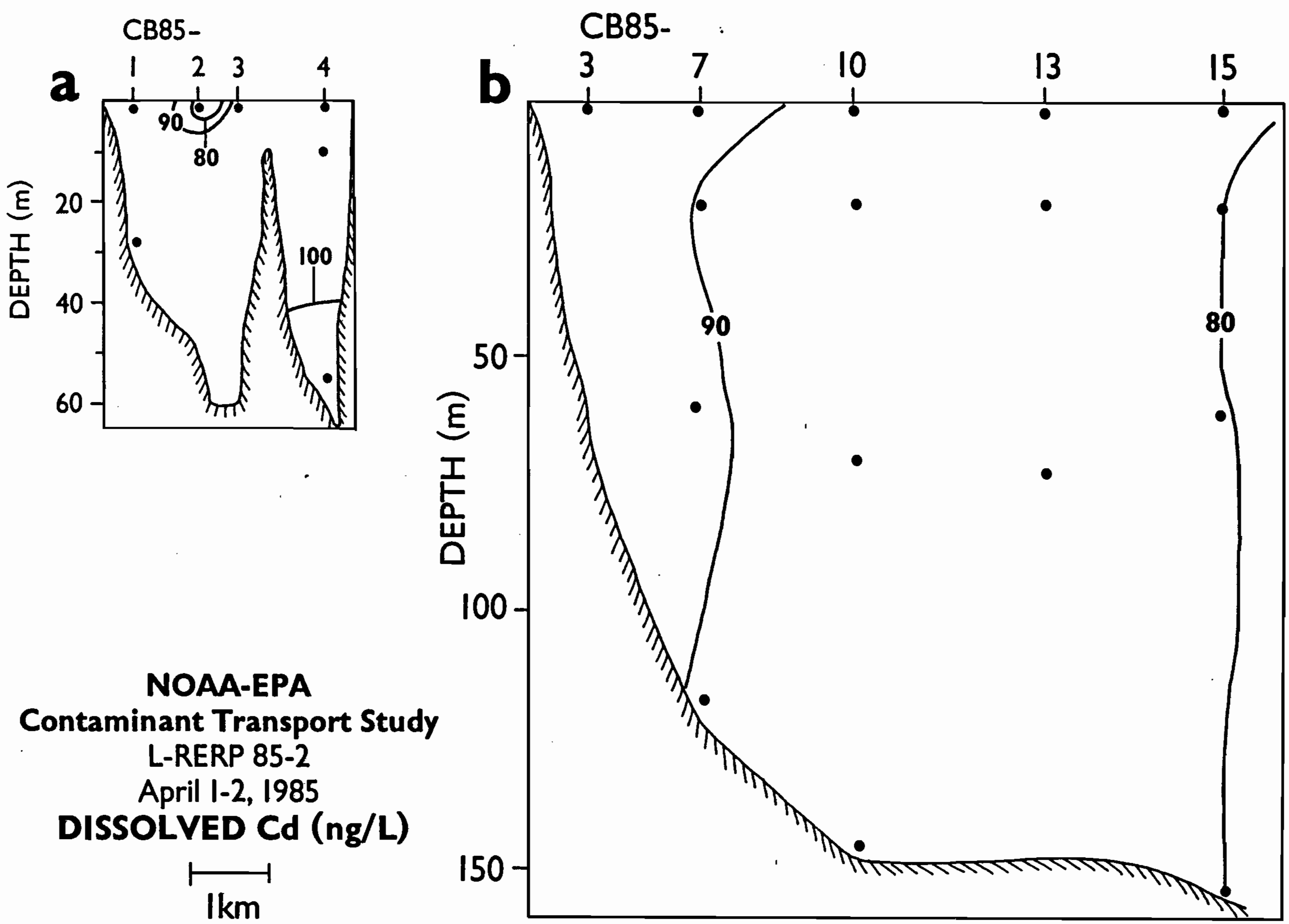


Figure II.59. Vertical transects of dissolved Cd (a and b) Commencement Bay during April, 1985. The transect across the heads of the the waterways is depicted in Figs. a while the transect into outer Commencement Bay is shown in Figs. b.

Commencement Bay. Particulate Cr concentrations in the nepheloid layer were 2 to 5 times higher than mid-depth concentrations.

II.2.4.2. Toxic Organics

Commencement Bay PAH concentrations in April 1985 were 3.5 µg/g in the surface waters and 2.0 µg/g at 20 m (Fig. II.60). The concentration at the lower depth compares well with the concentration of 2.2 µg/g found on settling particulates at the same depth in May of 1981 (Bates *et al.*, 1987).

Polychlorinated biphenyl concentrations in Commencement Bay were near or below our detection limits. DDT, DDE and DDD were all below detection limits. Since widespread use of these chlorinated hydrocarbons was curtailed in the 1970's, the low concentrations we observe are not surprising.

II.2.4.3. Summary

The major source of both dissolved and particulate metals discharged into Commencement Bay clearly is the Puyallup River plume. Whether this source originates from the Puyallup River itself or entrained from anthropogenic sources on the Commencement Bay waterfront can not be determined from this study. While particulate Fe and Pb are the dominant forms of these trace metals in the plume, dissolved Mn, Cu, Zn and Ni predominate. The surface concentration of most metals decreases to the sides of the plume and with distance into the outer Bay. This decrease is a result of dilution by deeper, more-saline water which has lower metal concentrations. The distribution of particulate and dissolved metals in the water column is distinctly different. For dissolved metals, only dissolved Mn shows any indication of a significant increase near the bottom. In contrast, the presence of a near-bottom nepheloid layer containing a large particulate concentration results in near-bottom maximums for all particulate metals. This behavior shifts the partitioning of all metals towards the particulate phase.

The low PAH concentrations on settling particulates in Commencement Bay are consistent with the low values on surface sediments in the deeper waters of Commencement Bay (Crecelius *et al.*, 1983). The strong currents in Commencement Bay prevent the accumulation of fine-grained sediment and their associated PAH. The suspended PAH in Commencement Bay are likely transported out of the Bay, through Colvos Passage and ultimately deposited in the sediments of the central Main Basin (Bates *et al.*, 1987). The small amounts of PCB present presumably result from scouring of pipes in which PCB compounds were previously deposited and perhaps from dredging and relocation of PCB-contaminated sediments.

PAH CONCENTRATIONS IN COMMENCEMENT BAY (ng/g)

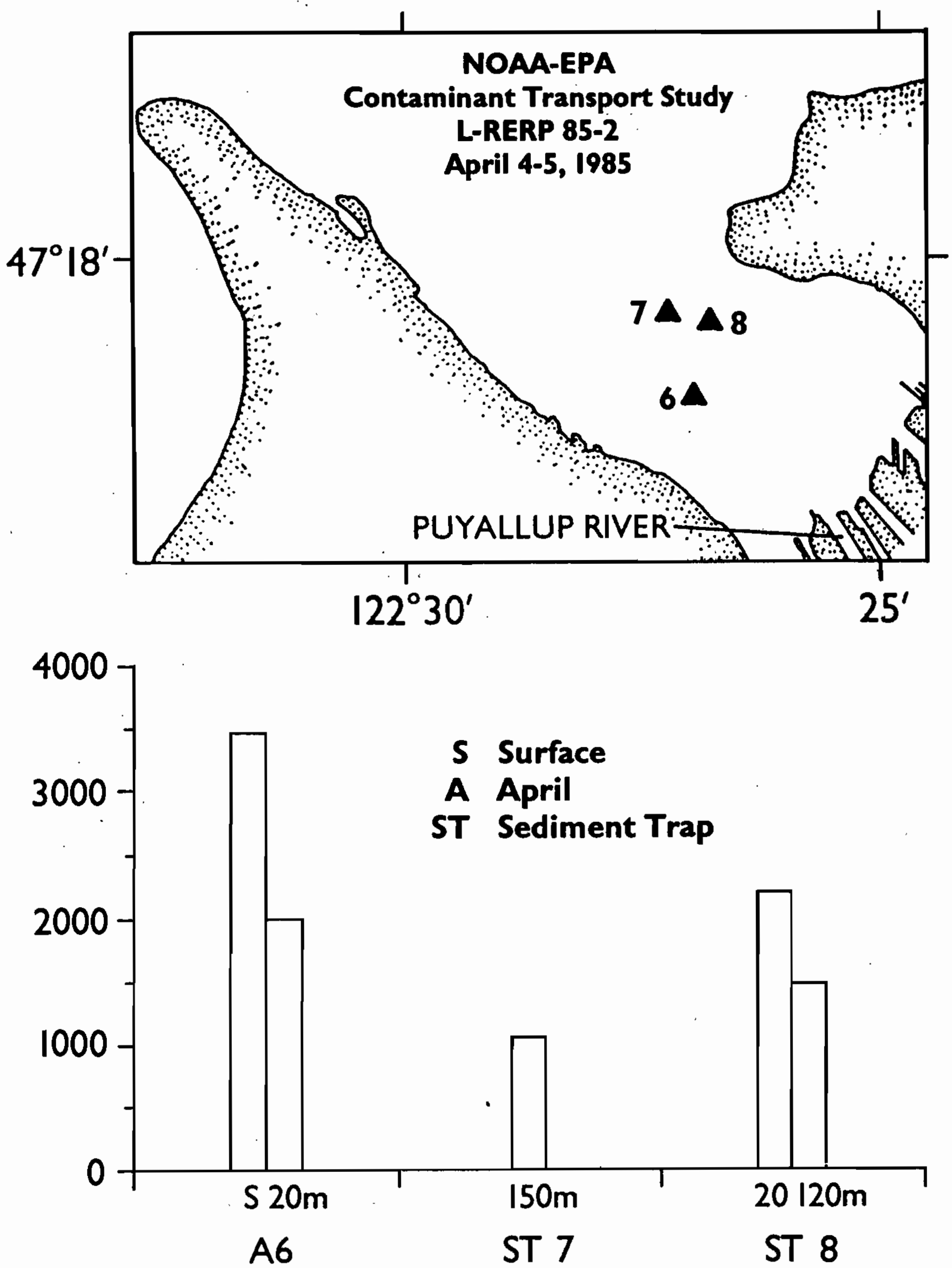


Figure II.60. PAH in Commencement Bay.

ACKNOWLEDGMENTS

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APPENDIX I.

PARTICULATE CHEMISTRY DATA FOR ELLIOTT BAY
(in units of wt./vol. of water)
L-RERP 85-2, April 4-5, 1985

Station	Date/Time	Position N/W	Depth m	Sal g/kg	TSM µg/L	Al µg/L	Ti µg/L	Cr ng/L	Mn µg/L	Fe µg/L	Ni ng/L	Cu ng/L	Zn ng/L	Pb ng/L
EB85-1	4APR85/1506	47°35.80/122°20.65	2	28.61	945.8	80.2	5.05	77	2.23	58.7	30	60	232	78
			10	29.74	320.7	20.5	1.16	21	1.51	13.3	10	9	50	42
			20	29.80	373.5	22.3	1.53	26	2.31	16.7	14	16	82	41
			50	29.94	491.5	33.3	2.17	34	2.85	22.7	20	30	118	49
EB85-2	4APR85/1525	47°36.23/122°20.65	2	29.38	515.4	33.6	2.22	36	1.34	26.6	18	55	111	66
			10	29.75	301.0	19.3	1.19	23	1.67	13.4	11	16	64	37
			20	29.77	354.3	19.1	1.21	22	2.04	13.3	11	13	77	41
			60	29.96	460.6	33.8	2.14	36	2.83	22.4	22	29	84	49
EB85-3	4APR85/0858	47°35.57/122°21.55	2	28.62	887.6	67.7	5.19	80	2.01	60.3	35	204	229	97
			10	29.74	260.0	16.2	1.04	19	1.69	11.4	10	7	60	28
			20	29.79	273.1	13.9	1.09	19	1.47	11.7	11	11	58	24
			50	30.05	426.6	31.8	1.93	31	2.62	19.7	20	16	61	32
EB85-4	4APR85/1033	47°35.80/122°21.90	2	27.74	1240.0	98.2	6.99	97	2.52	83.6	42	95	227	101
			10	29.56	307.2	15.8	1.14	18	1.12	13.5	9	15	70	23
			20	29.80	342.2	19.8	1.43	24	2.07	15.5	14	12	65	45
			40	29.94	427.2	25.8	1.73	30	2.67	18.3	17	18	106	34
			65	30.00	391.1	32.7	2.09	34	3.94	21.5	21	18	70	42
EB85-5	4APR85/1139	47°36.27/122°21.30	10	27.08	1422.7	116.1	8.04	106	2.50	99.4	48	92	213	112
			20	29.76	304.5	18.6	1.17	20	1.84	13.5	10	10	90	37
			40	29.95	416.5	26.3	1.68	29	2.82	18.2	17	12	148	50
			60	30.06	391.8	28.1	1.53	26	2.47	16.6	14	4	79	27
			90	30.10	483.1	37.3	2.16	37	3.16	22.3	23	19	89	42
EB85-6	4APR85/1405	47°36.70/122°21.58	2	25.98*	2347.9	237.6	13.79	186	3.92	171.0	87	171	456	146
			10	29.74*	259.9	15.3	0.92	17	0.88	10.4	8	3	36	28
			40	29.88*	647.1	46.4	3.16	54	3.29	33.0	33	74	142	94
			60	30.05	639.2	41.2	2.82	45	3.29	29.7	28	40	142	44
EB85-7	5APR85/1451	47°37.02/122°21.73	2	29.02*	1010.2	87.9	6.02	76	1.97	66.6	35	64	186	80
			10	29.71*	389.2	22.7	1.71	25	1.44	18.5	12	17	69	81
			30	29.86	424.5	27.8	1.71	30	2.70	18.3	15	17	80	36
EB85-8	4APR85/1741	47°36.08/122°23.07	10	29.31*	386.1	22.8	1.40	42	1.69	15.8	37	56	48	47
			40	29.96	362.0	26.7	1.61	29	2.51	16.6	16	24	54	38

* Salinity calculated from CTD data while sample was being collected.

APPENDIX I. (Continued)

PARTICULATE CHEMISTRY DATA FOR ELLIOTT BAY
(in units of wt./vol. of water)
L-RERP 85-2, April 4-5, 1985

Station	Date/Time	Position N/W	Depth m	Sal g/kg	TSM µg/L	Al µg/L	Ti µg/L	Cr ng/L	Mn µg/L	Fe µg/L	Ni ng/L	Cu ng/L	Zn ng/L	Pb ng/L
EB85-9	4APR85/1257	47°36.73/122°22.92	2	27.60	1388.6	118.1	7.68	107	2.68	93.1	46	91	220	60
			20	29.83	261.6	17.8	0.84	**	1.65	9.3	7	**	30	**
			40	29.96	372.1	25.5	1.59	26	2.47	16.2	15	14	67	44
			60	30.03	361.0	26.2	1.49	26	2.28	15.5	15	11	83	34
			100	30.22	804.1	61.7	4.25	66	3.45	44.4	42	59	130	88
			150	30.34	856.5	66.8	4.57	69	3.01	45.9	46	53	131	81
EB85-10	5APR85/1159	47°37.27/122°22.83	2	26.48*	2267.1	207.0	14.47	167	3.84	160.5	78	171	316	122
			20	29.77*	378.8	22.4	1.26	29	1.72	13.6	14	10	43	30
			40	30.05	369.1	28.4	1.50	25	1.49	16.0	14	13	66	41
EB85-11	4APR85/2101	47°35.28/122°24.70	2	29.77*	471.3	30.3	1.60	27	2.03	17.1	14	8	88	25
			20	29.80*	499.4	30.5	1.81	30	2.26	18.7	15	10	66	35
			40	29.86*	529.3	40.4	2.18	36	2.63	22.3	21	19	67	39
			70	30.19	809.8	50.3	3.68	55	3.12	36.0	35	38	106	56
EB85-12	4APR85/1806	47°35.98/122°24.77	SFC	29.73*	481.3	27.6	1.70	29	1.82	18.1	15	10	62	33
			160	30.49	2040.2	95.7	9.81	140	4.34	62.5	98	141	264	125
EB85-13	4APR85/1702	47°36.70/122°24.77	2	28.79*	650.5	58.7	3.59	53	1.89	43.5	24	35	112	66
			20	29.81*	395.0	25.0	1.56	26	2.43	16.6	14	14	62	34
			40	29.91*	320.3	22.0	1.48	26	2.31	15.0	14	16	56	41
			60	30.03*	328.4	19.3	1.26	23	1.63	12.6	12	11	48	34
			100	30.22*	509.4	32.7	2.36	39	2.65	23.4	23	20	84	37
			180	30.53	442.4	35.6	1.81	33	2.26	19.4	19	58	86	50
EB85-14	5APR85/1423	47°37.53/122°24.68	2	27.45*	2451.6	211.1	15.59	182	4.24	138.6	88	190	365	146
			20	29.81*	365.9	24.4	1.48	26	2.13	15.9	14	11	63	45
			40	29.93*	376.3	29.0	1.70	30	2.70	17.5	17	16	64	32
			60	29.97*	437.1	29.9	1.77	30	2.61	18.2	18	21	71	48
			80	30.39	1401.0	77.6	6.56	99	3.40	63.4	64	78	170	82

* Salinity calculated from CTD data while sample was being collected.

** Below Detection Limits

APPENDIX I. (Continued)

PARTICULATE CHEMISTRY DATA FOR ELLIOTT BAY
Small Boat
(in units of wt./vol. of water)
L-RERP 85-2, April 4-5, 1986

Station	Date/Time	Position N/W	Depth m	Sal g/kg	TSM µg/L	Al µg/L	Ti µg/L	Cr ng/L	Mn µg/L	Fe µg/L	Ni ng/L	Cu ng/L	Zn ng/L	Pb ng/L
EB85-SB1	4Apr85/1038	47°35.96/122°20.43	SFC	20.84	3312.8	322.2	20843	464	5.60	278.9	131	392	565	244
EB85-SB2	4Apr85/1246	47°36.31/122°20.71	SFC	18.44	3495.4	290.6	22387	449	5.58	278.0	145	335	520	195
EB85-SB3	4Apr85/1019	47°35.42/122°21.53	SFC	9.62	8564.3	586.1	51766	1041	12.88	633.6	334	838	1261	475
EB85-SB4	4Apr85/1047	47°35.90/122°21.63	SFC	14.46	7525.0	606.8	48419	967	12.01	595.5	288	877	1257	472
EB85-SB5	4Apr85/1238	47°36.30/122°21.67	SFC	18.43	4861.9	320.9	32054	670	8.34	322.9	197	578	952	352
EB85-SB6	4Apr85/1257	47°36.72/122°21.06	SFC	19.31	4216.7	347.3	26988	576	7.00	350.4	160	454	754	265
EB85-SB7	4Apr85/1408	47°37.26/122°22.22	SFC	19.91	3941.5	313.0	25613	548	0.72	334.9	159	428	735	272
EB85-SB8	4Apr85/1224	47°35.97/122°23.20	SFC	28.02	1005.0	80.3	5647	127	2.21	72.3	35	144	224	205
EB85-SB9	4Apr85/1316	47°36.70/122°22.95	SFC	23.20	2971.7	234.5	19330	401	5.16	247.4	122	354	515	207
EB85-SB10	4Apr85/1425	47°37.40/122°23.22	SFC	20.62	2937.9	218.6	18446	407	5.22	255.6	126	370	742	234
EB85-SB13	4Apr85/1343	47°36.80/122°24.66	SFC	24.29	2155.1	178.5	1537	284	3.77	171.6	86	224	349	148
EB85-SB14	4Apr85/1439	47°38.17/122°24.88	SFC	21.46	2658.0	207.0	17274	393	4.68	230.5	125	348	551	424
EB85-SBDR0	4Apr85/0918	47°35.01/122°21.54	SFC	8.39	10644.1	622.1	66752	1381	16.98	821.7	459	1127	1456	633
EB85-SBT1	4Apr85/0608	47°35.41/122°22.52	SFC	***	1061.5	44.2	6967	203	2.82	75.1	42	223	229	278
EB85-SBT8	4Apr85/1333	47°36.79/122°24.58	SFC	29.33	407.5	23.7	12985	32	1.03	17.9	[2]	15	22	[49]
EB85-SBT9	4Apr85/1349	47°37.12/122°24.67	SFC	24.87	2425.0	207.0	15146	333	4.38	196.7	109	291	475	415
EB85-SBT13	4Apr85/1449	48°38.19/122°25.51	SFC	25.95	1440.0	130.0	8012	180	2.61	109.9	50	143	251	134
EB85-SBT14	4Apr85/1501	47°38.56/122°25.60	SFC	22.04	3437.5	283.2	21855	500	5.96	299.6	172	430	680	394

*** Not Reported

The Fe values for stations EB85-SBDR0 and EB85-SB3 were calculated from the K2 peak.

APPENDIX II.

PARTICULATE CHEMISTRY DATA FOR ELLIOTT BAY
(in units of wt./wt. of suspended matter)
L-RERP 85-2, April 4-5, 1986

Station	Date/Time	Position N/W	Depth m	Sal g/kg	TSM µg/L	Al %	Ti %	Cr ppm	Mn ppm	Fe %	Ni ppm	Cu ppm	Zn ppm	Pb ppm
EB85-1	4APR85/1506	47°35.80/122°20.65	2	28.61	945.8	8.48	0.53	82	2372	6.20	32	64	245	83
			10	29.74	320.7	6.39	0.36	66	4707	4.15	32	29	155	132
			20	29.80	373.5	5.98	0.41	69	6187	4.46	38	42	219	110
			50	29.94	491.5	6.78	0.44	69	5797	4.62	40	61	239	99
EB85-2	4APR85/1525	47°36.23/122°20.65	2	29.38	515.4	6.52	0.43	70	2598	5.17	35	106	216	127
			10	29.75	301.0	6.42	0.39	75	5556	4.46	36	51	211	122
			20	29.77	354.3	5.39	0.34	62	5764	3.76	30	37	216	115
			60	29.96	460.6	7.33	0.46	77	6140	4.87	47	62	183	106
EB85-3	4APR85/0858	47°35.57/122°21.55	2	28.62	887.6	7.63	0.59	90	2261	6.80	40	231	258	109
			10	29.74	260.0	6.21	0.40	73	6484	4.38	37	27	231	108
			20	29.79	273.1	5.10	0.40	69	5381	4.30	38	41	214	89
			50	30.05	426.6	7.45	0.45	73	6142	4.62	45	37	142	75
EB85-4	4APR85/1033	47°35.80/122°21.90	2	27.74	1240.0	7.91	0.56	78	2032	6.74	34	76	183	82
			10	29.56	307.2	5.13	0.37	58	3634	4.38	31	50	229	75
			20	29.80	342.2	5.77	0.42	71	6017	4.52	42	35	191	132
			40	29.94	427.2	6.05	0.41	69	6258	4.27	39	43	249	80
			65	30.00	391.1	8.35	0.54	86	10062	5.49	55	45	179	108
EB85-5	4APR85/1139	47°36.27/122°21.30	10	27.08	1422.7	8.16	0.57	75	1755	6.98	34	65	149	79
			20	29.76	304.5	6.10	0.39	67	6030	4.45	33	34	295	122
			40	29.95	416.5	6.31	0.40	71	6761	4.36	41	29	355	120
			60	30.06	391.8	7.18	0.39	66	6310	4.23	37	10	202	70
			90	30.10	483.1	7.72	0.45	77	6531	4.62	47	39	185	87
EB85-6	4APR85/1405	47°36.70/122°21.58	2	25.98*	2347.9	10.12	0.59	79	1669	7.28	37	73	194	62
			10	29.74*	259.9	5.87	0.35	65	3388	4.01	31	12	138	108
			40	29.88*	647.1	7.17	0.49	83	5074	5.11	50	115	220	145
			60	30.05	639.2	6.44	0.44	70	5152	4.65	44	62	222	68
EB85-7	5APR85/1451	47°37.02/122°21.73	2	29.02*	1010.2	8.70	0.60	75	1942	6.59	34	64	184	79
			10	29.71*	389.2	5.84	0.44	63	3699	4.74	31	45	176	208
			30	29.86	424.5	6.56	0.40	70	6358	4.30	36	40	189	84
EB85-8	4APR85/1741	47°36.08/122°23.07	10	29.31*	386.1	5.91	0.36	108	4375	4.08	97	146	125	121
			40	29.96	362.0	7.39	0.45	80	6939	4.58	45	66	148	106

* Salinity calculated from CTD data while sample was being collected.

APPENDIX II. (Continued)

PARTICULATE CHEMISTRY DATA FOR ELLIOTT BAY
(in units of wt./wt. of suspended matter)
L-RERP 85-2, April 4-5, 1986

Station	Date/Time	Position N/W	Depth m	Sal g/kg	TSM µg/L	Al %	Ti %	Cr ppm	Mn ppm	Fe %	Ni ppm	Cu ppm	Zn ppm	Pb ppm
EB85-9	4APR85/1257	47°36.73/122°22.92	2	27.60	1388.6	8.51	0.55	77	1929	6.71	33	65	158	43
			20	29.83	261.6	6.80	0.32	**	6299	3.54	26	**	116	**
			40	29.96	372.1	6.86	0.43	70	6636	4.36	40	36	180	119
			60	30.03	361.0	7.26	0.41	72	6316	4.28	42	31	229	94
			100	30.22	804.1	7.67	0.53	82	4294	5.52	52	73	162	109
			150	30.34	856.5	7.79	0.53	81	3592	5.36	53	62	152	94
EB85-10	5APR85/1159	47°37.27/122°22.83	2	26.48*	2267.1	9.13	0.64	74	1695	7.08	35	75	140	54
			20	29.77*	378.8	5.90	0.33	76	4528	3.59	36	27	113	79
			40	30.05	369.1	7.70	0.41	67	4045	4.32	38	34	178	111
EB85-11	4APR85/2101	47°35.28/122°24.70	2	29.77*	471.3	6.44	0.34	57	4302	3.63	30	17	186	53
			20	29.80*	499.4	6.11	0.36	61	4529	3.74	31	21	131	71
			40	29.86*	529.3	7.63	0.41	67	4964	4.21	40	36	126	74
			70	30.19	809.8	6.21	0.45	68	3854	4.44	44	47	131	69
EB85-12	4APR85/1806	47°35.98/122°24.77	SFC	29.73*	481.3	5.73	0.35	60	3789	3.77	32	20	129	68
			160	30.49	2040.2	4.69	0.48	69	2126	3.06	48	69	129	61
EB85-13	4APR85/1702	47°36.70/122°24.77	2	28.79*	650.5	9.03	0.55	81	2906	6.68	36	54	172	101
			20	29.81*	395.0	6.32	0.40	66	6148	4.19	36	35	157	85
			40	29.91*	320.3	6.88	0.46	82	7214	4.67	45	50	174	128
			60	30.03*	328.4	5.87	0.39	70	4968	3.84	36	34	147	102
			100	30.22*	509.4	6.42	0.46	77	5197	4.59	45	39	164	73
			180	30.53	442.4	8.06	0.41	74	5117	4.37	42	130	195	113
EB85-14	5APR85/1423	47°37.53/122°24.68	2	27.45*	2451.6	8.61	0.64	74	1727	5.65	36	77	149	59
			20	29.81*	365.9	6.68	0.40	71	5828	4.33	37	31	172	123
			40	29.93*	376.3	7.72	0.45	79	7167	4.64	44	41	171	84
			60	29.97*	437.1	6.84	0.41	68	6057	4.16	40	48	163	110
			80	30.39	1401.0	5.54	0.47	70	2424	4.52	45	56	121	65

* Salinity calculated from CTD data while sample was being collected.

** Below Detection Limits

PARTICULATE CHEMISTRY DATA FOR ELLIOTT BAY
Small Boat
(in units of wt./wt. of suspended matter)
L-RERP 85-2, April 4-5, 1985

Station	Date/Time	Position N/W	Depth m	Sal g/kg	TSM µg/L	Al %	Ti %	Cr ppm	Mn ppm	Fe %	Ni ppm	Cu ppm	Zn ppm	Pb ppm
EB85-SB1	4APR85/1038	47°35.96/122°20.43	SFC	20.84	3312.8	9.72	6292	140	1689	8.42	40	118	171	74
EB85-SB2	4APR85/1246	47°36.31/122°20.71	SFC	18.44	3495.4	8.31	6405	128	1598	7.95	41	96	149	56
EB85-SB3	4APR85/1019	47°35.42/122°21.53	SFC	9.62	8564.3	6.84	6044	122	1504	7.42	39	98	147	55
EB85-SB4	4APR85/1047	47°35.90/122°21.63	SFC	14.46	7525.0	8.06	6434	128	1596	7.91	38	117	167	63
EB85-SB5	4APR85/1238	47°36.30/122°21.67	SFC	18.43	4861.9	6.60	6593	138	1715	6.64	41	119	196	72
EB85-SB6	4APR85/1257	47°36.72/122°21.06	SFC	19.31	4216.7	8.24	6400	137	1661	8.31	38	108	179	63
EB85-SB7	4APR85/1408	47°37.26/122°22.22	SFC	19.91	3941.5	7.94	6498	139	1705	8.50	40	109	186	69
EB85-SB8	4APR85/1224	47°35.97/122°23.20	SFC	28.02	1005.0	7.98	5619	127	2195	7.19	35	144	222	204
EB85-SB9	4APR85/1316	47°36.70/122°22.95	SFC	23.20	2971.7	7.89	6505	135	1737	8.33	41	119	173	70
EB85-SB10	4APR85/1425	47°37.40/122°23.22	SFC	20.62	2937.9	7.44	6279	138	1777	8.70	43	126	252	80
EB85-SB13	4APR85/1343	47°36.80/122°24.66	SFC	24.29	2155.1	5.82	3771	79	2535	4.40	**	37	54	121
EB85-SB14	4APR85/1439	47°38.17/122°24.88	SFC	21.46	2658.0	7.79	6499	148	1761	8.67	47	131	207	159
EB85-SBDR0	4APR85/0918	47°35.01/122°21.54	SFC	8.39	10644.1	5.84	6271	130	1595	7.72	43	106	137	59
EB85-SBT1	4APR85/0608	47°35.41/122°22.52	SFC	***	061.5	4.16	6563	192	2651	7.07	40	210	216	262
EB85-SBT8	4APR85/1333	47°36.79/122°24.58	SFC	29.33	407.5	8.28	6025	132	1751	7.96	40	104	162	68
EB85-SBT9	4APR85/1349	47°37.12/122°24.67	SFC	24.87	2425.0	8.54	6246	137	1807	8.11	45	120	196	171
EB85-SBT13	4APR85/1449	48°38.19/122°25.51	SFC	25.95	1440.0	9.03	5564	125	1809	7.63	34	99	174	93
EB85-SBT14	4APR85/1501	47°38.56/122°25.60	SFC	22.04	3437.5	8.24	6358	145	1732	8.71	50	125	198	115

** Below Detection Limits

*** Not Reported

The Fe values for stations EB85-SBDR0 and EB85-SB3 were calculated using the K2 peak.

APPENDIX III.

PARTICULATE CHEMISTRY DATA FOR ELLIOTT BAY
(in units of wt./vol. of water)
L-RERP 86-1, January 8, 9, and 23, 1986

Station	Date/Time	Position N/W	Depth m	Sal g/kg	TSM µg/L	Al µg/L	Ti µg/L	Cr ng/L	Mn µg/L	Fe µg/L	Ni ng/L	Cu ng/L	Zn ng/L	Pb ng/L
S1	8JAN86/0840	47°37.1/122°21.6	SFC	20.40	36000.0	844	75.78	1444	12080	845.3	1023	6608	14504	10155
S2	8JAN86/0855	47°36.9/122°22.0	SFC	28.61	1876.7	134	7.20	151	2562	95.8	86	194	295	448
S3	8JAN86/0924	47°36.6/122°22.4	SFC	29.99	792.0	72	3.32	61	3441	36.8	34	15	165	116
S3	8JAN86/0924	47°36.6/122°22.4	SFC	29.99	792.0	65	3.61	64	3757	39.9	33	30	152	124
S4	8JAN86/0946	47°36.5/122°23.3	SFC	30.19	760.O	54	2.47	44	3628	26.3	30	**	119	44
S5	8JAN86/1021	47°37.2/122°23.1	SFC	29.01	1290.0	110	5.40	107	2836	76.5	56	112	241	295
S5	8JAN86/1021	47°37.2/122°23.1	SFC	29.01	1290.0	110	5.22	95	2737	73.6	57	121	246	254
S6	8JAN86/1045	47°37.2/122°22.7	SFC	29.22	1250.6	100	5.41	104	3135	71.7	46	198	267	251
S6	8JAN86/1045	47°37.2/122°22.7	SFC	29.22	1250.6	104	5.31	108	3090	71.1	52	162	270	245
S7	8JAN86/1105	47°37.6/122°22.7	SFC	27.36	1913.3	132	7.08	148	2737	105.7	78	339	579	596
S8	8JAN86/1126	47°37.6/122°22.1	SFC	27.92	4016.7	225	16.58	285	3858	185.3	196	178	427	336
S8	8JAN86/1126	47°37.6/122°22.1	SFC	27.92	3420.0	237	15.50	289	4133	184.9	210	**	357	346
S9	8JAN86/1256	47°37.5/122°23.2	SFC	27.79	2330.0	170	9.17	164	3134	127.3	96	229	585	579
S10	8JAN86/1307	47°37.2/122°23.3	SFC	27.75	1403.3	105	5.58	108	2594	75.3	56	151	327	470
S11	8JAN86/1320	47°36.9/122°23.5	SFC	29.94	796.0	57	3.17	47	3511	34.0	24	11	127	90
S12	8JAN86/1331	47°36.7/122°23.3	SFC	30.04	704.0	53	2.54	53	3448	29.0	22	2	111	90
S13	8JAN86/1400	47°36.8/122°23.7	SFC	30.00	658.0	41	2.49	38	2951	25.5	22	**	149	94
S14	8JAN86/1411	47°38.3/122°24.4	SFC	30.10	700.0	55	2.99	53	3953	30.9	24	**	110	77
S15	8JAN86/1520	47°37.7/122°24.6	SFC	28.42	1770.0	139	7.06	138	2847	100.3	78	65	321	293
S16	8JAN86/1528	47°38.2/122°24.7	SFC	28.17	1546.7	137	5.90	102	2421	103.7	62	19	390	120
S17	8JAN86/1541	47°38.1/122°25.1	SFC	28.66	1370.0	102	5.36	98	2612	**	56	112	431	263
S18	8JAN86/1555	47°37.8/122°25.6	SFC	28.89	1183.3	104	5.07	86	2729	70.9	47	107	2125	302
S19	8JAN86/1622	47°38.7/122°25.6	SFC	29.45	1393.3	114	6.85	126	2986	79.7	63	42	237	179
S20	8JAN86/1631	47°38.7/122°25.1	SFC	28.45	1858.0	125	7.07	127	2797	92.8	82	145	356	279
S21	9JAN86/0842	47°34.1/122°20.8	SFC	9.21	5386.7	417	18.99	545	4786	574.7	241	420	1509	1138
S22	9JAN86/0855	47°34.4/122°21.5	SFC	14.85	3933.3	322	15.32	399	3709	391.4	200	223	1237	786
S23	9JAN86/0904	47°35.0/122°21.6	SFC	18.13	3660.0	262	13.01	339	3572	316.1	145	258	1012	788
S24	9JAN86/0914	47°35.5/122°21.6	SFC	22.65	3106.7	216	10.45	232	2843	226.5	117	258	659	591
S25	9JAN86/0925	47°35.4/122°21.1	SFC	28.14	1320.0	104	6.81	141	3297	118.3	138	1524	2288	571
S26	9JAN86/0933	47°35.5/122°20.7	SFC	26.45	2135.0	169	8.73	133	2969	124.9	82	222	587	366

** Below Detection Level

APPENDIX III. (Continued)

PARTICULATE CHEMISTRY DATA FOR ELLIOTT BAY
(in units of wt./vol. of water)
L-RERP 86-1, January 8, 9, and 23, 1986

Station	Date/Time	Position N/W	Depth m	Sal g/kg	TSM µg/L	Al µg/L	Ti µg/L	Cr ng/L	Mn µg/L	Fe µg/L	Ni ng/L	Cu ng/L	Zn ng/L	Pb ng/L
S27	9JAN86/0943	47°35.4/122°20.7	SFC	25.19	2186.7	171	8.95	178	2767	160.1	86	201	572	552
S28	9JAN86/0952	47°36.0/122°20.4	SFC	28.00	2030.0	175	9.31	162	2782	125.4	85	374	530	530
S29	9JAN86/1014	47°35.9/122°21.0	SFC	25.86	2890.0	158	7.31	146	3013	137.3	73	373	831	578
S30	9JAN86/1026	47°35.9/122°21.6	SFC	27.20	1310.0	103	5.29	105	2876	89.7	54	166	356	262
S31	9JAN86/1035	47°35.6/122°22.3	SFC	30.16	708.0	72	3.87	78	3236	43.3	42	59	183	152
S32	9JAN86/1043	47°35.4/122°22.1	SFC	25.64	1305.0	111	5.03	106	2274	99.4	57	130	390	347
S33	9JAN86/1051	47°35.1/122°22.1	SFC	30.13	658.0	42	2.68	45	3367	28.6	22	15	429	94
S34	9JAN86/1146	47°35.4/122°22.4	SFC	30.01	672.0	61	2.76	63	2832	39.4	42	71	151	59
S35	9JAN86/1154	47°35.5/122°22.7	SFC	30.02	486.0	34	1.57	32	2024	23.2	27	19	78	49
S36	9JAN86/1202	47°35.9/122°23.1	SFC	30.16	766.7	46	2.12	33	2748	24.2	26	**	48	43
S37	9JAN86/1215	47°36.0/122°22.6	SFC	29.89	860.0	76	3.88	51	3275	43.2	42	41	197	89
S38	9JAN86/1235	47°36.1/122°21.5	SFC	27.68	1265.0	110	4.92	124	2696	88.0	60	43	336	410
S39	9JAN86/1310	47°36.3/122°21.3	SFC	27.68	1530.0	119	5.34	117	2647	95.1	57	89	422	295
S40	9JAN86/1319	47°36.4/122°20.8	SFC	27.39	1405.0	118	4.85	105	1926	84.3	51	52	270	215
S41	9JAN86/1327	47°36.3/122°20.4	SFC	27.44	2380.0	40	6.48	135	2592	106.4	77	146	461	282
S42	9JAN86/1333	47°36.4/122°20.5	SFC	27.83	1530.0	124	5.54	111	2101	100.7	54	99	355	165
S43	9JAN86/1340	47°36.3/122°21.0	SFC	27.89	1365.0	110	5.14	111	2276	86.0	67	54	321	174
S44	9JAN86/1348	47°36.9/122°21.5	SFC	27.06	1753.3	127	6.01	131	2404	107.9	72	16	352	109
S45	9JAN86/1400	47°36.7/122°21.9	SFC	26.74	1295.0	125	5.42	132	2434	100.1	70	67	381	435
S46	9JAN86/1407	47°36.5/122°22.3	SFC	27.48	1430.0	129	5.85	113	2514	100.2	67	86	414	452
S47	9JAN86/1421	47°36.3/122°22.9	SFC	26.65	1190.0	140	6.70	105	2717	118.1	78	139	491	403
S49	23JAN86/1600	47°34.2/122°21.1	SFC	26.42	8613.3	827	39.67	693	8302	547.6	452	616	1698	1153

** Below Detection Level

APPENDIX IV.

PARTICULATE CHEMISTRY DATA FOR ELLIOTT BAY
(in units of wt./wt. of suspended matter)
L-RERP 86-1, January 8, 9, and 23, 1986

Station	Date/Time	Position N/W	Depth m	Sal g/kg	TSM µg/L	Al %	Ti %	Cr ppm	Mn ppm	Fe %	Ni ppm	Cu ppm	Zn ppm	Pb ppm
S1	8JAN86/0840	47°37.1/122°21.6	SFC	20.40	36000.0	2.34	0.21	40	336	2.4	28	184	403	282
S2	8JAN86/0855	47°36.9/122°22.0	SFC	28.61	1876.7	7.32	0.38	81	1365	5.1	46	103	157	239
S3	8JAN86/0924	47°36.6/122°22.4	SFC	29.99	792.0	9.07	0.46	81	4743	5.0	41	38	191	157
S3	8JAN86/0924	47°36.6/122°22.4	SFC	29.99	792.0	8.35	0.42	77	4344	4.7	43	**	208	146
S4	8JAN86/0946	47°36.5/122°23.3	SFC	30.19	760.0	7.07	0.32	57	4774	3.5	39	**	157	58
S5	8JAN86/1021	47°37.2/122°23.1	SFC	29.01	1290.0	8.56	0.42	83	2198	5.9	43	87	187	228
S5	8JAN86/1021	47°37.2/122°23.1	SFC	29.01	1290.0	8.55	0.40	74	2122	5.7	44	94	191	197
S6	8JAN86/1045	47°37.2/122°22.7	SFC	29.22	1250.6	8.02	0.42	87	2471	5.7	42	129	216	196
S6	8JAN86/1045	47°37.2/122°22.7	SFC	29.22	1250.6	8.29	0.43	83	2507	5.7	37	158	213	201
S7	8JAN86/1105	47°37.6/122°22.7	SFC	27.36	1913.3	6.89	0.37	78	1430	5.5	40	177	303	312
S8	8JAN86/1126	47°37.6/122°22.1	SFC	27.92	3420.0	6.93	0.45	85	1209	5.4	61	**	104	101
S8	8JAN86/1126	47°37.6/122°22.1	SFC	27.92	4016.7	5.45	0.41	71	961	4.6	49	44	106	84
S9	8JAN86/1256	47°37.5/122°23.2	SFC	27.79	2330.0	7.32	0.39	71	1345	5.5	41	98	251	249
S10	8JAN86/1307	47°37.2/122°23.3	SFC	27.75	1403.3	7.51	0.40	77	1849	5.4	40	107	233	335
S11	8JAN86/1320	47°36.9/122°23.5	SFC	29.94	796.0	7.16	0.40	59	4410	4.3	30	**	159	113
S12	8JAN86/1331	47°36.7/122°23.3	SFC	30.04	704.0	7.57	0.36	76	4898	4.1	31	**	157	128
S13	8JAN86/1400	47°36.8/122°23.7	SFC	30.00	658.0	6.28	0.38	57	4485	3.9	34	**	227	142
S14	8JAN86/1411	47°38.3/122°24.4	SFC	30.10	700.0	7.79	0.43	75	5648	4.4	35	**	156	110
S15	8JAN86/1520	47°37.7/122°24.6	SFC	28.42	1770.0	7.86	0.40	78	1609	5.7	44	37	181	166
S16	8JAN86/1528	47°38.2/122°24.7	SFC	28.17	1190.0	8.78	0.56	88	2284	9.9	66	117	413	338
S17	8JAN86/1541	47°38.1/122°25.1	SFC	28.66	1370.0	7.48	0.39	71	1907	0.0	41	82	315	192
S18	8JAN86/1555	47°37.8/122°25.6	SFC	28.89	1183.3	8.78	0.43	73	2306	6.0	40	91	1796	255
S19	8JAN86/1622	47°38.7/122°25.6	SFC	29.45	1393.3	8.21	0.49	90	2143	5.7	45	30	170	128
S20	8JAN86/1631	47°38.7/122°25.1	SFC	28.45	1858.0	6.70	0.38	68	1505	5.0	44	78	192	150
S21	9JAN86/0842	47°34.1/122°20.8	SFC	9.21	5386.7	7.74	0.35	101	888	10.7	45	78	280	211
S22	9JAN86/0855	47°34.4/122°21.5	SFC	14.85	3933.3	8.18	0.39	102	943	10.0	51	57	314	200
S23	9JAN86/0904	47°35.0/122°21.6	SFC	18.13	3660.0	7.16	0.36	93	976	8.6	40	71	276	215
S24	9JAN86/0914	47°35.5/122°21.6	SFC	22.65	3106.7	6.95	0.34	75	915	7.3	38	83	212	190
S25	9JAN86/0925	47°35.4/122°21.1	SFC	28.14	1320.0	7.89	0.52	107	2498	9.0	105	1155	1733	432
S26	9JAN86/0933	47°35.5/122°20.7	SFC	26.45	2135.0	7.90	0.41	62	1390	5.9	38	104	275	171

** Below Detection Level

APPENDIX IV. (Continued)

PARTICULATE CHEMISTRY DATA FOR ELLIOTT BAY
(in units of wt./wt. of suspended matter)
L-RERP 86-1, January 8, 9, and 23, 1986

Station	Date/Time	Position N/W	Depth m	Sal g/kg	TSM µg/L	Al %	Ti %	Cr ppm	Mn ppm	Fe %	Ni ppm	Cu ppm	Zn ppm	Pb ppm
S27	9JAN86/0943	47°35.4/122°20.7	SFC	25.19	2186.7	7.83	0.41	82	1266	7.3	39	92	261	252
S28	9JAN86/0952	47°36.0/122°20.4	SFC	28.00	2030.0	8.63	0.46	80	1370	6.2	42	184	261	261
S29	9JAN86/1014	47°35.9/122°21.0	SFC	25.86	2890.0	5.48	0.25	50	1042	4.8	25	129	288	200
S30	9JAN86/1026	47°35.9/122°21.6	SFC	27.20	1310.0	7.84	0.40	80	2196	6.9	41	126	272	200
S31	9JAN86/1035	47°35.6/122°22.3	SFC	30.16	708.0	10.12	0.55	110	4571	6.1	59	83	259	215
S32	9JAN86/1043	47°35.4/122°22.1	SFC	25.64	1305.0	8.52	0.39	81	1743	7.6	44	99	299	266
S33	9JAN86/1051	47°35.1/122°22.1	SFC	30.13	658.0	6.38	0.41	68	5117	4.4	34	23	651	142
S34	9JAN86/1146	47°35.4/122°22.4	SFC	30.01	672.0	9.04	0.41	93	4214	5.9	62	105	225	88
S35	9JAN86/1154	47°35.5/122°22.7	SFC	30.02	486.0	6.92	0.32	65	4164	4.8	55	39	160	102
S36	9JAN86/1202	47°35.9/122°23.1	SFC	30.16	766.7	6.05	0.28	42	3584	3.1	34	**	62	57
S37	9JAN86/1215	47°36.0/122°22.6	SFC	29.89	860.0	8.82	0.45	59	3808	5.0	48	47	228	104
S38	9JAN86/1235	47°36.1/122°21.5	SFC	27.68	1265.0	8.68	0.39	98	2131	7.0	47	34	265	324
S39	9JAN86/1310	47°36.3/122°21.3	SFC	27.68	1530.0	7.79	0.35	76	1730	6.2	37	58	276	193
S40	9JAN86/1319	47°36.4/122°20.8	SFC	27.39	1405.0	8.37	0.35	75	1370	6.0	37	37	192	153
S41	9JAN86/1327	47°36.3/122°20.4	SFC	27.44	2380.0	1.70	0.27	57	1089	4.5	32	61	194	118
S42	9JAN86/1333	47°36.4/122°20.5	SFC	27.83	1530.0	8.14	0.36	73	1373	6.6	35	65	232	108
S43	9JAN86/1340	47°36.3/122°21.0	SFC	27.89	1365.0	8.08	0.38	82	1667	6.3	49	40	235	127
S44	9JAN86/1348	47°36.9/122°21.5	SFC	27.06	1753.3	7.24	0.34	75	1371	6.2	41	9	201	62
S45	9JAN86/1400	47°36.7/122°21.9	SFC	26.74	1295.0	9.65	0.42	102	1879	7.7	54	52	294	336
S46	9JAN86/1407	47°36.5/122°22.3	SFC	27.48	1430.0	9.01	0.41	79	1758	7.0	47	62	289	316
S47	9JAN86/1421	47°36.3/122°22.9	SFC	26.65	1546.7	11.55	0.38	66	1565	6.7	40	12	252	78
S49	23JAN86/1600	47°34.2/122°21.1	SFC	26.42	8613.3	9.61	0.46	80	964	6.4	52	72	197	134

** Below Detection Level

APPENDIX V.

PARTICULATE CHEMISTRY DATA FOR COMMENCEMENT BAY
(in units of wt./vol. of water)
L-RERP 85-2, April 1-2, 1985

Station	Date/Time	Position N/W	Depth m	Sal g/kg	TSM µg/L	Al µg/L	Ti µg/L	Cr ng/L	Mn µg/L	Fe µg/L	Ni ng/L	Cu ng/L	Zn ng/L	Pb ng/L
CB85-1	1APR85/1145	47°16.57/122°25.02	5	29.53	712.7	44.9	2.16	41	1729	26.7	18	31	88	102
			15	29.86	1000.0	84.3	3.89	53	3204	38.7	29	47	133	65
CB85-2	1APR85/1230	47°16.39/122°25.19	4	29.14	807.7	56.4	2.85	45	1990	32.6	19	41	108	139
			40	30.15	1697.2	90.7	5.67	83	3156	56.4	41	57	143	109
CB85-3	1APR85/1243	47°16.29/122°25.43	4	29.27	940.7	55.3	2.66	52	1709	29.4	25	42	155	202
			40	30.18	1741.4	111.6	7.03	86	3496	67.2	45	81	160	124
CB85-4	1APR85/1342	47°16.07/122°26.07	3	29.41	755.4	46.0	2.29	37	1563	25.8	19	58	97	77
			10	29.69	703.6	45.3	2.30	45	1648	24.1	14	58	80	51
			40	30.15	1681.3	114.0	7.21	89	3955	68.6	48	72	164	84
CB85-5	1APR85/1632	47°17.35/122°26.15	4	30.27	2008.6	5.3	7.51	104	4319	72.8	58	70	178	80
			100	30.27	2080.9	6.1	8.49	109	4674	79.5	62	69	225	114
CB85-6	1APR85/1917	47°17.05/122°26.28	4	27.87	1313.9	72.9	3.97	79	1927	48.2	23	42	147	57
			100	30.29	2074.1	112.3	7.14	92	3740	69.2	56	65	181	91
CB85-7	1APR85/2025	47°16.35/122°26.51	4	28.99	934.5	49.7	3.11	53	1723	33.0	20	28	109	41
			20	29.90	646.9	42.6	2.55	35	2389	24.8	37	87	74	43
			60	30.24	1270.0	81.4	4.97	73	4263	48.7	42	43	208	39
			100	30.33	2336.1	138.0	9.39	118	4721	89.1	76	103	315	165
CB85-8	1APR85/2058	47°17.57/122°26.56	3	28.82	898.2	54.7	2.73	47	1737	34.6	28	35	152	62
			90	30.29	1032.9	75.5	4.47	69	3767	43.6	45	26	133	38
CB85-9	1APR85/2133	47°17.32/122°26.57	3	28.60	902.0	49.3	2.51	32	1566	32.7	18	160	238	23
			140	30.38	2020.4	95.6	8.52	110	4566	81.3	73	102	220	101
CB85-10	1APR85/2216	47°16.58/122°27.47	3	29.59	575.6	31.4	1.94	32	1676	18.4	19	57	104	33
			20	29.80	615.7	36.2	2.07	34	2314	21.1	18	19	69	28
			75	29.92	602.9	37.4	2.31	36	2700	23.2	20	22	95	23
			140	30.19	1814.9	92.0	7.59	98	4561	72.7	59	97	188	83
CB85-11	1APR85/2243	47°17.03/122°28.07	4	29.70	649.2	69.8	1.98	31	2071	20.4	17	25	72	16
CB85-12	2APR85/1018	47°18.32/122°20.48	4	29.23	717.4	80.4	2.09	31	1726	24.5	15	30	120	45
			100	30.32	1878.6	295.4	7.43	99	4415	70.7	73	81	196	69

* Data Not Available
** Below Detection Limits

APPENDIX V. (Continued)

PARTICULATE CHEMISTRY DATA FOR COMMENCEMENT BAY
(in units of wt./vol. of water)
L-RERP 85-2, April 1-2, 1985

Station	Date/Time	Position N/W	Depth m	Sal g/kg	TSM µg/L	Al µg/L	Ti µg/L	Cr ng/L	Mn µg/L	Fe µg/L	Ni ng/L	Cu ng/L	Zn ng/L	Pb ng/L
CB85-13	2APR85/1134	47°18.38/122°28.38	4	29.23	804.6	68.5	2.20	33	1650	24.4	13	14	82	53
			20	29.93	379.6	41.5	1.11	18	1881	11.5	11	**	40	22
			80	30.03	756.9	96.5	2.57	40	2950	25.6	23	20	81	30
			160	30.45	1713.7	212.9	6.52	96	3429	63.6	63	89	237	103
CB85-14	2APR85/1329	47°18.36/122°30.36	4	29.65	2651.8	*	1.36	27	1679	15.0	14	51	55	40
			85	30.43	211.4	*	7.07	94	3785	67.6	65	87	176	84
CB85-15	2APR85/1522	47°19.05/122°30.04	3	29.37	534.8	51.2	1.52	36	1370	17.0	22	75	65	43
			20	30.04	610.6	74.6	2.15	35	2606	21.4	21	16	64	38
			60	30.29	940.9	126.4	3.78	58	3355	37.3	38	36	101	40
			120	30.42	1673.4	210.0	6.87	92	3621	65.6	66	76	178	64
CB85-16	2APR85/1457	47°19.14/122°29.43	3	29.37	625.0	57.8	1.66	28	1477	18.5	15	8	103	42
			85	30.25	701.3	98.7	2.84	44	3295	28.4	27	29	85	27

* Data Not Available
** Below Detection Limits

APPENDIX VI.

PARTICULATE CHEMISTRY DATA FOR COMMENCEMENT BAY
(in units of wt./wt. of suspended matter)
L-RERP 85-2, April 1-2, 1985

Station	Date/Time	Position N/W	Depth m	Sal g/kg	TSM µg/L	Al %	Ti %	Cr ppm	Mn ppm	Fe %	Ni ppm	Cu ppm	Zn ppm	Pb ppm
CB85-1	1APR85/1145	47°16.57/122°25.02	5	29.53	712.7	6.37	0.30	57	2425	3.6	25	43	124	143
			15	29.86	1000.0	8.56	0.39	53	3204	3.9	29	47	133	65
CB85-2	1APR85/1230	47°16.39/122°25.19	4	29.14	807.7	7.09	0.35	56	2463	4.0	23	51	134	172
			40	30.15	1697.2	5.35	0.33	49	1859	3.3	24	33	84	64
CB85-3	1APR85/1243	47°16.29/122°25.43	4	29.27	940.7	6.00	0.28	55	1816	3.1	27	45	165	215
			40	30.18	1741.4	6.40	0.40	49	2007	3.6	26	47	92	71
CB85-4	1APR85/1342	47°16.07/122°26.07	3	29.41	755.4	6.20	0.30	50	2069	3.4	25	77	128	102
			10	29.69	703.6	6.54	0.33	63	2342	3.4	20	83	114	73
			40	30.15	1681.3	6.78	0.43	53	2352	4.1	28	43	98	50
CB85-5	1APR85/1632	47°17.35/122°26.15	4	30.27	2008.6	5.27	0.37	52	2150	3.6	29	35	89	40
			100	30.27	2080.9	6.09	0.41	52	2246	3.8	30	33	108	55
CB85-6	1APR85/1917	47°17.05/122°26.28	4	27.87	1313.9	5.64	0.30	60	1466	3.7	17	32	112	43
			100	30.29	2074.1	5.42	0.34	44	1803	3.3	27	31	87	44
CB85-7	1APR85/2025	47°16.35/122°26.51	4	28.99	934.5	6.40	0.33	56	1844	3.5	21	30	116	44
			20	29.90	646.9	6.58	0.39	53	3693	3.8	57	134	114	66
			60	30.24	1270.0	6.41	0.39	57	3357	3.8	33	34	164	31
			100	30.33	2336.1	5.91	0.40	50	2021	3.8	32	44	135	71
CB85-8	1APR85/2058	47°17.57/122°26.56	3	28.82	898.2	6.16	0.30	52	1934	3.9	31	39	169	69
			90	30.29	1033.0	7.31	0.43	66	3647	4.2	43	25	129	37
CB85-9	1APR85/2133	47°17.32/122°26.57	3	28.60	902.0	5.47	0.28	35	1736	3.6	20	178	264	25
			140	30.38	2020.4	4.73	0.42	54	2260	4.03	36	50	109	50
CB85-10	1APR85/2216	47°16.58/122°27.47	3	29.59	575.6	5.53	0.34	56	2913	3.2	34	100	181	57
			20	29.80	615.7	5.94	0.34	55	3759	3.4	29	30	112	46
			75	29.92	602.9	6.27	0.38	59	4477	3.8	33	37	158	38
			140	30.19	1814.9	5.07	0.42	54	2513	4.0	32	53	103	46
CB85-11	1APR85/2243	47°17.03/122°28.07	4	29.70	649.2	10.74	0.31	48	3191	3.2	26	38	110	25
CB85-12	2APR85/1018	47°18.32/122°20.48	4	29.23	717.4	11.21	0.29	43	2407	3.4	21	41	168	62
			100	30.32	1878.6	15.72	0.40	53	2350	3.8	39	43	104	37

* Data Not Available
** Below Detection Limits

APPENDIX VI. (Continued)

PARTICULATE CHEMISTRY DATA FOR COMMENCEMENT BAY
(in units of wt./wt. of suspended matter)
L-RERP 85-2, April 1-2,1985

Station	Date/Time	Position N/W	Depth m	Sal g/kg	TSM µg/L	Al %	Ti %	Cr ppm	Mn ppm	Fe %	Ni ppm	Cu ppm	Zn ppm	Pb ppm
CB85-13	2APR85/1134	47°18.38/122°28.38	4	29.23	804.6	8.51	0.27	41	2050	3.0	16	17	102	65
			20	29.93	379.6	10.93	0.29	48	4955	3.0	28	**	106	57
			80	30.03	756.9	12.76	0.34	52	3897	3.4	31	27	107	39
			160	30.45	1713.7	12.42	0.38	56	2001	3.7	37	52	138	60
CB85-14	2APR85/1329	47°18.36/122°30.36	4	29.65	2651.8	*	0.05	10	633	0.6	5	19	21	15
			85	30.43	211.4	*	3.34	444	17907	32.0	306	412	832	397
CB85-15	2APR85/1522	47°19.05/122°30.04	3	29.37	534.8	9.57	0.28	67	2562	3.2	40	140	122	80
			20	30.04	610.6	12.22	0.35	57	4268	3.5	35	27	105	63
			60	30.29	940.9	13.43	0.40	62	3566	4.0	40	38	107	43
			120	30.42	1673.4	12.55	0.41	55	2164	3.9	39	46	107	38
CB85-16	2APR85/1457	47°19.14/122°29.43	3	29.37	625.0	9.25	0.27	45	2363	3.0	24	12	165	67
			85	30.25	701.3	14.10	0.41	62	4698	4.1	38	42	121	39

* Data Not Available
** Below Detection Limits

APPENDIX VII.

DISSOLVED TRACE METAL DATA FOR ELLIOTT BAY L-RERP 85-2, APRIL 4-5, 1985

Station	Date/Time	Position N/W	Depth m	Sal g/kg	Mn µg/L	Cu ng/L	Ni ng/L	Cd ng/L	Zn ng/L	Pb ng/L	Fe µg/L	Rem
EB85-SBDR0	4APR85/0918	47°35.0/122°21.5	0	8.39	24.80	500	490	41	2280	46.	10.62	
			5	29.09	2.66	460	520	79	1660	96.	1.78	
EB85-SB1	4APR85/1038	47°36.0/122°20.4	0	20.84	14.06	520	470	72	2470	32.	3.96	
EB85-SB2	4APR85/1246	47°36.3/122°20.7	0	18.44	16.21	540	510	66	2770	29.	8.94	
EB85-SB3	4APR85/1019	47°35.4/122°21.5	0	9.62	28.17	520	550	54	2880	40.	4.70	
EB85-3	4APR85/0845	47°35.6/122°21.5	10	29.78	0.85	320	380	71	570	9	0.56	
			69	30.08	0.93	310	430	81	420	15.	0.62	
EB85-SB4	4APR85/1047	47°35.9/122°21.6	0	14.46	20.64	590	560	77	3480	35.	4.35	
EB85-4	4APR85/1010	47°35.8/122°21.5	10	29.74	1.43	390	370	85	770	30.	0.66	
			40	29.92	1.28	320	370	78	550	10.	0.35	
			67	30.06	1.08	290	360	74	530	15.	1.12	
EB85-SB5	4APR85/1238	47°36.3/122°21.7	0	18.43	14.83	590	530	82	2980	28.	2.37	
EB85-5	4APR85/1232	47°36.3/122°21.4	20	29.79	0.91	360	390	79	720	18.	0.33	
			40	29.92	0.92	350	360	77	570	11.	0.32	
			95	30.18	4.25	370	370	80	590	56.	14.86	1
EB85-SB6	4APR85/1257	47°36.7/122°21.1	0	19.31	15.35	640	560	86	3230	31.	2.82	
EB85-SB7	4APR85/1408	47°37.3/122°22.2	0	19.91	13.86	560	480	97	2210	41.	2.23	
EB85-SB9	4APR85/1316	47°36.7/122°23.0	0	23.20	10.39	570	480	75	2650	25.	1.80	
EB85-9	4APR85/1426	47°36.8/122°22.7	20	29.84	1.59	410	390	81	640	11.	0.29	
			40	29.90	0.79	340	380	77	650	14.	0.24	
EB85-13	4APR85/1643	47°36.8/122°24.8	1	29.33	2.28	370	370	82	880	22.	0.55	
			17	29.87	1.34	360	370	79	570	*	0.35	
			37	30.02	0.91	350	430	83	640	18.	0.54	
EB85-14	5APR85/1521	47°37.6/122°24.7	1	29.32	0.82	340	370	76	800	11.	0.12	
			20	29.85	1.65	350	410	79	650	10.	0.40	
			40	29.94	1.28	340	420	79	690	*	0.28	
EB85-14	5APR85/1405	47°37.7/122°24.7	110	30.24	1.89	360	430	85	690	13.	0.59	
			120	30.32	2.94	260	430	82	650	23.	0.52	
			125	30.36	3.31	310	380	78	500	21.	0.66	

* Below Detection Limit

1) Possible contamination by natural particulates.

APPENDIX VIII.
DISSOLVED TRACE METAL DATA FOR ELLIOTT BAY
L-RERP 86-1, JANUARY 8, 9 and 23, 1986

Station	Date/Time	Position N/W	Depth m	Sal g/kg	Mn µg/L	Cu ng/L	Ni ng/L	Cd ng/L	Zn ng/L	Pb ng/L	Fe µg/L	Rem
S1	08Jan86/0840	47°37.1/122°21.6	0	20.40	14.20	5910	1030	247	33010	2570	6.15	
S2	08Jan86/0855	47°36.9/122°22.0	0	28.61	7.81	410	380	72	2250	27	1.57	
S3	08Jan86/0924	47°36.6/122°22.4	0	29.99	3.05	330	340	72	850	18	0.66	
S4	08Jan86/0946	47°36.5/122°23.3	0	30.19	2.34	320	390	68	640	20	0.41	
S5	08Jan86/1021	47°37.2/122°23.1	0	29.01	6.34	450	400	75	2000	36	1.28	
S6	08Jan86/1045	47°37.2/122°22.7	0	29.22	5.17	390	390	69	1630	28	1.13	
S7	08Jan86/1105	47°37.6/122°22.7	0	27.36	7.81	730	480	76	4040	50	1.90	
S8	08Jan86/1126	47°37.6/122°22.1	0	27.92	8.93	470	380	68	2400	19	2.69	
S9	08Jan86/1256	47°37.5/122°23.2	0	27.79	9.25	630	480	79	4130	74	1.82	
S10	08Jan86/1307	47°37.2/122°23.3	0	27.75	6.39	520	360	72	2270	105	1.95	
S11	08Jan86/1320	47°36.9/122°23.5	0	29.94	3.16	350	390	77	990	22	0.57	
S12	08Jan86/1331	47°36.7/122°23.3	0	30.04	3.50	370	390	80	1180	36	2.84	
S13	08Jan86/1400	47°36.8/122°23.7	0	30.00	2.88	350	370	79	880	19	0.44	
S14	08Jan86/1411	47°38.3/122°24.4	0	30.10	2.90	360	370	77	990	20	0.63	
S15	08Jan86/1520	47°37.7/122°24.6	0	28.42	7.77	570	440	85	3240	44	1.44	
S16	08Jan86/1528	47°38.2/122°24.7	0	28.17	8.77	580	430	81	3220	41	1.03	
S17	08Jan86/1541	47°38.1/122°25.1	0	28.66	7.08	570	430	91	3080	72	1.45	
S18	08Jan86/1555	47°37.8/122°25.6	0	28.89	6.63	490	390	86	2440	50	0.75	
S19	08Jan86/1622	47°38.7/122°25.6	0	29.45	4.68	400	380	78	1770	20	0.84	
S20	08Jan86/1631	47°38.7/122°25.1	0	28.45	7.40	430	320	72	2220	34	0.98	
S21	09Jan86/0842	47°34.1/122°20.8	0	9.21	39.28	930	900	68	9210	39	18.17	
S22	09Jan86/0855	47°34.4/122°21.5	0	14.85	31.77	870	810	63	7780	20	9.00	
S23	09Jan86/0904	47°35.0/122°21.6	0	18.13	25.70	830	710	75	7510	41	7.47	
S24	09Jan86/0914	47°35.5/122°21.6	0	22.65	14.31	520	430	55	3610	22	3.82	
S25	09Jan86/0925	47°35.4/122°21.1	0	28.14	7.86	4960	670	155	20520	122	1.69	
S26	09Jan86/0933	47°35.5/122°20.7	0	26.45	12.98	570	530	93	3800	58	3.95	
S27	09Jan86/0943	47°35.4/122°20.7	0	25.19	20.12	770	690	98	5170	35	4.42	
S28	09Jan86/0952	47°36.0/122°20.4	0	28.00	10.70	860	640	90	5150	73	2.24	
S29	09Jan86/1014	47°35.9/122°21.0	0	25.86	21.11	2140	860	122	8920	58	4.82	
S30	09Jan86/1026	47°35.9/122°21.6	0	27.20	9.79	610	540	85	4000	31	2.63	
S31	09Jan86/1035	47°35.6/122°22.3	0	30.16	3.31	380	380	80	1280	34	0.59	
S32	09Jan86/1043	47°35.4/122°22.1	0	25.64	6.88	1010	630	91	6090	54	4.11	
S33	09Jan86/1051	47°35.1/122°22.1	0	30.13	2.61	330	380	80	850	13	0.40	
S34	09Jan86/1146	47°35.4/122°22.4	0	30.01	3.96	480	510	86	1810	33	1.32	
S35	09Jan86/1154	47°35.5/122°22.7	0	30.02	3.65	400	440	74	1880	30	0.87	
S36	09Jan86/1202	47°35.9/122°23.1	0	30.16	3.03	350	400	83	1100	26	0.43	
S37	09Jan86/1215	47°36.0/122°22.6	0	29.89	3.86	310	370	86	3210	24	0.63	
S38	09Jan86/1235	47°36.1/122°21.5	0	27.68	9.56	720	550	106	3380	42	2.36	
S39	09Jan86/1310	47°36.3/122°21.3	0	27.68	9.33	630	510	85	5480	33	1.66	
S40	09Jan86/1319	47°36.4/122°20.8	0	27.39	10.07	590	490	84	4350	34	1.57	
S41	09Jan86/1327	47°36.3/122°20.4	0	27.44	11.70	710	480	77	3690	160	9.32	
S42	09Jan86/1333	47°36.4/122°20.5	0	27.83	8.76	530	480	78	3760	43	1.68	
S43	09Jan86/1340	47°36.3/122°21.0	0	27.89	11.01	590	480	88	3740	96	4.22	
S44	09Jan86/1348	47°36.9/122°21.5	0	27.06	11.33	610	640	94	4410	71	2.00	
S45	09Jan86/1400	47°36.7/122°21.9	0	26.74	12.83	700	580	86	3460	45	2.06	
S46	09Jan86/1407	47°36.5/122°22.3	0	27.48	11.06	710	530	97	3470	33	1.64	
S47	09Jan86/1421	47°36.3/122°22.9	0	26.65	13.55	780	520	83	5090	265	37.29	1
S49	23Jan86/1600	47°34.2/122°21.1	0	6.42	58.15	1160	760	69	6320	103	29.52	

1) Contaminated by natural particulates.

APPENDIX IX.

DISSOLVED TRACE METAL DATA FOR COMMENCEMENT BAY
L-RERP 85-2, APRIL 1-2, 1985

Station	Date/Time	Position N/W	Depth m	Sal g/kg	Mn µg/L	Cu ng/L	Ni ng/L	Cd ng/L	Zn ng/L	Pb ng/L	Fe µg/L	Rem
CB85-1	1Apr85/1138	47°16.9/121°24.9	1	29.58	2.11	495	454	92	1127	19	1.03	
CB85-1			28	29.92	2.96	394	458	98	769	37	0.73	
CB85-2	1Apr85/1210	47°16.7/121°25.5	1	22.65	6.25	573	412	75	1835	65	7.01	
CB85-2			46	30.20	6.50	384	444	92	1140	68	20.14	1
CB85-2			46		5.39	370	431		1090	30		2
CB85-3	1Apr85/1311	47°16.6/121°25.7	1	26.04	11.87	751	531	98	2642	80	7.64	
CB85-3			58	30.08	7.66	437	464	91	1028	119	29.20	1
CB85-3			58		6.18	403	445		960	67		3
CB85-4	1Apr85/1431	47°16.1/121°26.2	1	29.35	2.76	507	451	92	1174	19	1.20	
CB85-4			10	29.67	2.01	511	454	94	1255	36	1.13	
CB85-4			55	29.97	2.55	419	555	111	1206	72	1.04	
CB85-7	1Apr85/1957	47°16.7/122°26.8	1	29.51	2.74	763	444	93	1099	16	0.67	
CB85-7			20	29.97	2.99	476	418	89	826	12	0.46	
CB85-7			60	29.95	3.31	382	421	91	548	45	0.53	
CB85-7			117	30.32	9.22	345	432	89	663	27	0.82	
CB85-10	1Apr85/2154	47°17.2/122°27.6	1	29.26	3.27	472	420	86	1054	17	0.83	
CB85-10			20	29.94	2.51	466	396	87	847	20	0.47	
CB85-10			70	29.86	1.97	370	440	84	690	39	0.26	
CB85-10			148	30.33	4.71	313	393	81	565	10	0.25	
CB85-13	2Apr85/1056	47°18.7/122°28.7	1	29.27	2.99	439	406	83	1542	16	1.07	
CB85-13			20	29.95	0.99	345	454	87	744	*	0.25	
CB85-13			75	30.25	2.56	289	401	79	664	34	0.28	
CB85-13			143	30.42	8.69	318	422	84	631	68	5.86	1
CB85-13			143		8.42	311	417		650	60		4
CB85-14	2Apr85/1311	47°18.6/122°29.7	1	29.62	1.91	385	404	83	785	15	0.52	
CB85-14			95	30.28	4.41	308	394	83	731	24	0.53	
CB85-15	2Apr85/1550	47°19.1/122°29.9	1	29.39	2.15	397	432	89	1552	19	1.09	
CB85-15			20	29.93	0.87	312	398	80	782	6	0.23	
CB85-15			60	30.27	2.74	269	396	81	726	9	0.25	
CB85-15			155	30.42	4.59	265	386	80	673	*	0.29	

* Below Detection Limit

1) Field Logs indicated skewed filters. Contaminated by natural particulates

2) Corrected assuming 35% of the particles passed into the dissolved sample (see QA/QC text).

3) Corrected assuming 42% of the particles passed into the dissolved sample (see QA/QC text).

4) Corrected assuming 8% of the particles passed into the dissolved sample (see QA/QC text).

APPENDIX X.

TRACE ORGANIC COMPOUNDS QUANTIFIED DURING THIS PROJECT

Phenanthrene (Phe)

Anthracene (Ant)

Methyl Phenanthrene (MPH)

(Four isomers)

Fluoranthene (FLa)

Pyrene (Pyr)

Retene (Ret)

Benzofluoranthene (BF1)

(Three-isomers)

Benzo(e)pyrene (BEP)

Benzo(a)pyrene (BAP)

Indeno Pyrene (IPY)

Benzo(g,h,i)perylene (BPe)

Chrysene (Chr)

Benz(a)anthracene(BAA)

DDE

DDD

DDT

Dichlorobiphenyls (CL2)

Trichlorobiphenyls (CL3)

Tetrachlorobiphenyls (CL4)

Pentachlorobiphenyls (CL5)

Hexachlorobiphenyls (CL6)

Heptachlorobiphenyls (CL7)

Octachlorobiphenyls (CL8)

Nonachlorobiphenyls (CL9)

APPENDIX XI.

TRACE ORGANICS
(in total ng/g)
COLLECTED BY CENTRIFUGE 4/85

SAMPLE NAME	S1SURF1	S1SURF2	S1-20m	S2SURF	S3SURF	S4SURF	S4-20m	S6SURF	S6-20m
DATE/TIME	40485, 0930	40485, 0930	40385, 0800	40885, 0900	40985, 0930	40385, 2130	40485, 2230	40185, 1830	40285, 0800
LATITUDE	47°35.4'N	47°35.4'N	47°35.4'N	47°36.3'N	47°36.8'N	47°37.2'N	47°37.2'N	47°17.0'N	47°17.0'N
LONGITUDE	122°21.6'W	122°21.6'W	122°21.6'W	122°21.2'W	122°22.8'W	122°24.6'W	122°24.6'W	122°27.0'W	122°27.0'W
LOCATION	ELLIOTT BAY	ELLIOTT BAY	ELLIOTT BAY	ELLIOTT BAY	ELLIOTT BAY	ELLIOTT BAY	ELLIOTT BAY	COMM. BAY	COMM. BAY
VOL SAMPLED	320L	320L	715L	615L	624L	633L	624L	638L	618L
Phe	67	130	1100	420	380	310	440	780	350
Ant	24	26	210	160	110	120	100	95	160
MPh	57	140	1200	†	730	450	†	1200	560
Fla	120	420	3500	1400	1100	790	580	920	440
Pyr	110	310	2900	1400	1100	790	580	720	450
Ret	68	210	1900	940	900	†	920	520	430
BAA	42	92	870	470	410	260	340	200	120
Chr	69	150	1400	410	610	390	320	350	190
BFl	140	230	2300	760	1100	740	740	540	380
BEP	52	86	1100	260	230	260	250	220	140
BAP	45	75	780	210	260	190	180	150	110
IPy	37	74	710	170	210	160	170	150	110
BPe	37	84	760	170	210	170	180	210	110
DDE	<0.35	<0.17	<2.9	<0.69	<1.4	<1.1	<2.9	<0.47	<1.0
DDT	<1.4	<0.70	<11	<2.7	<5.7	<4.6	<12	<1.9	<4.0
DDD	<1.4	<0.70	<11	<2.7	<5.7	<4.6	<12	<1.9	<4.0
CL2	<0.35	<0.17	<2.9	<0.69	<1.4	<1.1	<2.9	<0.47	<1.0
CL3	<0.35	1.33	<2.9	<0.69	10	<1.1	9.4	<0.47	<1.0
CL4	0.6	<0.28	<4.6	1.4	11	<1.1	<4.7	<0.75	<1.6
CL5	2.5	1.5	250*	5.5	<2.3	2.1	43	15	65
CL6	3.2	3.4	34	9.1	13	4.4	<2.9	6.5	1.5
CL7	<0.7	2.0	9	1.6	4	<1.8	<4.7	4.7	3.9
CL8	<0.55	<0.28	<4.6	<1.1	<2.3	<1.8	<4.7	<0.75	<1.6
CL9	<1.1	<0.56	<9.1	<2.2	<4.6	<3.7	<9.4	<1.5	<3.2

* one large peak fits the criteria outlined in the QA/QC document but upon further investigation was shown by a 4 ion GCMS scan not to be a PCB. This peak accounts for 210 ng/g of this sum.
† quantitation was precluded by an interfering peak.

APPENDIX XII.

TRACE ORGANICS
(in total ng/g)
COLLECTED BY SEDIMENT TRAPS

MOORING#	85-1/17	85-1/20	85-2/18	85-4/15	85-5/16
DEPTH(m)	6 m	50 m	95 m	6 m	150 m
START/STOP	32985, 62285	32985, 62285	32985, 62285	32685, 41585	32585, 41585
LATITUDE	47°37.0'N	47°37.0'N	47°37.0'N	47°17.6'N	47°17.6'N
LONGITUDE	122°22.7'W	122°22.7'W	122°22.7'W	122°27.5'W	122°27.3'W
LOCATION	ELLIOTT BAY	ELLIOTT BAY	ELLIOTT BAY	COMM. BAY	COMM BAY
Phe	590	820	440	<260	190
Ant	160	270	190	<260	53
MPh	320	670	360	<260	370
Fla	1000	930	720	<260	240
Pyr	900	850	630	<260	200
Ret	150	380	260	<260	400
BAA	340	330	260	<260	62
Chr	710	580	410	<260	90
BFl	520	580	560	<260	124
BEP	320	330	250	<260	84
BAP	210	230	280	<260	90
IPy	210	230	280	<260	90
BPe	210	230	280	<260	90
DDE	12	<5.2	<.18	<26	<.15
DDT	<21	<21	<.71	<104	<.61
DDD	<21	<21	<.71	<104	<.61
CL2	<5.2	<5.2	<.18	<26	<.15
CL3	<5.2	<5.2	<.18	<26	<.15
CL4	<8.3	<8.4	5.5	<42	0.7
CL5	12	<8.4	15	<42	2.2
CL6	33	<5.2	12	<26	2.3
CL7	<8.3	<8.4	5.9	<42	1.4
CL8	<8.3	<8.4	3.2	<42	<.24
CL9	<17	<17	.81	<84	<.48

APPENDIX XIII.

TRACE ORGANICS
(in total ng/g)
COLLECTED BY CENTRIFUGE 1/86

SAMPLE NAME	S1SURF1	S1SURF2	S2SURF	S3SURF
DATE/TIME	10886, 1250	10886, 1250	10986, 0950	11086, 0915
LATITUDE	47°37.1'N	47°37.1'N	47°35.0'N	47°36.6'N
LONGITUDE	122°21.6'W	122°21.6'W	122°21.5'W	122°21.3'W
LOCATION	ELLIOTT BAY	ELLIOTT BAY	ELLIOTT BAY	ELLIOTT BAY
VOL SAMPLED	140L	193L	510L	525L
Phe	15000	14000	1100	950
Ant	3000	2700	380	420
MPh	24000	22000	1300	960
Fla	12000	13000	3600	2100
Pyr	9400	9000	3400	1800
Ret	<320	<310	230	260
BAA	2100	1900	950	730
Chr	2900	2500	1600	1100
BFl	3100	2000	3100	2200
BEP	1400	1200	1400	720
BAP	1800	1300	1200	790
IPy	1400	1100	1200	670
BPe	1400	1100	1100	620
DDE	<8.8	<12	<2.1	<1.6
DDT	<35	<50	<8.5	<6.5
DDD	<35	<50	<2.1	<6.5
CL2	<8.5	<12	<2.1	<1.6
CL3	<8.5	32	<2.1	<1.6
CL4	<14	25	<3.4	<2.6
CL5	86	25	28	10
CL6	160	19	84	59
CL7	100	36	59	29
CL8	<14	<20	11	<2.6
CL9	<28	<40	<6.8	<5.2

APPENDIX XIV.

STORM DRAIN CALCULATIONS

Area drained by seven major storm drains discharging to west waterway = 1569 acres (Tetra Tech 1986)

1569 acres $\times$ 43,560 ft^2/acre = 68,345,640 ft^2
Rainfall for January 8-9, 1986 = 0.0375 ft (NOAA NWS 1986)

68,345,640 $ft^2 \times$ 0.0375 ft = 2,562,962 ft^3 = 72.75 million L rainfall collected.

Duwamish River flow 32 m^3/sec (2 days) (86,400 sec/day) = 5,529,600 m^3/2 days

Low PAH Loading of Storm Drain Effluent

0.4 mg PHA/L (Tetra Tech 1986)
$(72.75 \times 10^6 L)$ (0.4 mg/L) = 29.1 kg PAH
Assume PAH put into waterway at constant rate:
29.1 kg PAH / 2 days
29.1 kg PAH / 5,529,600 m^3 river water in 2 days = 5.3 mg/m^3
At Spokane Street the waterway depth is 9 m but the fresh water depth is 5 m at 32 m^3/sec flow rate (Santos and Stoner, 1972)
(5.3 mg/m^3) (9/5) = 9.5 mg/m^3
(9.5 mg/m^3) ($10^{-1} m^3/cm^3$) = 9.5 ng/L

High PAH Loading of Storm Drain Effluent

2.2 mg PAH/L (Tetra Tech 1986)
$(72.75 \times 10^6 L)$ (2.2 mg/L) = 160.1 kg PAH
Assume PAH put into waterway at constant rate:
160.1 kg PAH / 2 days
160.1 kg PAH / 5,529,600 m^3 river water in 2 days = 29 mg/m^3
At Spokane Street the waterway depth is 9 m but the fresh water depth is 5 m at 32 m^3/sec flow rate (Santos and Stoner, 1972)
(29 mg/m^3) (9/5) = 52 mg/m^3
(52 mg/m^3) (10^6 m^3 cm^3) = 52 ng/L

APPENDIX XV.

TRACE METALS IN SEDIMENT TRAP SAMPLES
(in units of wt./wt. sample)

Mooring	Bay	Depth ppm	Vertical mass flux ($g/m^{-1}day^{-1}$)	Cu ppm	Mn ppm	Cd ppm	Pb
85-1	Elliott	6	0.09 (0.16±0.07)	52	553	*	100
		52	0.11 (0.16±0.05)	76	1113	3.60	229
85-2	Elliott	95	7.3 (7.7±1.9)	61	1725	0.17	76
85-4	Commencement	6	0.22 (0.22±0.07)	52	625	0.16	68
85-5	Commencement	150	31.7 (29.3±8.7)	57	1436	0.21	48

*Below Detection Limit

APPENDIX XVI.

Elliott Bay Plume Mapping Data

Station	Depth (m)	Date/Time	Position N/W	Cor. Sal. (ppt)	Temp (C)	Atten (1/m)	SPM (mg/L)
EB85-SBDRO	0.00	4Apr85/0918	47°35.01/122°21.54	9.5	3.60	8.00	10.64
	0.50			10.5	4.00	7.10	
	1.00			18.2	7.80	4.50	
	2.00			20.2	7.90	3.70	
	3.00			25.7	8.00	1.60	
	0.00			12.4	7.80	7.10	
EB85-SBT1	0.00	4Apr85/0608	47°35.41/122°22.52	22.1	9.90	1.20	1.06
	1.00			27.9	8.40	0.70	
	0.50			27.1	8.40	1.00	
	0.25			27.0	8.30	1.00	
EB85-SB3	0.00	4Apr85/1019	47°35.42/122°21.53	10.0	8.20	7.80	8.56
	0.25			12.9	8.00	8.00	
	0.50			11.9	8.00	7.80	
	1.00			25.0	8.10	1.60	
	2.00			27.9	8.10	1.00	
SB85-SBT2	0.00	4Apr85/1025	47°35.53/122°20.90	18.7	8.70	2.90	
	0.50			22.6	8.70	2.40	
	1.00			23.6	8.20	2.60	
SB85-SBT3	0.00	4Apr85/1031	47°35.62/122°20.62	14.4	8.20	6.50	
	0.25			14.4	8.10	4.70	
	0.50			20.0	8.00	3.50	
	1.00			20.7	8.00	3.20	
	1.50			23.6	8.20	1.60	
EB85-SB1	0.00	4Apr85/1038	47°35.96/122°20.43	21.6	8.40	2.70	3.31
	0.50			22.1	8.20	2.60	
	1.00			23.1	8.20	2.10	
	1.50			23.9	8.20	1.90	
	0.00			21.1	8.50	2.80	
EB85-SB4	0.00	4Apr85/1047	47°35.90/122°21.63	16.1	8.30	4.80	7.53
	0.25			17.8	8.30	4.60	
	0.50			22.3	8.20	2.50	
	1.00			24.5	8.20	1.70	
	2.00			26.7	8.10	1.20	
EB85-SBT4	0.00	4Apr85/1217	47°35.77/122°22.70	19.1	8.60	1.00	
	0.25			19.3	8.50	1.10	
	0.50			23.1	8.60	1.20	
	1.00			26.5	8.60	1.10	
	1.50			27.1	8.40	1.00	
EB85-SB8	0.00	4Apr85/1224	47°35.97/122°23.20	27.7	8.50	1.00	1.01
	0.25			26.0	8.40	1.00	
	0.50			26.0	8.40	0.90	
	1.00			27.2	8.30	0.70	
	1.50			28.8	8.30	0.70	
EB85-SBT5	0.00	4Apr85/1229	47°36.13/122°23.28	27.4	8.50	1.00	
	0.25			27.6	8.50	1.00	
	0.50			27.8	8.40	0.90	
	1.00			28.1	8.40	0.80	
	1.50			28.6	8.30	0.70	

APPENDIX XVI. (Continued)

Elliott Bay Plume Mapping Data

Station	Depth (m)	Date/Time	Position N/W	Cor. Sal. (ppt)	Temp (C)	Atten (1/m)	SPM (mg/L)
EB85-SB5	0.00	4Apr85/1238	47°36.30/122°21.67	19.2	8.70	3.70	4.86
	0.25			20.4	8.70	3.10	
	0.50			22.4	8.50	2.30	
	1.00			26.2	8.40	1.20	
	1.50			27.2	8.20	1.30	
EB85-SB2	0.00	4Apr85/1246	47°36.31/122°20.71	18.7	8.40	4.30	3.50
	0.25			19.0	8.30	3.50	
	0.50			18.8	8.30	3.40	
	1.00			21.4	8.30	2.50	
	1.50			26.0	8.30	1.50	
	2.00			26.5	8.20	1.30	
EB85-SB6	0.00	4Apr85/1257	47°36.72/122°21.06	17.9	8.80	4.00	4.22
	0.25			18.5	8.70	3.70	
	0.50			20.0	8.50	3.20	
	1.00			21.8	8.20	2.40	
	1.50			24.8	8.30	1.70	
	2.00			26.2	8.30	1.20	
EB85-SBT6	0.00	4Apr85/1311	47°36.55/122°22.57	24.1	8.70	2.20	
	0.25			23.9	8.40	1.90	
	0.50			25.9	8.40	1.40	
	1.00			26.8	8.30	1.20	
	1.50			27.3	8.30	1.20	
	2.00			27.4	8.30	1.10	
EB85-SB9	0.00	4Apr85/1316	47°36.70/122°22.95	26.2	8.40	1.50	
	0.25			26.0	8.50	1.70	
	0.50			26.2	8.50	1.50	
	1.00			26.5	8.50	1.40	
	1.50			27.0	8.30	1.30	
	2.00			27.1	8.30	1.30	
EB85-SBT7	0.00	4Apr85/1327	47°36.52/122°24.03	28.2	8.50	0.80	
	0.25			28.5	8.50	0.80	
	0.50			28.6	8.60	0.80	
	1.00			28.6	8.60	0.80	
	1.50			28.7	8.40	0.80	
EB85-SB13	0.00	4Apr85/1343	47°36.80/122°24.66	28.9	8.50	0.70	0.41
	0.25			28.9	8.40	0.70	
	0.50			28.9	8.40	0.70	
	1.00			28.9	8.40	0.70	
	1.50			28.9	8.40	0.70	
EB85-SBT8	0.00	4Apr85/1333	47°36.79/122°24.58	24.5	8.70	1.80	2.16
	0.25			26.5	8.60	1.10	
	0.50			28.1	8.50	0.80	
	1.00			28.7	8.50	0.80	
	1.50			28.8	8.50	0.80	
	0.00			25.2	8.80	1.80	
EB85-SBT9	0.00	4Apr85/1349	47°37.12/122°24.67	23.6	8.70	2.10	2.43
	0.25			24.7	8.60	1.90	
	0.50			26.0	8.50	1.50	
	1.00			27.1	8.50	1.10	
	1.50			27.9	8.40	0.80	
	2.00			28.1	8.40	0.80	

APPENDIX XVI. (Continued)

Elliott Bay Plume Mapping Data

Station	Depth (m)	Date/Time	Position N/W	Cor. Sal. (ppt)	Temp (C)	Atten (1/m)	SPM (mg/L)
EB85-SBT10	0.00	4Apr85/1400	47°37.22/122°22.60	20.4	9.00	2.90	
	0.25			20.4	9.00	2.90	
	0.50			20.4	9.00	2.90	
	1.00			25.5	8.50	2.80	
	1.50			27.0	8.40	1.20	
	2.00			28.3	8.30	1.10	
EB85-SB7	0.00	4Apr85/1408	47°37.26/122°22.22	21.0	8.60	3.40	3.94
	0.25			21.1	8.70	3.60	
	0.50			20.2	8.90	3.50	
	1.00			23.1	8.50	2.30	
	1.50			24.1	8.30	1.80	
	2.00			26.0	8.20	1.50	
EB85-SBT11	0.00	4Apr85/1418	47°37.53/122°22.07	21.1	8.80	2.50	
	0.25			21.0	8.70	2.50	
	0.50			21.0	8.70	2.50	
	1.00			21.6	8.50	2.50	
	1.50			23.1	8.30	1.80	
	2.00			27.0	8.30	1.10	
EB85-SB10	0.00	4Apr85/1425	47°37.40/122°23.22	20.2	8.90	2.90	
	0.25			20.4	8.90	2.90	
	0.50			22.1	8.70	2.70	
	1.00			24.5	8.70	1.60	
	1.50			26.5	8.30	1.40	
	2.00			26.7	8.30	1.30	
EB85-SBT12	0.00	4Apr85/1433	47°37.40/122°23.40	21.3	8.80	2.80	
	0.25			21.5	8.80	2.80	
	0.50			22.1	8.70	2.60	
	1.00			25.2	8.60	1.80	
	1.50			26.5	8.40	1.30	
	2.00			28.4	8.40	0.90	
EB85-SB14	0.00	4Apr85/1439	47°38.17/122°24.88	21.6	8.90	2.50	2.66
	0.25			21.6	8.90	2.50	
	0.50			21.6	8.90	2.50	
	1.00			21.8	8.90	2.40	
	1.50			22.6	8.60	1.80	
	2.00			27.7	8.60	1.00	
EB85-SBT13	0.00	4Apr85/1449	48°38.19/122°25.51	25.9	8.80	1.40	1.44
	0.25			25.9	8.80	1.40	
	0.50			26.0	8.80	1.40	
	1.00			28.1	8.60	0.90	
	1.50			28.6	8.50	0.80	
	2.00			28.8	8.40	0.80	
EB85-SBT14	0.00	4Apr85/1501	47°38.56/122°25.60	21.8	8.90	2.20	3.44
	0.25			22.3	8.90	2.20	
	0.50			22.3	8.80	2.00	
	0.75			26.0	8.60	1.10	
	1.00			27.1	8.40	0.80	
	1.50			28.9	8.30	0.70	
	2.00			29.0	0.00	0.00	
	0.00			22.4	8.80	2.20	