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US Army Corps  
of Engineers  
Seattle District

**BIOLOGICAL TESTING OF SOLID PHASE AND  
SUSPENDED PHASE DREDGED MATERIAL  
FROM COMMENCEMENT BAY,  
TACOMA, WASHINGTON**

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PREPARED BY:

FISHERIES RESEARCH INSTITUTE  
University of Washington

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<p>The study evaluates, using bioassays, potential acute chemical toxicity of waters originating from the disposal of sediments dredged from Blair and Sitcum Waterways that might return to Commencement Bay, Tacoma, Washington. Sediments from nine sites in Blair and Sitcum Waterways were tested, using chinook salmon (<i>Oncorhynchus tshawytscha</i>) smolts, Pacific oyster (<i>Crassostrea gigas</i>) larvae, and phoxocephalid amphipods (<i>Grandifoxus grandis</i>). Survival of salmon smolts was not affected by 96 hour exposure to elutriates of up to one part per thousand by volume from sites S-1, S-2, B-1, B-2, and B-5. Oyster larvae developed</p>		

abnormal shells following 48 hour exposure using undiluted water drained from defrosted sediment from sites S-2, B-2, B-3, and B-5, but were not affected by 1:5 dilutions of artificially prepared elutriates. Two hundred four hour exposure to sediments from each of the nine sites neither decreased survival of amphipods nor altered the time spent in the sediment or the amphipod's ability to rebury in sand. Ammonia-nitrogen concentrations in artificially prepared 1:5 elutriates at ambient pHs would be potentially toxic to salmonids and other fishes; therefore, dredging methods that dilute the elutriate are recommended. An elutriate dilution of 1:1000 was shown to be safe; elutriate concentrations greater than 1:1000 could be toxic to salmonids and other fishes. Amphipod bioassays should not be used to assess potential chemical toxicity of dredged sediments until further research clarifies confounding factors such as anoxia and starvation.

FISHERIES RESEARCH INSTITUTE  
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BIOLOGICAL TESTING OF SOLID PHASE AND SUSPENDED  
 PHASE DREDGED MATERIAL FROM COMMENCEMENT BAY,  
 TACOMA, WASHINGTON

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Approved by:

Date Submitted:  
 15 December 1982

*Roy E. Nakatani*  
 \_\_\_\_\_  
 Robert L. Burgner, Director  
 Fisheries Research Institute

DISCLAIMER

Data, interpretations, and conclusions in this report  
are those of the authors.

## ABSTRACT

Sediments from nine sites (S-1, S-2, S-3, B-1, B-2, B-3, B-4, B-5, and B-6) in Blair and Sitcum Waterways, Commencement Bay, Tacoma, Washington, were tested for potential acute chemical toxicity using chinook salmon (*Oncorhynchus tshawytscha*) smolts, Pacific oyster (*Crassostrea gigas*) larvae, and phoxocephalid amphipods (*Grandifoxus grandis*). Survival of salmon smolts was not affected by 96 hr exposure to elutriates of up to one part per thousand by volume from sites S-1, S-2, B-1, B-2, and B-5. Oyster larvae developed abnormal shells following 48 hr exposure using undiluted water drained from defrosted sediment from sites S-2, B-2, B-3, and B-5, but were not affected by 1:5 dilutions of artificially prepared elutriates. Two hundred four hr exposure to sediments from each of the nine sites neither decreased survival of amphipods nor altered the time spent in the sediment or the amphipod's ability to rebury in sand. Ammonia-nitrogen concentrations in artificially prepared 1:5 elutriates at ambient pHs would be potentially toxic to salmonids and other fishes; therefore dredging methods that dilute the elutriate are recommended. An elutriate dilution of 1:1000 was shown to be safe; elutriate concentrations greater than 1:1000 could be toxic to salmonids and other fishes. Amphipod bioassays should not be used to assess potential chemical toxicity of dredged sediments until further research clarifies confounding factors such as anoxia and starvation.

*Robert W. ...*

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## 1.00 INTRODUCTION

The City of Tacoma, located on Commencement Bay, Puget Sound, Washington (Fig. 1), is a major Pacific Northwest shipping center. Approximately 10.3 million tons of cargo were handled by the Port of Tacoma in 1980 (Port of Tacoma, 1982), and this shipping activity continues to increase.

In 1975 the Seattle District, Corps of Engineers, initially considered the feasibility of improving navigation within Blair and Sitcum Waterways (Fig. 2). In 1982 the Port of Tacoma applied to the Seattle District, U.S. Army Corps of Engineers, for permission to build a new containerized cargo terminal by filling Milwaukee Waterway (Fig. 2) with sediment dredged from Blair and Sitcum Waterways. Existing chemical data (for example, Matias et al., 1980 and Riley et al., 1981) suggested that the sediments to be used as fill were not acceptable for open water disposal under Section 404 (b)(1) of the Clean Water Act (Public Law 92-500 as amended in 1977). Hence, the Corps of Engineers and the Port of Tacoma designed the proposed project so that the sediments to be used as fill would be presumed to be confined within Milwaukee Waterway and thereby isolated from aquatic ecosystems. Accordingly the Corps of Engineers' concern focused upon the potential acute toxicity to aquatic biota of any effluent returning to Commencement Bay. The Fisheries Research Institute, University of Washington, was requested to evaluate using bioassays any potential chemical toxicity of waters originating from the disposal of sediments dredged from Blair and Sitcum Waterways which might return to Commencement Bay.

In accordance with Section 404 (b)(1) of the Clean Water Act



Figure 1. Locations of Grays Harbor, Tacoma, and Wollochet Bay in Washington State.

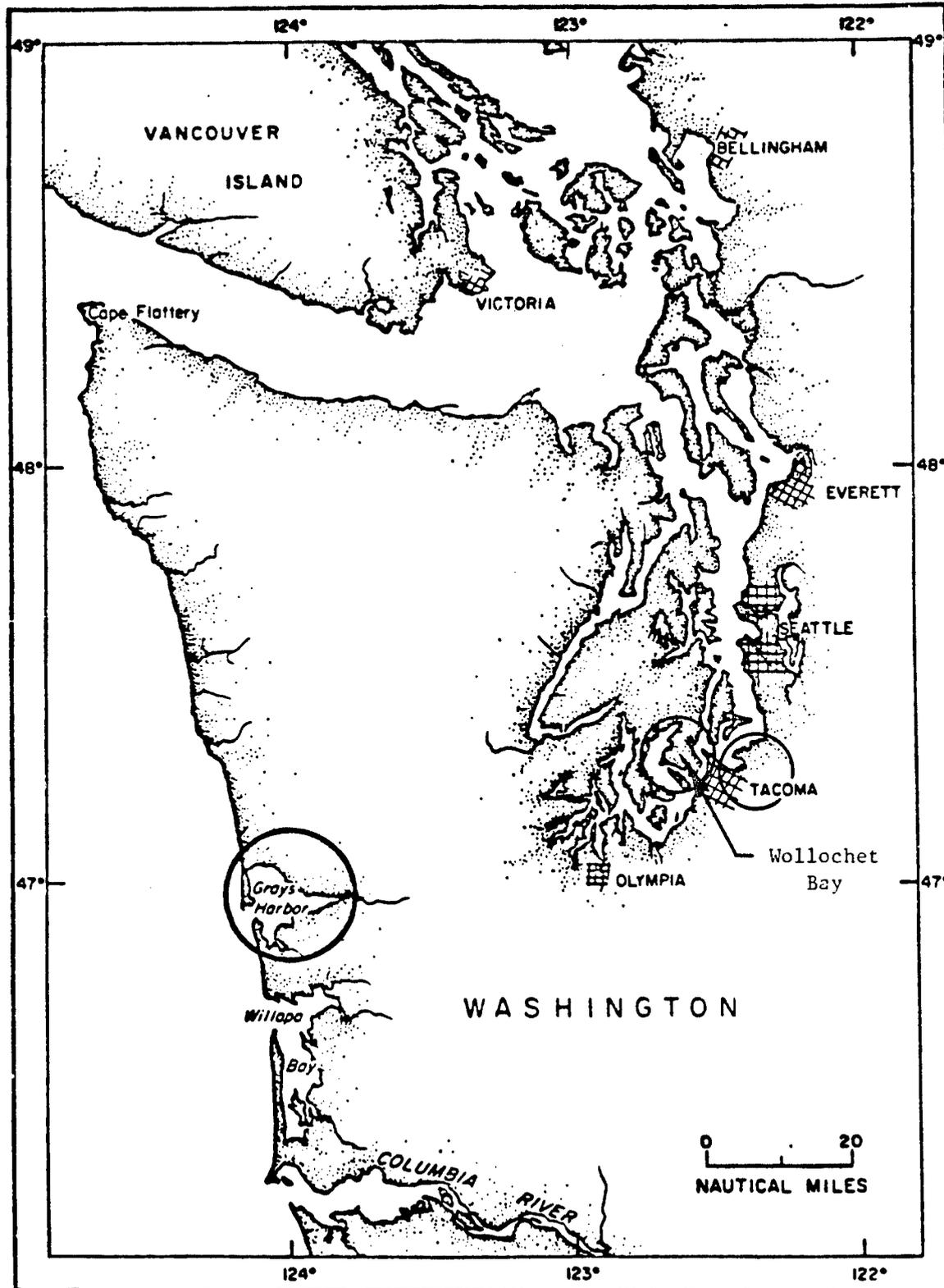
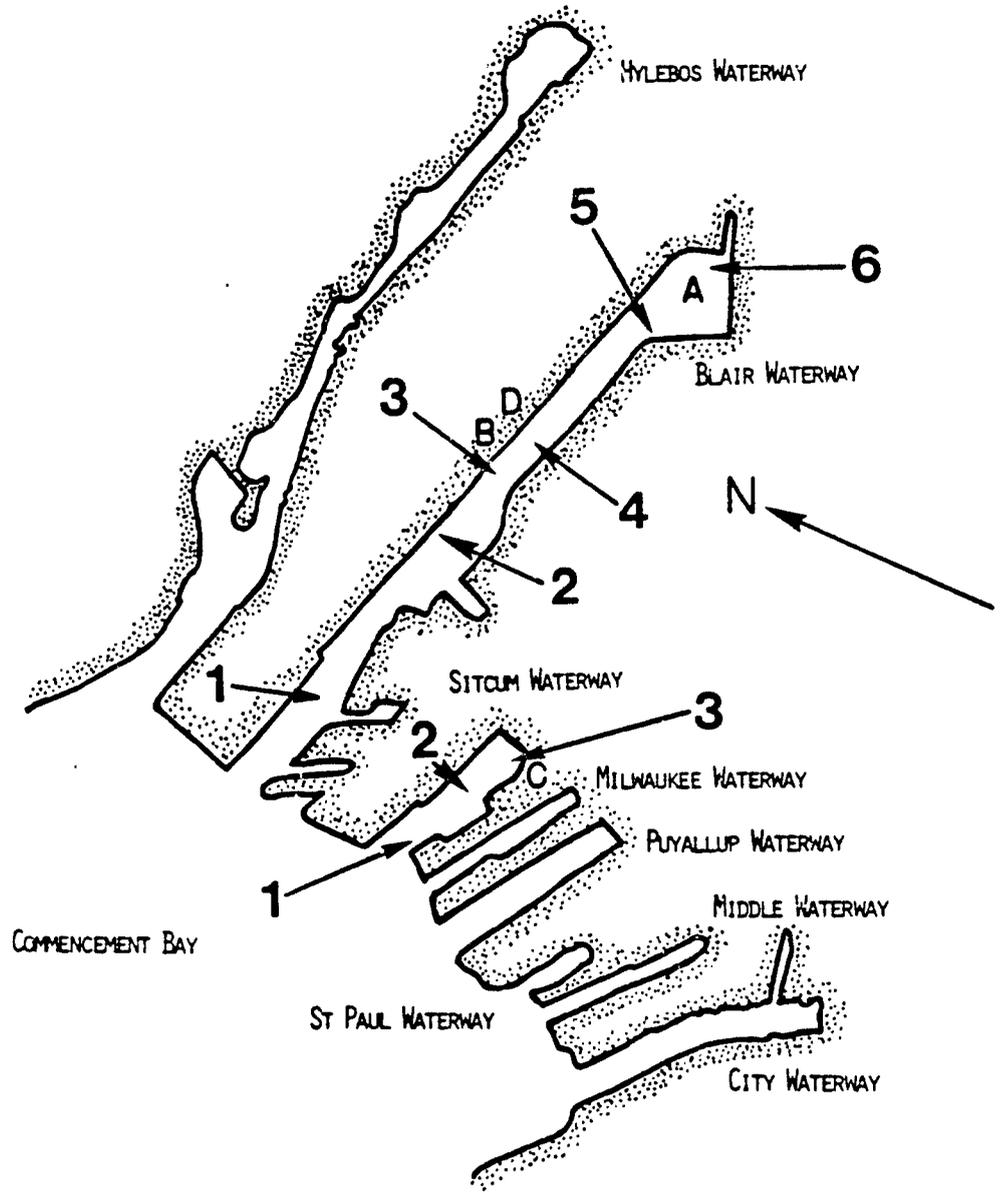




Figure 2. Locations of the nine sampling sites in Blair and Sitcum Waterways, Commencement Bay, Tacoma, Wa. Blair sites were designated B (for example, B-1) and Sitcum sites were designated S. A refers to the turning basin, B refers to the Lincoln Avenue bridge, C refers to the drain, and D refers to the Reichold Chemical Company.



1 inch = 0.22 mile = 1,167 feet

(Public Law 92-500 as amended in 1977) and related Environmental Protection Agency (EPA) regulations (40 CFR, Parts 220-230), the Fisheries Research Institute in consultation with the Seattle District Corps of Engineers selected three bioassays (see Pierson et al., 1982a) to be used in a testing program. As suggested by the above laws both vertebrate (salmon) and invertebrate animals (oysters, amphipods) were chosen for testing as were animals that live in the sediment (amphipods) and pelagic species (salmon) known to reside in or near the waterways at some times of the year. Both solid and suspended phase tests were selected. To evaluate potential mortality, tests exposing (1) chinook salmon to sediment elutriate, and (2) phoxocephalid amphipods to solid phase sediments were chosen. To evaluate potential sublethal effects, elutriate bioassays using oyster larvae were included.

## 2.00 METHODS AND MATERIALS

Bioassays were conducted between July and October, 1982, in a mobile laboratory designed and constructed by the Fisheries Research Institute, University of Washington (Pierson et al., 1982a). The facility was located near the mouth of Grays Harbor, adjacent to the Westport boat basin at Westport, Washington (Fig. 3). Seawater was pumped from outside the boat basin from an average depth of 32 feet at mean lower low water.

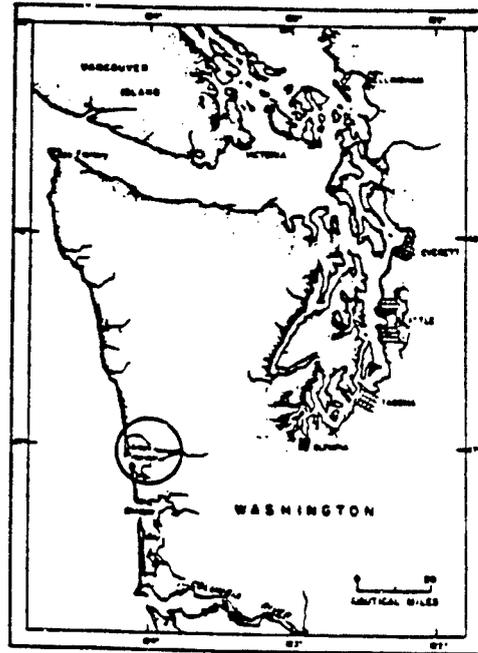
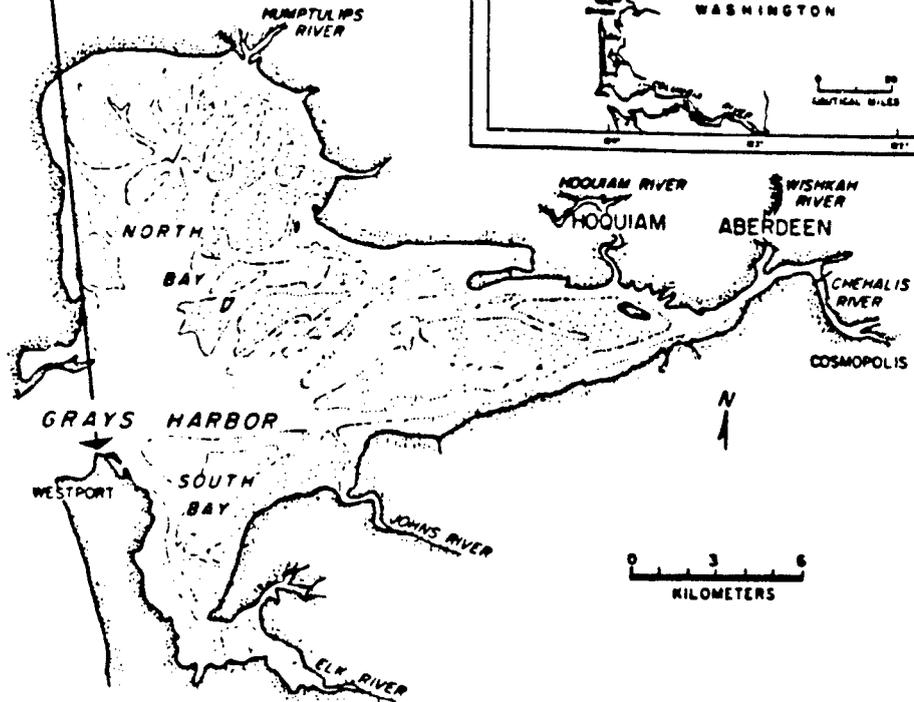
### 2.10 ANIMALS

Two thousand fall chinook salmon smolts (*Oncorhynchus tshawytscha*, Deschutes River stock) from the George Adams Hatchery on southern Hood Canal, Washington, were acclimated for two weeks in fiberglass troughs in flowing, non-chlorinated freshwater at Grayland, Washington. On each of the last two days of freshwater acclimation, 24 randomly chosen fish were sacrificed and their blood collected for plasma sodium analyses. The fish were then held for an additional two weeks acclimation at the laboratory at Westport, Washington in circular polyethylene tanks containing ambient, flowing seawater. For each of the first three days in seawater, 24 randomly chosen fish were again sacrificed and their blood collected for plasma sodium analyses. The fish were fed pelleted trout chow (Moore Clarke Co.) at ~ 2% of the total fish body weight per day. During the seven weeks of acclimation and testing, the average weight of an individual fish increased from 10 to 14 g.

Twenty-four adult Pacific oysters (*Crassostrea gigas*) from Grays Harbor, Washington, were obtained from a commercial oyster grower.

Figure 3. Location of the trailer/laboratory at Westport, Washington.

# TRAILER/ LABORATORY



Oysters were held in a circular polyethylene tank in ambient flowing seawater.

Nine hundred fifty amphipods (*Grandifoxus grandis*) were collected at Eagle Cove, San Juan Island, Washington. The amphipods collected included juveniles and adults ranging in length from 4-12 mm. The amphipods were shipped by air to Seattle-Tacoma International Airport and driven directly to the laboratory. The amphipods were acclimated in their native sand in two five gal buckets with screened overflows supplied with 1.5-2 L/min ambient, flowing seawater. Acclimation continued until after 11 d mortality had been less than 1% for three consecutive days.

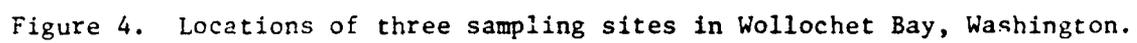
#### 2.20 SEDIMENT COLLECTION, STORAGE, AND HANDLING

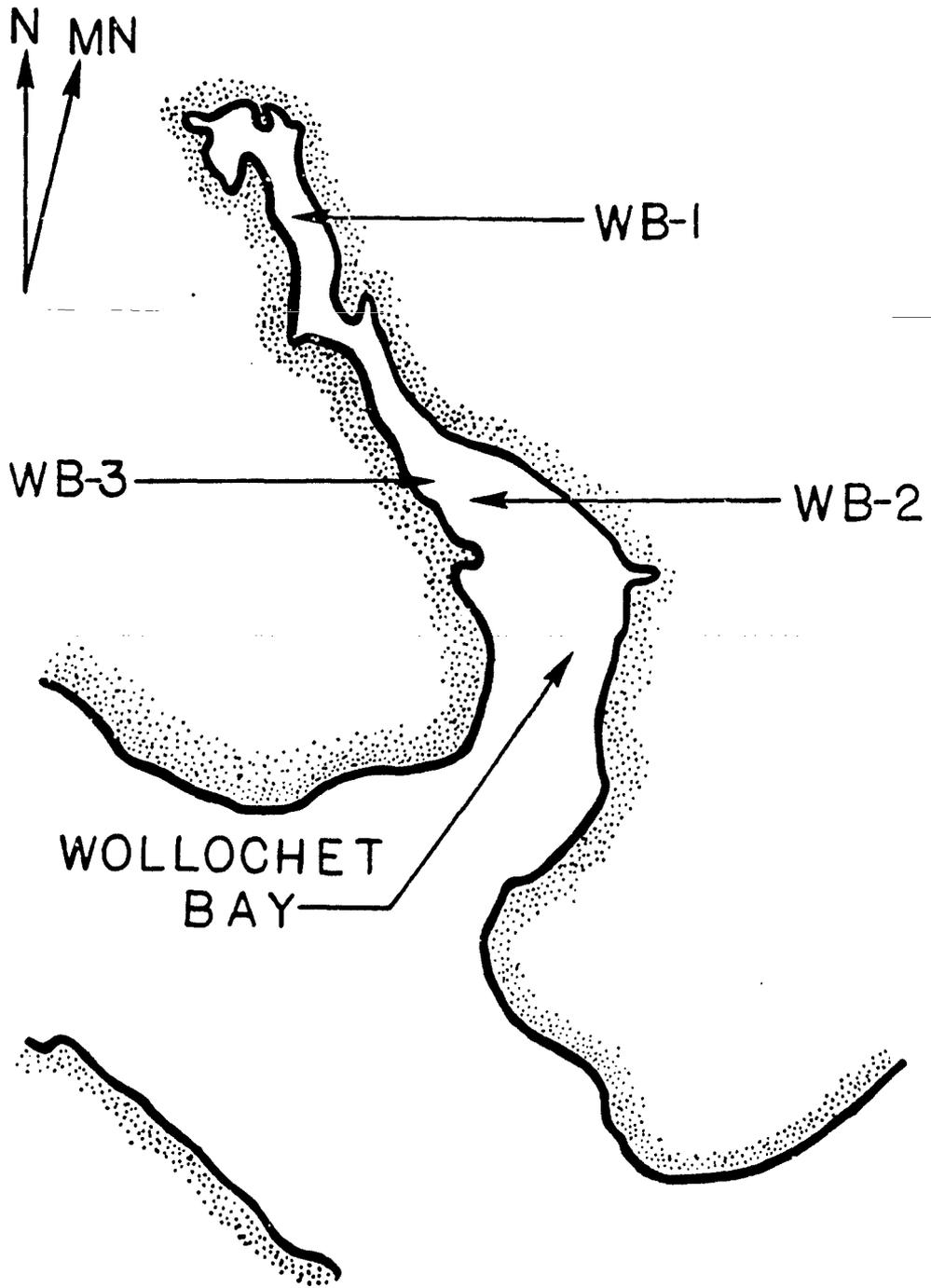
Test and control sediments were collected by commercial divers from six sites in Blair Waterway (designated sites B-1 through B-6) and three sites in Sitcum Waterway (numbered S-1 through S-3) chosen by the Corps of Engineers (Fig. 2). Control sediments were collected from three sites in Wollochet Bay, Washington (Fig. 4), pooled, and designated as site WB. Criteria for selection of test sites included: (1) previously reported toxicity (Swartz et al., 1982), (2) consultation with the EPA and the National Oceanographic and Atmospheric Administration, (3) proximity to shipping-related industries, and (4) inclusion within the proposed dredging area.

Sediments were collected by a commercial diver who hand filled and capped 5 gal polyethylene buckets while underwater. Buckets were stored at  $-2^{\circ}\text{C}$  for one to three days. All sediment from one site was

1

Figure 4. Locations of three sampling sites in Wollochet Bay, Washington.





1 inch = 0.38 miles = 2000 feet

pooled, mixed, redistributed among the five gal buckets, sealed, and frozen at  $-18^{\circ}\text{C}$ . Frozen sediments were transported to Westport, Washington and held at  $-22^{\circ}\text{C}$ . Sediments were thawed immediately prior to testing; thawing time varied from several hr to one day depending upon air temperature. Following two and occasionally three days of use, thawed sediment samples (buckets) were discarded and new samples utilized.

### 2.30 WATER QUALITY ANALYSES

Dissolved oxygen, ammonia-nitrogen, and pH were measured at least once during each bioassay; salinity and temperature were measured daily. Dissolved oxygen concentrations were measured with a Yellow Springs Instrument model 51B dissolved oxygen meter calibrated with the sodium azide modification of the Winkler method (APHA, 1981) where phenylarsine oxide was substituted for sodium thiosulfate. Ammonia-nitrogen concentrations were measured using the phenate method (EPA, 1979) without a preliminary distillation. Salinity and pH were measured using a Yellow Springs Instrument model S-6-T salinity meter and a Corning model 12 pH meter respectively. Temperature was measured with a mercury thermometer. Total non-filterable residue concentrations were measured by filtration (APHA, 1981).

### 2.40 PLASMA SODIUM ANALYSES

Fish were anaesthetized in 2-phenoxyethanol; the caudal peduncle was then severed and  $\sim 100 \mu\text{L}$  blood was collected in ammonium heparinized microcapillary tubes. The tubes were sealed and spun at

7000 RPM for 5 min. Tubes were then broken at the plasma-cell interface and the plasma portions were resealed and frozen at  $-10^{\circ}\text{C}$ . Frozen samples were shipped on dry ice from the laboratory to the University of Washington at Seattle.

After thawing a 20  $\mu\text{L}$  aliquot of plasma was removed from each tube. Samples were diluted 1:1000 in deionized water and analyzed for sodium using a Hitachi model 180-77 Zeeman effect atomic absorption spectrophotometer. An EPA sodium standard (5.0 ppm) had a mean value of  $5.04 \pm 0.05$  ppm ( $n = 13$ ).

#### 2.50 BIOASSAY METHODOLOGY

The bioassays included (1) a 96 hr elutriate test using fall chinook salmon smolts to assess potential mortality, (2) a 48 hr elutriate test using Pacific oyster larvae to evaluate sublethal effects, and (3) a 204 hr solid phase test using a phoxocephalid amphipod to assess potential mortality. All bioassays were conducted using a simulated natural photoperiod.

#### 2.51 Fall Chinook Salmon Bioassays

Chinook salmon smolts were exposed for 96 hr to a continuously flowing combined liquid-suspended phase (Pierson et al., 1982a) elutriate (Fig. 5). A 2% (by volume) stock sediment slurry was mixed, allowed to settle for 20 sec, and decanted over 1180 and 750  $\mu\text{m}$  mesh nitex screens. The slurry reservoir was refilled with this stock slurry four times daily. Serial dilution (Garton, 1980) of the elutriate from the baffle chambers resulted in final concentrations (by volume) of 1.0, 0.50, and

Figure 5. Flow scheme illustrating sediment and elutriate preparation for continuous flow bioassays.

Sediment is initially mixed in five gal buckets. The sediment to water ratio to produce a particular desired slurry depends upon the physical nature of the sediment being tested, and the amount of material within the sediment that will go into solution. The sediment is then screened to remove sediment debris which might clog the pumps as the sediment is poured into the sediment reservoir (C, 1). A recirculating pump maintains the sediment in continuous suspension. The sediment slurry is then pumped to the sediment delivery chamber (D). The excess slurry overflows (K) from the sediment delivery chamber and returns to the sediment reservoir. The slurry then flows (2) into the mixing chamber of the baffle chamber (3) where it is thoroughly mixed by a high speed stirrer (J) to assure maximum solution of sediment-associated chemicals into seawater. The rate of entry is controlled by a PVC valve (M). The elutriate flows through a series of 11 baffles allowing suspended material to settle out producing an elutriate that is free of macro-particulates (thus avoiding physical toxicity), but which retains colloids and small particulates which require an hr or more to settle. We term this elutriate the 'liquid-suspended' phase. This phase (4) flows into the first chamber (5) of the diluter (G), a sample is withdrawn (7), is split into equal volumes (8), and flows directly to the 15 gal testing aquaria. Excess elutriate flows from the first to the second chamber of the diluter, is diluted by seawater (6) from the head tank (F) to produce the second concentration. The length, height, and diameter of the tube (6) controls the concentration generated. The funnel (7) must be present to assure equal water flow rates. The control (10) is generated from water obtained directly from the head tank.



0.25 parts per thousand. Untreated seawater controls were incorporated into each apparatus. Seawater controls and exposure concentrations were replicated once resulting in eight test aquaria per sediment type. Four apparatus allowed simultaneous testing of three test sediments and the control (WB) sediment per cycle; hence, three cycles were required to test all nine Commencement Bay sites.

Ten salmon were randomly placed in each of thirty-two, 15 gal test aquaria approximately 12 hr prior to starting the bioassay. Fish feeding was suspended 24 hr prior to starting each bioassay, and fish were not fed during the bioassays. Each tank received 700 mL/min of elutriate which resulted in 95% molecular exchange in three hr (Sprague, 1969). Control (WB) sediment (1.0 ppt) passed through a continuously monitoring surface scatter turbidometer (Hach). Total non-filterable residue concentrations (APHA, 1981) were measured at the beginning and end of each experiment for each elutriate concentration from all four systems. Fish were observed three, six, 12, and 24 hr after initiation of each test and daily thereafter through termination of the experiment at 96 hr.

#### 2.52 Oyster Larvae Bioassay

Elutriates were prepared by diluting one part sediment to five parts unfiltered ambient seawater. These concentrated slurries were vigorously stirred for 30 min and allowed to settle for 1 hr. The supernatant was then siphoned off and filtered through a 1.2 µm Whatman GF/C filter. One to ten and 1:20 dilutions were prepared from the 1:5 elutriate using filtered seawater. Eighty-five one L beakers

containing 800 mL elutriate per beaker were used, including two replicates of each sediment elutriate concentration, 12 filtered seawater controls, and three water quality controls. Also included were filtered samples of the water drained from the buckets containing sediments after thawing.<sup>1</sup>

Twenty-four adult Pacific oysters (*Crassostrea gigas*) were held in a polyethylene circular tank with ambient, flowing seawater. Fourteen oysters were placed under ambient conditions in recirculating, temperature-controlled water baths. The temperature was slowly raised to 20°C which induced spawning. Spawning oysters were transferred to individual containers for the collection of gametes. Each test beaker (except for water quality controls) was inoculated with 0.24 mL of an undiluted, homogenous embryo suspension, producing a density of  $3.0 \times 10^4$  embryos/L (Woelke, 1972). All beakers were set in water baths at  $20.5 \pm 0.5^\circ\text{C}$ . After 48 hr the contents of each

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<sup>1</sup>Prior to pooling the sediments, all the water present in each bucket of sediment was drained and discarded. The sediments were then pooled, homogenized, and redistributed among the different buckets and frozen. After thawing some water was present in all buckets. This water was drained from each bucket and used for testing as described. Although this elutriate is not the actual interstitial water from a field sample, the water had been in intimate contact with the sediment for several weeks and hence, contained those chemicals present in or on the sediments which would dissolve into the water. This elutriate will subsequently be termed 'water drained from defrosted dredged sediment.'

beaker were made homogenous by slowly raising and lowering a perforated plunger, and two 10 mL samples were removed and preserved in buffered formalin.

### 2.53 Amphipod Bioassay

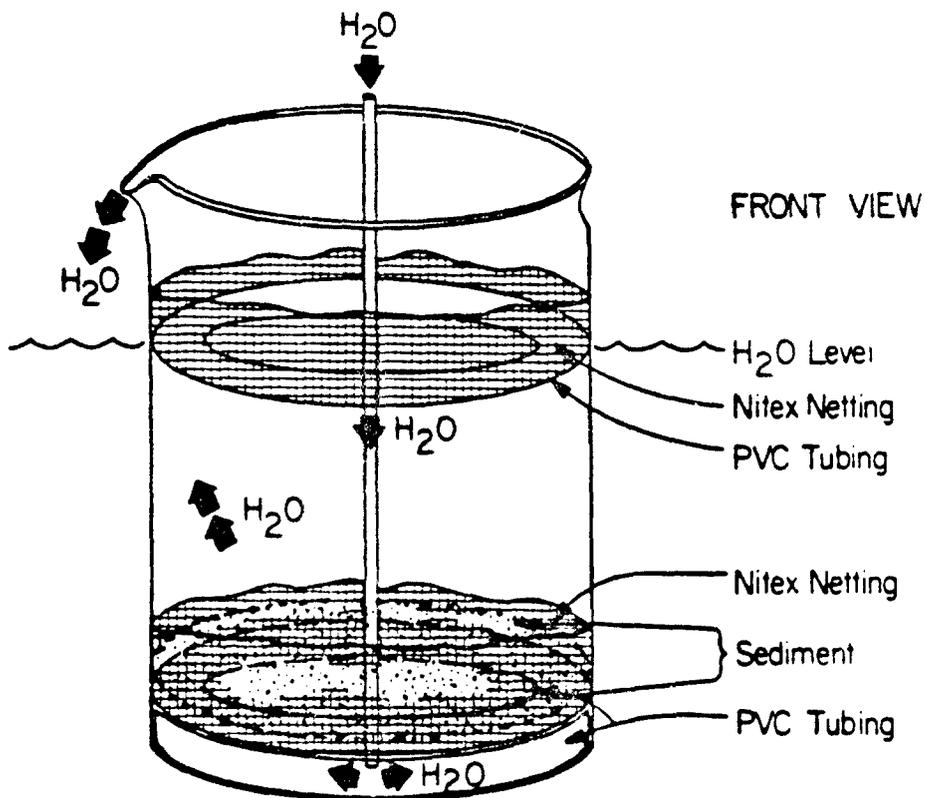
Amphipods were exposed for 204 hr to sediments in 2 L beakers (Fig. 6) with continuously flowing seawater. Three replicate beakers were used to test each sediment type. Four seawater controls (no sediment), three Eagle Cove (native) sand controls, and three controls containing sand collected from the beach at Grayland, Washington (approximately eight miles south of the laboratory) were also used. Eagle Cove and Grayland sands were not frozen prior to use.

The Eagle Cove sand control allowed the data to be corrected for the percent mortality present when the amphipod lived in its native habitat while the Grayland sand control (which had a particle size distribution similar to that of Eagle Cove sand) allowed comparison of these data with those data collected by Pierson et al. (1982b) for *G. gracilis* in Grayland sand and Grays Harbor dredged sediments. This second comparison was needed so that amphipod mortality data could be corrected for the effect of transferring the amphipods from their native sand into an unpolluted sediment of an entirely different physical nature.

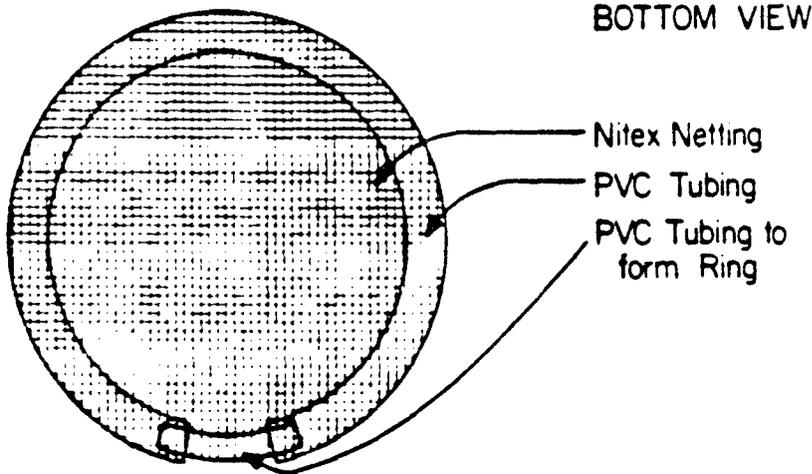
Ten randomly selected amphipods were placed in each beaker. The water flow averaged 110 mL/min which yielded a 90% molecular replacement in one hr. Perculation of seawater through the sediment was insured by delivery of the water through a glass tube to the area

Figure 6. Experimental apparatus used for exposing amphipods to dredged sediments.

Four and a half cm of sediment rested on a Nitex screen (28  $\mu\text{m}$  mesh) positioned 1.2 cm above the bottom of a 2 L beaker. The nitex was held in place between 2 PVC tubing rings (3/8" ID, 1/16" wall, Clearflow PVC). Seawater was delivered by glass tubing (1.8 mm ID Pyrex standard wall) to the area beneath the sediment. Amphipod escape in the overflow of the beakers was prevented by a Nitex screen (750  $\mu\text{m}$  mesh) held in place 7 cm below the beaker lip with pressure exerted by a PVC tubing ring. In addition, this screen prevented exposure of amphipods to an air-water interface in which they could become trapped. Test beakers were set in a water bath to maintain an ambient temperature.



FRONT VIEW



BOTTOM VIEW

beneath the sediment. The number of amphipods out of the sediment was recorded immediately after test initiation and twice daily thereafter. After 204 hr the sediment from each beaker was removed and sieved and the number of live amphipods recorded. These live amphipods were transferred to a beaker containing Eagle Cove sand and the number of amphipods that had buried in the sand after five and 15 min was recorded.

## 3.00 RESULTS

### 3.10 WATER CHEMISTRY

Ambient water conditions varied with the tide. Salinities ranged from 24.8 to 32.3 parts per thousand (ppt) and usually varied less than three ppt over 24 hr (Appendices 2 and 3). Temperatures remained relatively stable averaging  $\sim 14^{\circ}\text{C}$ , but ranged from 10.2 to 16.0 $^{\circ}\text{C}$  (Appendices 2 and 3). pH ranged from 7.79-8.27 (Appendices 2, 3, and 4). Except where noted below, water quality parameters were similar in both control and treated aquaria and were within acceptable ranges. Dissolved oxygen concentrations remained at or near 100% saturation except in the interstitial waters used during the oyster larvae bioassay (Appendices 2, 3, and 4). Ammonia-nitrogen concentrations were generally below 0.20 ppm in the salmon bioassays and below 0.50 ppm in the amphipod bioassays, but approached an estimated five ppm in some beakers using interstitial elutriate during the oyster larvae bioassay (Appendix 3).

### 3.20 CHINOOK SALMON BIOASSAYS

Plasma sodium concentrations of chinook salmon held in freshwater averaged 3.23 ppt (Table 1). After 24 hr in seawater, the mean blood sodium concentration had risen to 4.28 ppt, but after three days in seawater the mean sodium concentration had declined to 3.40 ppt. Only seven of the 24 fish tested after three days in seawater had sodium concentrations exceeding 3.50 ppt; hence, the chinook salmon had clearly developed the osmoregulatory ability to tolerate seawater.

Three cycles of bioassays were performed. During cycles one and

Table 1. Plasma sodium concentrations in parts per thousand for chinook salmon (Oncorhynchus tshawytscha) smolts held in fresh- and seawater.

Fish No.	Freshwater		Seawater		
	14 July	15 July	16 July	17 July	18 July
1	2.97	3.35	4.07	3.71	3.15
2	2.91	2.82	3.99	4.07	3.27
3	3.60	3.44	4.74	3.37	3.39
4	3.29	3.44	4.76	3.36	3.48
5	3.51	3.00	4.13	3.33	3.21
6	3.17	--	5.72	4.20	3.36
7	--	3.56	3.60	3.54	4.17
8	3.40	2.67	4.14	3.56	3.93
9	--	3.05	3.93	3.90	3.57
10	3.25	3.29	4.47	3.81	3.21
11	3.74	3.34	3.86	3.78	3.29
12	3.26	3.13	4.82	3.90	3.53
13	4.80	3.38	4.55	4.23	3.45
14	3.59	3.18	4.02	3.58	3.35
15	3.20	3.51	4.46	4.50	2.93
16	3.18	--	3.90	4.25	3.15
17	3.07	3.89	4.22	3.63	3.17
18	2.67	3.20	4.01	3.50	3.54
19	2.84	3.32	4.26	3.47	3.69
20	3.16	2.94	4.39	3.66	3.86
21	2.48	3.45	3.57	3.66	3.21
22	2.60	2.97	4.31	3.60	3.17
23	3.04	3.00	4.55	4.26	3.21
24	2.85	3.51	4.34	3.63	3.29
$\bar{X}$	3.21	3.25	4.28	3.77	3.40
S.D.	0.483	0.283	0.455	0.325	0.286

two the mortality in both the seawater controls and in the holding aquaria remained essentially zero. However, during the third cycle unexplained mortalities occurred in both the seawater controls and in the holding aquaria. These mortalities were initially believed to stem from a *Vibrio* infection, but histological examination of formalin-preserved specimens showed that the minor lesions noted were healing and no bacterial infection was observed. Hence, results of the third bioassay cycle (sites S-3, B-4, and B-6) are not reported because these results can be misleading.

Chinook salmon survival was not affected by 96 hr exposure to elutriates from sites WB, S-1, S-2, B-2, B-3, and B-5. No tank, control or treated, had more than one mortality (Table 2). Fin erosion was noted on some salmon fingerlings (Table 2) in both the seawater controls and some sediment elutriates, but the distribution seemed random.

Sediments from the different sites produced elutriates of varying total non-filterable residue concentrations (Table 3). The baffle chambers were fairly efficient at settling particulates from all sites; mean concentrations in the 1.00 ppt elutriates ranged from 0.11 to 0.37 g/L (Table 3).

### 3.30 OYSTER LARVAE BIOASSAY

Ammonia-nitrogen concentrations equalled or exceeded two ppm in some of the filtered 1:5 elutriates (WB, S-1), while seawater control concentrations never exceeded 0.050 ppm (Table 4). The ambient pH ranged from 7.79 to 8.15 (Table 4). Even so, no significant differences

Table 2. Responses of chinook salmon (*Oncorhynchus tshawytscha*) smolts exposed for 96 hr to continuously flowing sediment elutriates prepared from dredged sediments from six sites in Blair and Sitcum Waterways, Commencement Bay, Tacoma, Wa. Sediment concentrations are in parts per thousand.

Site	Cycle	Tank No.	Sediment concentration (ppt)	No. fish at start	Mortality			Total number of survivors	Total mortality (%)	Number with fin erosion	Fin erosion (%)
					24 hr	48 hr	72 hr				
Seawater Control	1	1	0	10	0	0	0	0	0	0	0
	1	2	0	10	0	0	0	0	0	0	0
	1	9	0	10	0	0	0	0	0	0	0
	1	10	0	10	0	0	0	0	0	0	0
	1	17	0	10	0	0	0	0	0	0	0
	1	18	0	10	0	0	0	0	0	0	0
Seawater Control	1	25	0	10	0	0	0	0	0	0	0
	1	26	0	10	0	0	0	0	0	2	20
Seawater Control	2	7	0	10	0	0	0	0	0	0	0
	2	8	0	10	0	0	0	0	0	0	0
	2	9	0	10	0	1	0	1	10	0	0
	2	10	0	10	0	0	0	0	0	0	0
	2	23	0	10	0	0	0	0	0	0	0
	2	24	0	10	0	0	0	0	0	0	0
Mollochet Bay	1	7	1.0	10	0	0	0	0	0	0	0
	1	8	1.0	10	0	0	0	0	0	0	0
Mollochet Bay	1	5	0.50	10	0	0	1	1	10	1	10
	1	6	0.50	10	0	0	0	0	0	0	0
	1	3	0.25	10	0	0	0	0	0	0	0
	1	4	0.25	10	0	0	0	0	0	0	0
Mollochet Bay	2	1	1.0	10	0	0	0	0	0	0	0
	2	2	1.0	10	0	0	0	0	0	0	0
	2	3	0.50	10	0	0	0	0	0	0	0
	2	4	0.50	10	0	0	0	0	0	0	0
	2	5	0.25	10	0	0	0	0	0	0	0
	2	6	0.25	10	0	0	0	0	0	0	0

Table 2 continued.

Site	Cycle	Day No.	Sediment Concn. (g/g)	No. fish at start	Mortality			Total number of mortalities	Number of survivors	Tot-1 mortality (%)	Number with fin erosion	Fin erosion (%)
					24 hr	72 hr	96 hr					
S-1	1	23	1.0	10	0	0	0	10	0	0	0	
S-1	1	24	1.0	10	0	0	0	10	0	0	0	
S-1	1	21	0.50	10	0	0	0	10	0	1	10	
S-1	1	22	0.50	10	0	0	0	10	0	1	10	
S-1	1	19	0.25	10	0	0	0	10	0	0	0	
S-1	1	20	0.25	10	0	0	0	10	0	0	0	
S-2	2	31	1.0	10	0	0	0	10	0	0	0	
S-2	2	32	1.0	10	0	0	0	10	0	0	0	
S-2	2	29	0.50	10	0	0	0	10	0	0	0	
S-2	2	30	0.50	10	0	0	0	10	0	0	0	
S-2	2	27	0.25	10	0	0	0	10	0	0	0	
S-2	2	28	0.25	10	0	0	0	10	0	0	0	
B-1	1	15	1.0	10	0	1	1	9	10	3	30	
B-1	1	16	1.0	10	0	0	0	10	0	1	10	
B-1	1	13	0.50	10	0	0	0	10	0	0	0	
B-1	1	14	0.50	10	0	0	0	10	0	0	0	
B-1	1	11	0.25	10	0	0	0	10	0	0	0	
B-1	1	12	0.25	10	0	0	0	10	0	0	0	
B-2	2	15	1.0	10	0	0	0	10	0	0	0	
B-2	2	16	1.0	10	0	0	0	10	0	0	0	
B-2	2	13	0.50	10	0	0	0	10	0	0	0	
B-2	2	14	0.50	10	0	0	0	10	0	0	0	
B-2	2	11	0.25	10	0	0	0	10	0	0	0	
B-2	2	12	0.25	10	0	0	1	9	10	0	0	
B-3	2	17	1.0	10	0	0	0	10	0	0	0	
B-3	2	18	1.0	10	0	0	0	10	0	0	0	
B-3	2	19	0.50	10	0	0	0	10	0	4	40	
B-3	2	20	0.50	10	0	0	0	10	0	0	0	
B-3	2	21	0.25	10	0	0	0	10	0	2	20	
B-3	2	22	0.25	10	0	0	0	10	0	0	0	

Table 2 continued.

Site	Cycle	Tank No.	Sediment concentration (ppt)	No. fish at start	Mortality			Total number of mortalities	Number of survivors	Total mortality (%)	Number with fin erosion	Fin erosion (%)
					24 hr	48 hr	72 hr					
B-5	1	31	1.0	10	0	0	0	10	0	3	30	
B-5	1	32	1.0	10	0	0	0	10	0	3	30	
B-5	1	29	0.50	10	0	0	0	10	0	1	10	
B-5	1	30	0.50	10	0	0	0	10	0	0	0	
B-5	1	27	0.25	10	0	0	0	10	0	0	0	
B-5	1	28	0.25	10	0	0	0	10	0	3	30	

Table 3. Mean total non-filterable residue concentrations (g/L) for elutriates prepared from dredged sediments from nine sites in Blair and Sitcum Waterways, Commencement Bay, Tacoma, Wa.

Site	Elutriate concentration (parts per thousand)											
	0			0.25			0.50			1.0		
	N	$\bar{x}$	SD	N	$\bar{x}$	SD	N	$\bar{x}$	SD	N	$\bar{x}$	SD
Seawater control	43	0.038	0.030	--	--	--	--	--	--	--	--	--
Wollochet Bay	--	--	--	9	0.10	0.081	10	0.089	0.037	11	0.13	0.054
S-1	--	--	--	4	0.10	0.026	4	0.091	0.059	2	0.24	0.013
S-2	--	--	--	--	--	--	3	0.015	0.010	4	0.11	0.12
S-3	--	--	--	4	0.12	0.025	3	0.14	0.017	3	0.35	0.14
B-1	--	--	--	4	0.073	0.033	4	0.13	0.039	4	0.12	0.068
B-2	--	--	--	2	0.055	0.078	4	0.051	0.030	3	0.21	0.058
B-3	--	--	--	4	0.089	0.060	3	0.17	0.13	4	0.29	0.15
B-4	--	--	--	4	0.061	0.036	4	0.17	0.052	4	0.37	0.17
B-5	--	--	--	4	0.080	0.0059	4	0.13	0.011	4	0.23	0.034
B-6	--	--	--	4	0.077	0.018	4	0.16	0.061	4	0.23	0.027

Table 4. Responses of oyster (*Crassostrea gigas*) larvae exposed for 48 hr to sediment elutriates prepared from dredged sediments from nine sites in Blair and Sitcum Waterways, Commencement Bay, Tacoma, Wa.

Site	Beaker No.	Dilution	Ammonia-nitrogen (mg/L)	Number normal	Mean number normal per site	Standard deviation	Number abnormal	Mean number abnormal per site	Standard deviation	Abnormal (%)	Mean percent abnormal per site	Standard deviation	pH
Seawater control	43	--	< 0.050	62	57	11	14	8.0	3.2	18.4	12.4	4.25	8.16
SWC	44	--	< 0.050	69			10			12.7			8.08
SWC	45	--	< 0.050	57			9			13.6			8.09
SWC	46	--	< 0.050	68			3			4.20			8.15
SWC	47	--	< 0.050	61			5			7.60			8.10
SWC	50	--	< 0.050	48			9			15.8			8.08
SWC	50	--	< 0.050	66			9			12.0			8.08
SWC	71	--	< 0.050	48			7			12.7			8.07
SWC	72	--	< 0.050	35			6			14.6			8.07
Wollochet Bay	64	1:5	2.4 <sup>a</sup>	43	42	13	8	6	2	15.7	13.2	2.19	7.79
WB	65	1:5	1.5	28			4			12.5			8.06
WB	65	1:5	1.5	54			7			11.5			8.06
S-1	13	1:5	1.4	37	47	12	7	5	2	15.9	10.2	5.06	7.99
S-1	13	1:5	1.4	44			4			8.30			7.99
S-1	14	1:5	2.0 <sup>a</sup>	60			4			6.30			7.99
S-2	40	1:5	0.99	53	53	8.5	12	7	5	18.5	11.7	6.18	7.99
S-2	41	1:5	0.91	61			7			10.3			7.94
S-2	41	1:5	0.91	44			3			6.40			7.94
S-3	35	1:5	1.3	65	71	6.6	13	10	2.7	16.7	12.5	3.81	7.84
S-3	36	1:5	--	78			8			9.30			7.89
S-3	36	1:5	--	70			9			11.4			7.89

Table 4 continued.

Site	Beaker No.	Dilution	Ammonia-nitrogen (mg/L)	Number normal	Mean number normal per site	Standard deviation	Number abnormal	Mean number abnormal per site	Standard deviation	Abnormal (%)	Mean percent abnormal per site	Standard deviation	pH
B-1	4	1:5	0.87	67	64	19	12	8	5	15.2	9.87	5.40	8.03
B-1	5	1:5	0.64	81			9			10.0			7.96
B-1	5	1:5	0.64	44			2			4.4			7.96
B-2	1	1:5	1.1	54	68	25	4	6	3	6.90	8.52	1.65	8.03
B-2	1	1:5	0.95	53			6			10.20			8.03
B-2	2	1:5	0.95	97			9			8.50			7.88
B-3	20	1:5	1.3	69	82	12	13	15	3.5	15.9	15.4	2.43	7.99
B-3	21	1:5	1.1	89			19			17.6			7.92
B-3	21	1:5	1.1	89			13			12.8			7.92
B-4	58	1:5	0.41	54	62	7.6	5	5	0	8.5	7.53	0.874	7.87
B-4	59	1:5	0.44	69			5			6.8			7.99
B-4	59	1:5	0.44	64			5			7.3			7.99
B-5	31	1:5	1.5	53	66	11	4	7	3	7.0	9.4	2.9	7.94
B-5	32	1:5	0.96	74			7			8.6			7.87
B-5	32	1:5	0.96	70			10			12.5			7.87
B-6	18	1:5	1.3	75	75	3.0	6	9	3	7.4	11	3.1	7.93
B-6	18	1:5	1.3	72			10			12.2			7.93
B-6	18	1:5	1.3	78			12			13.3			7.93

<sup>a</sup>Estimated ammonia-nitrogen concentration. The highest standard used was 2.0 mg/L ammonia-nitrogen.

in percent abnormal larvae were observed between seawater controls (4.2 to 18.4% abnormal larvae) and any sediment type (4.4 to 18.5% abnormal larvae; Table 4). Because there was no effect at the highest concentrations, larvae exposed to 1:10 and 1:20 elutriate dilutions of the various sediments were not evaluated.

Significant differences did occur between seawater controls and the water drained from sediment buckets after thawing (Table 5). Abnormal larvae varied from 21.7 to 100% in these samples (Table 5), with all but sites B-4 and B-6 having greater than 50% abnormality rates. Estimated ammonia-nitrogen concentrations approaching five ppm were observed in some of the elutriates (Table 5). In addition three elutriates from sites WB, S-1, and S-3, had dissolved oxygen concentrations less than 3.0 ppm.

#### 3.40 AMPHIPOD BIOASSAY

Mortalities in Eagle Cove and Grayland sand averaged 12.4 and 6.4% respectively yielding a mean control sand mortality of 9.4%. Pierson et al. (1982b) calculated 13.3% mean mortality for *G. grandis* living in unpolluted dredged sediment and no mortality for *G. grandis* living in Grayland beach sand. The amphipod mortalities from these bioassays (Table 6) were corrected for control mortality and substrate effect by subtracting 22.7% ( $13.3 + 9.4\%$ ) to yield a corrected mortality for each of the nine Blair and Sitcum sites. The mortalities observed in beaker 22 (site S-3) were discarded; following collapse of the nitex netting, water flow to the beaker was stopped causing the dissolved oxygen concentration in the seawater to drop to 1.4 ppm and the ammonia-nitrogen concentration to rise to 0.94 ppm.

Table 5. Responses of oyster (*Crassostrea gigas*) larvae exposed for 48 hr to water drained from defrosted sediments from nine sites in Blair and Sitcum Waterways, Commencement Bay, Tacoma, Wa.

Site	Beaker No.	Ammonia- <sup>a</sup> nitrogen (mg/L)	Dissolved oxygen (mg/L)	Number normal	Number abnormal	Abnormal (%)	pH
Wollochet Bay	85	4.65	0.20	0	34	100	7.74
S-1	84	4.27	0.90	0	19	100	8.02
S-2	83	4.63	3.8	0	46	100	7.96
S-3	76	4.16	1.8	2	76	97.4	7.86
B-1	74	--	3.1	11	35	76.1	7.80
B-2	75	3.78	4.2	21	27	56.3	7.79
B-3	82	3.50	5.0	8	37	82.2	8.05
B-4	73	--	4.4	47	13	21.7	7.64
B-5	77	2.26	3.3	14	19	57.6	7.94
B-6	81	4.11	3.3	55	23	29.5	7.76

<sup>a</sup> Estimated ammonia-nitrogen concentration. The highest standard used was 2.0 mg/L ammonia-nitrogen.

Table 6. Responses of the phoxocephalid amphipod, *Grandifoxus grandis*, exposed for 204.0 hr to sediments dredged from nine sites in Blair and Sitcum Waterways, Commencement Bay, Tacoma, Wa.

Site	Beaker No.	No. in beaker at start	Alive	Dead	Missing	204.0 hr		Corrected total mortality <sup>a</sup>	Mean corrected total mortality per site	Standard deviation
						$\left[ \frac{\text{Dead}}{\text{Alive+Dead}} \right] \times 100$	$\left[ \frac{\text{Dead+Missing}}{\text{No. at start}} \right] \times 100$			
Sewater control	15	10	8	1	1	11.1	20.0	--	17.5	17.1
SWC	19	10	10	0	0	0	0	--	--	--
SWC	27	10	6	1	3	14.3	40.0	--	--	--
SWC	35	10	9	0	1	0	10.0	--	--	--
Eagle Cove sand	3	10	9	0	1	0	10.0	--	12.4	13.8
ECS	2	11	8	3	0	27.3	27.3	--	--	--
ECS	1	12	12	0	0	0	0	--	--	--
Graylead sand	4	10	9	0	1	0	10.0	--	6.33	5.51
GS	5	11	11	0	0	0	0	--	--	--
GS	6	11	10	1	0	9.1	9.1	--	--	--
Wollochet Bay	10	10	7	3	0	30.0	30.0	7.30	11.5	14.1
WB	20	10	5	1	4	16.7	50.0	27.3	--	--
WB	30	10	8	0	2	0	20.0	0	--	--
S-1	12	10	7	0	3	0	50.0	27.3	21.5	19.3
S-1	18	11	9	1	1	10.0	18.2	0	--	--
S-1	29	10	4	1	5	20.0	60.0	37.3	--	--
S-2	16	10	9	1	0	10.0	10.0	0	9.10	15.8
S-2	32	11	10	0	1	0	9.10	0	--	--
S-2	39	10	5	2	3	28.6	50.0	27.3	--	--

Table 6 continued.

Site	Beaker No.	No. in beaker at start	Alive	Dead	Missing	204.0 hr		Corrected total mortality <sup>a</sup>	Mean corrected total mortality per site	Standard deviation
						$\left[ \frac{\text{Dead}}{\text{Alive+Dead}} \right] \times 100$	$\left[ \frac{\text{Dead+Missing}}{\text{No. at start}} \right] \times 100$			
S-3	8	10	9	0	1	0	10.0	8.65	12.2	
S-3	22	10	0	10	0	100 <sup>b</sup>	0			
S-3	27	10	6	1	3	14.3	40.0	17.3		
B-1	7	10	6	0	4	0	40.0	17.3	9.99	
B-1	28	10	8	2	0	20.0	20.0	0		
B-1	40	10	6	1	3	14.3	40.0	17.3		
B-2	21	10	5	1	4	16.7	50.0	27.3	10.0	
B-2	31	10	7	3	0	30.0	30.0	7.30		
B-2	38	10	6	2	2	25.0	40.0	17.3		
B-3	23	10	8	0	2	0	20.0	0	8.69	
B-3	25	10	6	0	4	0	40.0	17.3		
B-3	36	10	7	3	0	30.0	30.0	7.30		
B-4	13	10	7	0	3	0	30.0	7.30	5.77	
B-4	33	10	6	2	2	25.0	40.0	17.3		
B-4	34	10	6	0	4	0	40.0	17.3		
B-5	17	10	7	0	3	0	30.0	7.30	4.21	
B-5	24	10	9	1	0	10.0	10.0	0		
B-5	26	10	7	3	0	30.0	30.0	7.30		
B-6	9	10	8	1	1	11.1	20.0	0	11.5	
B-6	11	10	5	1	4	16.7	50.0	27.3	14.1	
B-6	14	10	7	1	2	14.3	30.0	7.30		

<sup>a</sup> [(Dead + Missing)/ No. at Start] - 13.3 - 9.4. The 13.3% correction factor for clean sediment was taken from Pierson et al., 1982. The 9.4% is the mean of the Eagle Cove and Grayland sand controls.

<sup>b</sup> The water flow to this beaker stopped and/or slowed. The result was that the sediment became anoxic and all the amphipods died.

The corrected mean mortalities at each of the 10 sites ranged from 4.86 to 21.5% (Table 6). The variation in response among amphipods in the replicate beakers was sufficiently high (standard deviations ranged from 4.21 to 19.3) that it was impossible to differentiate between the percent mortalities observed in the various controls and treatments. For example, mortalities among amphipods held in the two types of sand controls ranged from zero to 27.3%.

Behavioral observations were tabulated for each beaker by dividing the total number of actual sightings (number of amphipods visible out of the sediment) by the number of possible sightings [(the number of amphipods in beaker at start times number of observation periods) times 100, Table 7]. The resulting number represents the amount of time an 'average' amphipod spent out of the sediment in each beaker. Amphipods in Eagle Cove sand were never observed out of the sediment, while amphipods in Grayland beach sand were out of the sand at most 1.7% of the time. Sediment in three beakers--one each from sites B-1, B-3, and B-6--caused the amphipods to spend 10% or more of their time out of the sediment.



Table 7 continued.

Site	Beaker No.	No. in beaker at start	No. in beaker at start										Total number out of 204 hr observed	Percent of time alive at 204 hr	Corrected total mortality	No. not reburied in 5 min	Σ Not reburied in 5 min	No. not reburied in 10 min	Σ Not reburied in 10 min	
			2	12	34	41	59	66	82	89	131	139								155
B-3	8	10	0	2	0	0	1	1	0	0	0	0	5	4.2	0	0	0	0	0	0
B-3	22	10	1	1	1	0	0	1	0	5	6	6	--c	--c	--c	--c	--c	--c	0	
B-3	37	10	2	0	2	0	0	0	1	0	0	0	5.0	13.9	0	0	0	0	0	
B-1	7	10	0	0	0	0	1	0	0	0	0	0	0.8	13.9	0	0	0	0	0	
B-1	28	10	0	1	2	1	0	0	0	0	0	4	3.3	0	0	0	0	0	0	
B-1	40	10	5	0	0	0	0	0	2	3	1	0	11.7	13.9	0	0	0	0	0	
B-2	21	10	2	1	1	0	1	0	0	0	0	0	4.2	23.9	0	0	0	0	0	
B-2	31	10	1	1	1	1	0	0	0	0	0	3	4.5	3.90	2	28.6	3	42.9	0	
B-2	38	10	1	0	2	1	0	0	0	0	0	4	3.3	13.9	0	0	0	0	0	
B-3	23	10	0	0	0	0	0	0	1	0	1	0	1.7	0	0	0	0	0	0	
B-3	25	10	1	0	1	0	0	0	0	0	0	2	1.7	13.9	0	0	0	0	0	
B-3	36	10	4	2	5	1	1	1	0	1	0	0	12.5	3.90	0	0	0	0	0	
B-4	13	10	0	0	0	0	1	0	0	0	0	1	0.8	3.90	0	0	0	0	0	
B-4	33	10	0	0	2	0	1	0	1	0	2	3	5.8	13.9	2	33.3	2	33.3	0	
B-4	34	10	1	0	0	0	0	0	0	0	1	0	1.7	13.9	0	0	0	0	0	
B-5	17	10	0	0	0	0	0	0	0	0	0	0	0	3.90	0	0	0	0	0	
B-5	24	10	2	1	0	0	1	0	1	0	0	4	5.0	0	0	0	0	0	0	
B-5	26	10	0	1	0	0	0	0	0	0	0	1	0.8	3.90	0	0	0	1	16.3	
B-6	9	10	2	2	2	0	0	2	0	1	0	0	7.5	0	1	12.5	1	12.5	0	
B-6	11	10	3	1	0	0	1	0	0	0	0	1	5.0	23.9	0	0	0	0	0	
B-6	14	10	3	1	0	1	0	0	1	2	0	1	10.0	3.90	0	0	0	0	0	

<sup>a</sup>Number Observed/(Number in Beaker at Start x Number of Observation Periods) x 100.

<sup>b</sup>Based on number alive at 204 hr.

<sup>c</sup>The water flow to this beaker stopped and/or slowed. The result was that the sediment became anoxic and all amphipods died.

#### 4.00 DISCUSSION

These bioassays were performed using Commencement Bay sediments and Grays Harbor water. Water quality differences between Commencement Bay and Grays Harbor water may be potentially important because of the ammonia-nitrogen concentrations<sup>2</sup> noted in many of the artificially prepared sediment elutriates. The sediments used in this study were collected over four days and refrigerated. During refrigeration and subsequent mixing, the plant and animal life present (Appendix 1) in the sediment probably died. Hence, one cannot determine whether the ammonia-nitrogen concentrations observed are characteristic of the actual sediments or rather if they stem from the particular collection process used.

During the ammonia-nitrogen assay, ammonia ( $\text{NH}_3$ ) is converted to ammonium ion ( $\text{NH}_4^+$ ) by a decrease in pH. Hence, the ammonia-nitrogen assay measures both ammonia and ammonium ion rather than the actual quantity of ammonia present in the seawater. Ammonia ( $\text{NH}_3$ ) is the toxic component. To estimate the actual concentrations of ammonia and ammonium ion present in the water, one uses the pH. As the pH increases, the ammonia concentration increases. For example, increasing the pH from 7.9 to 8.2 at 20°C approximately doubles the ammonia concentration. Hence, if the pH in Commencement Bay differs seasonally (or in whatever way) from that in Grays Harbor, the concentration of ammonia present would be different in the two water sources and potential toxic effect (if any) might vary.

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<sup>2</sup>Other factors such as salinity, temperature, etc. can also modify toxicity.

The relatively high ammonia-nitrogen concentrations in the artificially prepared elutriates suggest that the dredging strategy used may be important in preventing toxicity. A dredging technique should be used that adequately dilutes the elutriate; a dilution of 1:5 was insufficient while a dilution of 1:1000 was adequate. Concentrations between 1:5 and 1:1000 were not tested; hence, elutriate concentrations greater than 1:1000 could be toxic to salmonids. Alternative strategies such as dredging when juvenile salmonids are absent may be considered, but resident fish species (such as perches of the family Embiotocidae) are equally sensitive to the ammonia-nitrogen concentrations in undiluted elutriates.

In future research a more suitable control sediment site should be selected. Chemical data were not available to justify describing Wollochet Bay sediment as pristine, and the high ammonia-nitrogen concentrations noted made its use particularly dubious. Finally, the particle size distribution of Wollochet Bay sediment was often very different from the Blair and Sitcum sediments.

Elutriates (1:1000) of sediments dredged from sites S-1, S-2, B-1, B-2, B-3, and B-5 did not produce acute toxicity in chinook salmon smolts after 96 hr exposure. The fin erosion data are insufficient for meaningful interpretation. Fin erosion is generally considered to be a non-specific response to polluted sediment, but few data exist to link fin erosion with specific chemicals, exposure times, or concentrations especially for pelagic fish species. The association of fin erosion with many bacterial fish diseases further confounds possible interpretation. No correlation of this fin erosion occurred with either the amphipod or oyster larvae data.

Statistical analyses were not performed using either the oyster larvae or amphipod data; it is important to understand why these statistical analyses were omitted. The replicate variability of these data was sufficiently great that the number of replicates employed would force the statistical analyses to show no significant toxic effect (unless the mortality were extremely high). Such analyses have no biological validity; rather they indicate only that either the experimental design was inadequate or that money and time precluded use of the necessary number of replicates. Because large differences in mortalities between the controls and treatments did not occur either in the oyster or amphipod bioassays, we elected to omit these statistical analyses and to focus on the biological meaning and implications of the data.

A post-innoculation oyster embryo count, needed to verify the innoculation density, was not made. Therefore the low mean numbers of larvae per sample may represent mortality or more probably an error in the pre-innoculation count (i.e., a non-representative sample was counted). The mean numbers of larvae per site cannot be considered significantly different from the seawater controls because of the variability between counts within a site--especially for replicate counts from the same beakers.

Abnormality rates were higher for the oyster larvae held in water drained from defrosted sediment (21.7-100%) than for oyster larvae held in the 1:5 prepared elutriates (4.4-18.5%). Ammonia-nitrogen concentrations were higher in the water drained from defrosted sediment samples; however, concentrations were below those (10 ppm) reported to

affect oyster larvae (Okubo and Okubo, 1962). Water drained from defrosted sediment from sites S-2, B-2, B-3, and B-5 was toxic to oyster larvae. This toxicity stemmed from either aging or freezing of the seawater present in the sediment, from chemical toxicity of the sediment, or most probably from a combination of these factors. The abnormalities observed among larvae in water drained from defrosted sediment from sites WB, S-1, and S-3 did not necessarily describe toxicity because the dissolved oxygen concentrations present in these samples were probably inadequate to allow normal larval development. An ammonia-nitrogen analysis was not performed on this water from site B-1, and hence, these larval abnormalities did not necessarily stem from toxicity. The percent abnormalities at sites B-4 and B-6 were sufficiently low (21.7 and 29.5%) that they were not different from the percent abnormalities seen among the 1:5 dilutions.

The low percentage of abnormalities caused by the 1:5 artificially prepared elutriates of the various sediments did not differ significantly from the percentage of abnormalities seen in the seawater controls; hence, 1:5 elutriate dilutions from all sites (S-1, S-2, S-3, B-1, B-2, B-3, B-4, B-5, and B-6) were not toxic to oyster larvae following 48 hr exposure. These data suggest that if the water drained from the defrosted sediments were diluted 1:5, toxicity would be lost.

Mortalities did not occur among *Grandifoxus* held in Eagle Cove sand in previous experiments (Pierson et al., 1982b). The reason for the higher mortalities (12.4%) in these experiments is unclear although it may stem from use of both juvenile and adult amphipods or from the initial mortality associated with transporting the amphipods to the laboratory at Westport. Similarly, amphipods held in Grayland sand

showed no mortality in previous experiments (Pierson et al., 1982b), but showed 6.33% mortality in these bioassays. The difference between the mortalities in the two different sands probably is not significant.

We elected to add the sand mortalities to the mortalities associated with the substrate change from sand to sediment (from Pierson et al., 1982b) to obtain our correction factor. Interaction between these mortality types may occur causing this correction factor to slightly overestimate the true value.

The corrected mean mortalities of amphipods held in the dredged sediments ranged from 4.86 to 21.5% (Table 6). The key issue is whether these mortalities stem from the experimental design used in these experiments or whether the mortalities were caused by chemical toxicity of the dredged sediments. These mortalities cannot be linked with chemical toxicity for at least three reasons. First, differences in particle sizes between the various sediments tested may alter the amount and type of food available to the amphipods making starvation a confounding factor in the experimental design. Second, the need to correct the observed mortalities for the effect of changing the amphipod's habitat from sand to sediment shows the uncontrolled nature of the bioassay. Ideally each sediment to be tested would be matched with a control sediment of identical particle size and composition. Third, the variability among survival of the amphipods in the replicate beakers using the same sediment was so high that little meaning can be derived from the corrected means for each site. Therefore, one cannot differentiate between mortalities in the sand controls and the sediment treatments.

To understand the potential role of food in biasing the results,

one must understand the biology of *Grandifoxus* and the influence of the experimental design upon that biology. This amphipod spends the bulk of its life dwelling directly in the sediment and remains out of the sediment only if (1) the sediment particle size differs significantly from the optimal particle size, (2) the type and quantity of food in the sediment is unsuitable, or (3) the sediment is anoxic (Oakden, 1981).

The sediment particle size preference and the food content of the sediment are directly related. *Grandifoxus* feeds only on live meiofauna (Oliver et al., 1982) and starves if only detrital particles are available (Oakden, 1981). Because the number of meiofauna per unit area decreases as the sediment particle size decreases (Oakden, 1981), the extremely fine sediments from the various waterway sites contain less suitable food than the amphipod's native sand. Freezing and thawing of the sediments would probably kill and/or degrade much of the remaining meiofauna. Organisms entering the beaker from the flowing seawater thus constitute the sole significant food for *Grandifoxus*. The suitability of this diet was shown by the high survival (82.5%; Table 6) of amphipods in the seawater controls which contained no sediment. The amount of this food available to the amphipods dwelling in the sediment varies with the amount of water circulation within the sediment. This circulation is partially a function of particle size. Hence, if the particle sizes of a series of sediments vary, one would expect starvation to occur at differing times and rates as was observed.

The flow-through design was chosen to eliminate the possibility of sediment anoxia. Revsbech et al. (1980) showed that little oxygen exchange occurred between water above a sediment and the sediment-interstitial water; bubbling pure oxygen in the water overlying the

sediment did not increase the oxygen content of the interstitial water. The importance of water flow was shown by the sediment tests for site S-2 (Table 6). When the water supply to the beaker was partially blocked by collapse of the nitex netting and sediment, the sediment (as shown by the water quality tests) became essentially anoxic. The amphipods left the sediment (Table 7) and died. If replicate, flow-through beakers had not been used, the data would have incorrectly been interpreted as indicating chemical toxicity.

An often mentioned disadvantage of a flow-through experimental design is the potential loss of chemicals from the sediment to the water during the experiment. Presumably this decline (if any; data documenting this effect are not available) in sediment chemical concentration would occur as the particles are diluted with seawater during the dredging process. However, the purpose of the amphipod bioassay was to evaluate whether animals that lived in and consumed the sediment showed toxic effects (lethality effects were measured in the oyster and salmon bioassays). As previously described, these amphipods do not eat detritus and hence, the uncontrolled nature of the experiment becomes obvious.

Swartz et al. (1982) using amphipods reported chemical toxicity from Blair and Sitcum Waterway sediments including some sites that we also used, but which did not generate chemical toxicity in these experiments. Swartz et al.'s sites 3, I-11; I-9; I-14; 17, A-6; and 22 correspond with our sites S-1; S-2; S-3; B-1; B-3; B-4; and B-6 respectively. Use of a different amphipod species (*Rhepoxynius abronius*) may partially explain the divergent results. *R. abronius* can feed on either detritus or meiofauna (how much of which under what circumstances

remains unknown), but rapidly dies in sterile sediments (Oakden, 1981). However, the static experimental design used by Swartz et al. (1982), we believe, played a greater role in causing the mortalities observed in their data than did diet.

Our data (Pierson et al., 1982b) show clearly the need to correct the observed mortalities by subtracting any mortalities associated with the substrate change (sand to sediment). Swartz et al.'s data have not been so corrected. Because their bioassays were static (and no water quality data were provided), we suspect that the majority of their observed mortalities were caused by sediment anoxia, confounded by starvation, rather than chemical toxicity. One cannot separate mortalities associated with anoxia from those caused by chemical toxicity and hence, cannot correct Swartz et al.'s data so that it can be compared with our data.

Secondly, Swartz et al. (1982) did not use replicate beakers containing aliquots of the same sediment samples in their bioassays. As a result, one cannot calculate the variance about each of their observed mortalities. Without this variance estimate, one cannot conclude that some sites show greater toxicity than other sites. For example, Swartz et al. attributed the different mortalities observed with the patchy distribution of chemicals (Malins et al., 1980; Riley et al., 1981) known to occur in the sediment. We suspect that if the variance in mortality for each of the sediments were known, it would not be possible to differentiate between the mortalities attributed to the different sediment samples.

Amphipods will swim rather than bury in unacceptable sediment, but

the 12.5% maximum time (Table 7) out of the sediment clearly does not allow the sediment to be described as unacceptable (Oakden, 1981). Secondly, most *Grandifoxus* reburied rapidly in Eagle Cove sand following sediment exposure, thus showing their robustness.

## 5.00 CONCLUSIONS AND RECOMMENDATIONS

1. Survival of chinook salmon (*Oncorhynchus tshawytscha*) smolts was not affected by exposure for 96 hr to continuously flowing elutriate (1.0 part per thousand) prepared from sediment collected from sites S-1, S-2, B-1, B-2, B-3, and B-5 from Blair and Sitcum Waterways, Commencement Bay, Tacoma, Washington.
2. Data concerning the 96-hr survival of chinook salmon exposed to elutriate prepared from sediments from sites S-3, B-4, and B-6 were not affected by control mortalities and hence, were not reported.
3. Shell formation was altered in oyster (*Crassostrea gigas*) larvae exposed for 48 hr to water decanted from defrosted sediment samples from sites S-2, B-2, B-3, and B-5.
4. Shell formation of oyster larvae was not affected by 1:5 dilutions of elutriate prepared from sediment from any of the sites (WB, S-1, S-2, S-3, B-1, B-2, B-3, B-4, B-5, and B-6). These data suggest that if the water described in number three above were mixed with ambient seawater, shell formation of oyster larvae would be normal.
5. Dredging techniques that dilute the interstitial water and elutriate prior to entry into Commencement Bay are recommended to avoid potential toxicity. A dilution of 1:1000 was shown to be safe for salmonids; concentrations greater than 1:1000 (which were

not tested) could be toxic to salmonids and other fishes.

6. Survival of the phoxocephalid amphipod, *Grandifoxus grandis*, was not affected by 204 hr exposure to sediments collected from any of the sites (WB, S-1, S-2, S-3, B-1, B-2, B-3, B-4, B-5, and B-6).
7. The above data suggest that sediments collected from Blair and Sitcum Waterways do not produce acute toxicity under the defined experimental conditions if sufficiently diluted. Absence of acute effects does *not* imply that chronic or sublethal biological effects (such as bioconcentration) may not result.
8. Blair and Sitcum Waterway sediments are known to contain significant concentrations of toxic chemicals (Malins et al., 1980; Riley et al., 1981). If these sediments (or significant amounts of undiluted elutriates originating from these sediments) were to become available to aquatic organisms, chronic bioassays using Commencement Bay water should be conducted to assess the potential of bioconcentration of the toxic chemicals in organism tissues.
9. Should the Corps of Engineers elect to do bioassays involving Commencement Bay sediments for future projects, these bioassays should be done on site using Commencement Bay water. Amphipod bioassays should *not* be used to evaluate potential chemical toxicity of dredged sediments until additional research explains

such biases as starvation, anoxia, and particle size-associated mortalities. Because mortality was *not* observed in amphipod bioassays done for this study, these tests did provide useful data.

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7.00 APPENDICES

Appendix 1. Location and description of sediments dredged from nine sites in Blair and Sitcum Waterways, Commencement Bay, Tacoma, Wa.

Site	Location	Water depth (meters at mean lower low water)	Sediment collection depth <sup>a</sup> (cm)	Description	Comments <sup>b</sup>
Wollochet Bay, C-1	Wollochet Bay, 3/4 mile south of head, mid-channel	2.1	45	Muddy sand	1,2,3
Wollochet Bay, C-2	Wollochet Bay, mid-channel, mid-bay	10.7	60+	Mud with silt	1,2,3
Wollochet Bay, C-3	Wollochet Bay, west side, mid-bay	7.9	30	Sandy mud	1,2,3
S-1	Sitcum Waterway, 200 m southwest of the northwest end of pier, south side of waterway	10.1	60	Mud/clay	4,7,9
S-2	Sitcum Waterway, 60 m northeast of the south end of pier, mid-channel	11.6	45	Mud, clay, sand	6,8
S-3	Head of Sitcum Waterway, 90 m north of drain	12.2	60	Mud, some sand	3,7
B-1	Blair Waterway, mid-channel, off Slip 2	11.0	60+	Mud, clay, sand	5,7,9
B-2	Blair Waterway, west of Lincoln Avenue, 15 m off Dometar Chemicals pier	11.0	60+	Mud, some sand	3,7
B-3	Blair Waterway at Lincoln Avenue, north side	10.7	60+	Mud with silt	3,8,9

Appendix 1 continued.

Site	Location	Water depth (meters at mean lower low water)	Sediment collection depth <sup>a</sup> (cm)	Description	Comments <sup>b</sup>
B-4	Blair Waterway, mid-channel off Reichold Chemicals Co.	13.4	60+	Mud, some sand	4
B-5	Blair Waterway, 15 m off northwest corner of the turning basin	9.1	60+	Mud with silt	3,8,9
B-6	Blair Waterway, 60 m off southeast corner of the turning basin	12.8	60+	Mud with silt	3,9

<sup>a</sup> Sediment was collected beginning at the surface and down to the indicated depth.

<sup>b</sup> Key to Comments:

- 1 Contained plant life.
- 2 Contained many shell fragments.
- 3 Contained many worms.
- 4 Contained intermediate number of worms.
- 5 Contained few worms.
- 6 Contained no worms.
- 7 Emitted hydrogen sulfide odor.
- 8 Emitted hydrocarbon-like odor.
- 9 Oily film on surface of water in bucket.

Appendix 2. Summary of water quality analyses performed during the three cycles of 96-hr bioassays with chinook salmon (*Oncorhynchus tshawytscha*) using sediments dredged from nine sites in Blair and Sircum Waterways, Commencement Bay, Tacoma, Wa.

Site	Tank No.	Elutriate conc. (ppt)	Temp °C		Dissolved oxygen (mg/L)		Salinity, ppt		pH		Ammonia-nitrogen (mg/L)		Total non-filterable residue (g/L)			
			N	$\bar{x} \pm SD$	N	$\bar{x} \pm SD$	N	$\bar{x} \pm SD$	N	$\bar{x} \pm SD$	N	$\bar{x} \pm SD$	N	$\bar{x} \pm SD$		
Seawater control <sup>a</sup>	1	0	6	13.6±1.45	6	8.1±0.20	6	30.1±1.17	6	8.01±0.108	1	0.18	--	1	0.42	
	2	0	6	13.5±1.42	6	8.2±0.18	6	30.3±1.20	6	8.01±0.0834	1	0.094	--	2	0.080 ±0.074	
	9	0	6	13.5±1.42	6	8.1±0.17	6	30.2±1.35	6	8.01±0.0867	1	0.14	--	2	0.070 ±0.011	
	10	0	6	13.6±1.43	6	8.2±0.16	6	30.1±1.29	6	8.02±0.0906	1	0.17	--	2	0.055 ±0.016	
	17	0	6	13.6±1.49	6	8.1±0.15	6	30.3±1.29	6	8.02±0.0911	1	0.25 <sup>d</sup>	--	2	0.044 ±0.0085	
	18	0	6	13.5±1.41	6	8.0±0.17	6	30.2±1.29	6	8.02±0.0940	1	0.15	--	2	0.045 ±0.0018	
SWC	25	0	6	13.5±1.43	6	8.1±0.22	6	30.2±1.37	6	8.02±0.107	1	0.12	--	2	0.0045±0.0071	
	26	0	6	13.4±1.39	6	8.1±0.22	6	30.1±1.28	6	8.03±0.123	1	0.13	--	2	0.050 ±0.0049	
Seawater control <sup>b</sup>	7	0	5	14.8±0.742	3	8.1±0.79	5	29.7±0.416	1	8.19	--	2	<0.050	--	--	
	8	0	5	14.8±0.686	2	7.9±0.99	5	29.7±0.377	1	8.20	--	2	<0.050	--	2	0.051 ±0.057
	9	0	5	14.8±0.716	3	8.2±0.59	5	29.7±0.349	1	8.18	--	2	<0.050	--	2	0.047 ±0.033
	10	0	5	14.7±0.733	2	7.9±0.99	5	29.7±0.349	1	8.16	--	2	<0.050	--	2	0.020 ±0.010
	23	0	5	14.6±1.04	3	8.1±0.76	5	29.9±0.451	1	8.16	--	2	<0.050	--	1	0.002
	24	0	6	14.8±0.814	2	7.7±0.71	6	29.6±0.223	1	8.16	--	2	<0.050	--	1	0.063
SWC	25	0	6	14.7±0.873	3	8.2±0.69	6	29.8±0.306	1	8.19	--	2	<0.050	--	--	
	26	0	6	14.8±0.753	2	7.8±0.99	6	29.7±0.245	1	8.16	--	2	<0.050	--	--	
Seawater control <sup>c</sup>	7	0	4	13.3±1.77	1	7.2	--	4	30.2±0.963	2	7.96±0.148	1	0.082	--	1	0.018
	8	0	4	13.2±1.90	2	8.2±0.85	--	4	30.2±1.02	2	7.97±0.170	1	0.082	--	1	0.031
	9	0	4	13.2±1.91	1	6.7	--	4	30.2±1.07	2	7.96±0.148	1	<0.050	--	1	0.027
	10	0	4	13.2±1.90	2	8.1±0.85	--	4	30.1±0.946	2	7.98±0.156	1	<0.050	--	2	0.017 ±0.016
	23	0	4	13.1±1.88	1	7.6	--	4	30.2±0.981	2	7.98±0.156	1	0.35	--	1	0.054
	24	0	4	13.1±1.89	2	7.4±0.28	--	4	30.2±0.957	2	7.99±0.120	1	0.53	--	2	0.070 ±0.0035
SWC	25	0	4	13.1±1.92	1	7.4	--	4	30.2±1.00	2	7.99±0.127	1	0.14	--	2	0.065 ±0.027
	26	0	4	13.1±1.91	2	7.8±0.28	--	4	30.2±1.07	2	7.98±0.163	1	0.37	--	2	0.045 ±0.0092

Appendix 2 continued.

Site	Tank No.	Elutriate conc. (ppt)	Temp °C		Dissolved oxygen (mg/L)		Salinity, ppt		pH		Ammonia-nitrogen (mg/L)		Total non-filterable residue (g/L)		
			N	$\bar{x} \pm SD$	N	$\bar{x} \pm SD$	N	$\bar{x} \pm SD$	N	$\bar{x} \pm SD$	N	$\bar{x} \pm SD$	N	$\bar{x} \pm SD$	
<b>Wollochet Bay<sup>a</sup></b>															
WB	8	1.0	6	13.8±1.58	6	8.1±0.15	6	30.4±1.25	6	8.01±0.0865	1	0.15	--	2	0.15 ±0.0078
WB	7	1.0	6	13.8±1.58	6	8.2±0.17	6	30.3±1.14	6	8.01±0.0947	1	0.15	--	2	0.16 ±0.014
WB	6	0.50	6	13.7±1.46	5	8.1±0.22	6	30.2±1.24	6	8.02±0.0850	1	0.13	--	2	0.089 ±0.019
WB	5	0.50	6	13.6±1.45	6	8.0±0.15	6	30.4±1.24	6	8.01±0.0787	1	0.14	--	1	0.089
WB	4	0.25	6	13.5±1.40	6	8.1±0.20	6	30.3±1.25	6	8.01±0.0827	1	0.16	--	2	0.16 ±0.17
WB	3	0.25	6	13.6±1.46	6	8.2±0.10	6	30.3±1.21	6	8.01±0.0828	1	0.40d	--	2	0.12 ±0.069
<b>Wollochet Bay<sup>b</sup></b>															
WB	1	1.0	4	15.1±0.585	3	8.2±0.85	4	29.6±0.435	2	8.15±0.0354	2	<0.050	--	2	0.12 ±0.11
WB	2	1.0	4	15.1±0.538	2	8.1±0.99	4	29.5±0.457	2	8.13±0.0354	2	<0.050	--	2	0.17 ±0.0049
WB	3	0.50	4	14.9±0.523	3	8.0±0.69	4	29.6±0.400	2	8.16±0.0354	2	<0.050	--	2	0.12 ±0.024
WB	4	0.50	4	14.8±0.479	2	7.7±0.99	4	29.6±0.400	2	8.14±0.0566	2	<0.050	--	2	0.11 ±0.029
WB	5	0.25	4	14.7±0.574	3	8.1±0.76	4	29.6±0.386	2	8.15±0.0424	2	<0.050	--	1	0.085
WB	6	0.25	4	14.6±0.600	2	7.8±1.1	4	29.6±0.400	2	8.16±0.0495	2	<0.050	--	2	0.060 ±0.040
<b>Wollochet Bay<sup>c</sup></b>															
WB	1	1.0	4	13.6±1.64	1	7.4	4	30.2±1.19	2	7.96±0.177	1	<0.050	--	1	0.083
WB	2	1.0	4	13.6±1.74	2	8.2±0.85	4	30.2±1.19	2	7.96±0.184	1	<0.050	--	2	0.068 ±0.020
WB	3	0.50	4	13.5±1.76	1	7.5	4	30.2±1.00	2	7.96±0.184	1	<0.050	--	1	0.087
WB	4	0.50	4	13.5±1.70	2	8.2±0.85	4	30.1±1.01	2	7.96±0.184	1	0.072	--	2	0.035 ±0.026
WB	5	0.25	4	13.4±1.82	1	7.6	4	30.2±0.954	2	7.97±0.191	1	0.072	--	1	0.056
WB	6	0.25	4	13.4±1.77	2	8.1±0.92	4	30.2±1.09	2	7.96±0.184	1	<0.050	--	1	0.065
<b>S-1<sup>a</sup></b>															
S-1	24	1.0	6	13.8±1.53	6	7.9±0.19	6	30.4±1.27	6	8.00±0.118	1	0.18	--	1	0.225
S-1	23	1.0	6	13.8±1.56	6	8.0±0.18	6	30.4±1.33	6	8.00±0.113	1	0.10	--	1	0.244
S-1	22	0.50	6	13.6±1.49	6	8.0±0.14	6	30.4±1.36	6	8.01±0.111	1	0.19	--	2	0.090 ±0.085
S-1	21	0.50	6	13.6±1.49	6	8.0±0.20	6	30.3±1.38	6	8.01±0.0858	1	0.14	--	2	0.091 ±0.055
S-1	20	0.25	6	13.5±1.42	6	7.9±0.15	6	30.2±1.28	6	8.02±0.100	1	0.16	--	2	0.11 ±0.041
S-1	19	0.25	6	13.5±1.46	6	7.9±0.19	6	30.2±1.29	6	8.02±0.104	1	0.13	--	2	0.089 ±0.0014

Appendix 2 continued.

Site	Tank No.	Elutriate conc. (ppt)	Temp °C		Dissolved oxygen (mg/L)		Salinity, ppt		pH		Ammonia-nitrogen (mg/L)		Total non-filterable residue (g/L)	
			N	$\bar{x}$ ± SD	N	$\bar{x}$ ± SD	N	$\bar{x}$ ± SD	N	$\bar{x}$ ± SD	N	$\bar{x}$ ± SD	N	$\bar{x}$ ± SD
S-2 <sup>b</sup>	32	1.0	5	15.0±0.907	2	8.2±0.78	5	29.8±0.230	2	8.14±0.0354	2	<0.050	2	0.15 ±0.18
S-2	31	1.0	5	14.9±0.858	3	8.4±0.49	5	29.7±0.329	2	8.14±0.0141	2	<0.050	2	0.077 ±0.067
S-2	30	0.50	5	14.8±0.797	2	7.9±0.85	5	29.8±0.274	2	8.15±0.0283	2	<0.050	2	0.015 ±0.014
S-2	29	0.50	5	14.8±0.831	3	8.1±0.64	5	29.7±0.228	2	8.16±0.0283	2	<0.050	1	0.015
S-2	28	0.25	5	14.8±0.808	2	8.0±0.92	5	29.7±0.230	2	8.16±0.0283	2	<0.050	1	0.015
S-2	27	0.25	5	14.7±0.789	3	8.0±0.81	5	29.7±0.249	2	8.17±0.0212	2	<0.050	1	0.015
S-3 <sup>c</sup>	32	1.0	4	13.5±1.85	2	8.0±0.49	4	30.2±1.03	2	7.97±0.156	1	<0.050	2	0.42 ±0.10
S-3	31	1.0	4	13.4±1.78	1	7.5	4	30.2±0.981	2	7.96±0.148	1	<0.050	1	0.21
S-3	30	0.50	4	13.3±1.93	2	7.9±0.42	4	30.2±1.07	2	7.98±0.127	1	<0.050	2	0.14 ±0.021
S-3	29	0.50	4	13.2±1.87	1	7.8	4	30.3±0.911	2	7.98±0.156	1	<0.050	1	0.15
S-3	28	0.25	4	13.2±1.91	2	8.0±0.64	4	30.2±0.929	2	7.99±0.148	1	0.12	2	0.12 ±0.032
S-3	27	0.25	4	13.1±1.89	1	7.6	4	30.2±0.929	2	7.98±0.148	1	0.061	2	0.11 ±0.028
B-1 <sup>a</sup>	16	1.0	6	13.8±1.49	6	8.2±0.075	6	30.3±1.12	6	8.02±0.0950	1	0.20	2	0.16 ±0.049
B-1	15	1.0	6	13.6±1.54	6	8.1±0.098	6	30.4±1.27	6	8.01±0.0954	1	0.15	2	0.19 ±0.10
B-1	14	0.50	6	13.5±1.51	6	8.0±0.26	6	30.3±1.27	6	8.01±0.103	1	0.18	2	0.15 ±0.037
B-1	13	0.50	6	13.5±1.47	6	8.1±0.22	6	30.3±1.34	6	8.02±0.0948	1	0.11	2	0.11 ±0.038
B-1	12	0.25	6	13.6±1.44	6	8.1±0.12	6	30.3±1.28	6	8.02±0.0989	1	0.17	2	0.061 ±0.042
B-1	11	0.25	6	13.5±1.42	6	8.0±0.14	6	30.2±1.27	6	8.01±0.0911	1	0.28 <sup>d</sup>	2	0.085 ±0.032
B-2 <sup>b</sup>	16	1.0	5	15.1±0.779	2	8.2±1.20	5	29.7±0.329	2	8.14±0.0141	2	<0.050	1	0.275
B-2	15	1.0	5	15.0±0.787	3	8.1±0.99	5	29.8±0.351	2	8.14±0.0212	2	<0.050	2	0.18 ±0.020
B-2	14	0.50	5	14.9±0.782	2	8.0±1.1	5	29.8±0.451	2	8.16±0.0212	2	<0.050	2	0.043 ±0.039
B-2	13	0.50	5	14.9±0.740	3	8.0±0.79	5	29.7±0.335	2	8.14±0.0354	2	<0.050	2	0.059 ±0.030
B-2	12	0.25	5	14.8±0.716	2	7.5±0.14	5	29.7±0.394	2	8.15±0.0424	2	<0.050	1	0.060
B-2	11	0.25	5	14.8±0.742	3	8.2±0.90	5	29.7±0.356	2	8.16±0.0212	2	<0.050	1	0.049
B-3 <sup>b</sup>	17	1.0	5	15.1±0.826	3	8.0±0.87	5	29.7±0.292	2	8.14±0.00707	2	<0.050	2	0.33 ±0.18
B-3	18	1.0	5	15.1±0.779	2	7.8±0.78	5	29.8±0.497	2	8.12±0.0212	2	<0.050	2	0.24 ±0.17
B-3	19	0.50	5	15.0±0.802	3	8.0±0.81	5	29.7±0.383	2	8.13±0.0141	2	<0.050	1	0.254

Appendix 2 continued.

Site	Tank No.	Elutriate conc. (ppt)	Temp °C			Dissolved oxygen (mg/L)			Salinity, ppt			pH			Ammonia-nitrogen (mg/L)			Total non-filterable residue (g/L)		
			N	$\bar{x}$	SD	N	$\bar{x}$	SD	N	$\bar{x}$	SD	N	$\bar{x}$	SD	N	$\bar{x}$	SD	N	$\bar{x}$	SD
B-3	20	0.50	5	14.9±0.503	2	7.7±0.71	5	29.8±0.351	2	8.14±0.0212	2	<0.050	2	<0.050	2	0.13 ±0.15				
B-3	21	0.25	5	14.9±0.808	3	8.1±0.72	5	29.7±0.335	2	8.14±0.0141	2	<0.050	2	<0.050	2	0.11 ±0.078				
B-3	22	0.25	5	14.8±0.857	2	8.0±0.85	5	29.7±0.332	2	8.14±0.0141	2	<0.050	2	<0.050	2	0.071 ±0.058				
B-4 <sup>c</sup>	16	1.0	4	13.6±1.73	2	8.2±0.85	4	30.3±1.07	2	7.97±0.177	1	0.28	2	0.36 ±0.24						
B-4	15	1.0	4	13.6±1.71	1	7.5	4	30.2±1.09	2	7.96±0.127	1	0.42	2	0.38 ±0.16						
B-4	14	0.50	4	13.4±1.72	2	8.1±0.85	4	30.2±1.10	2	7.98±0.141	1	0.28	2	0.15 ±0.017						
B-4	13	0.50	4	13.4±1.82	1	7.6	4	30.3±1.10	2	7.98±0.163	1	0.14	2	0.19 ±0.078						
B-4	12	0.25	4	13.6±2.06	2	6.6±3.1	4	29.9±1.17	2	7.95±0.106	1	<0.050	2	0.034 ±0.029						
B-4	11	0.25	4	13.3±1.94	1	7.7	4	30.2±1.08	2	7.98±0.163	1	<0.050	2	0.081 ±0.0042						
B-5 <sup>a</sup>	32	1.0	6	13.8±1.57	6	8.1±0.098	6	30.2±1.42	6	8.02±0.117	1	0.49d	2	0.25 ±0.018						
B-5	31	1.0	6	13.7±1.57	6	8.1±0.14	6	30.6±1.23	6	8.01±0.113	1	0.12	2	0.21 ±0.045						
B-5	30	0.50	6	13.6±1.49	6	8.1±0.18	6	30.5±1.35	6	8.02±0.112	1	0.10	2	0.14 ±0.0085						
B-5	29	0.50	6	13.6±1.49	6	8.2±0.14	6	30.3±1.22	6	8.03±0.127	1	0.069	2	0.12 ±0.0057						
B-5	28	0.25	6	13.6±1.46	6	8.0±0.15	6	30.3±1.29	6	8.02±0.125	1	0.12	2	0.081 ±0.010						
B-5	27	0.25	6	13.5±1.47	6	8.0±0.17	6	30.3±1.29	6	8.02±0.125	1	0.11	2	0.079 ±0.0014						
B-6 <sup>c</sup>	17	1.0	4	13.6±1.73	1	7.4	4	30.2±1.01	2	7.96±0.156	1	0.30	2	0.25 ±0.0028						
B-6	18	1.0	4	13.6±1.75	1	7.2	4	30.1±0.963	2	7.95±0.148	1	0.31	2	0.21 ±0.0092						
B-6	19	0.50	4	13.4±1.79	1	7.4	4	30.2±0.947	2	7.97±0.163	1	<0.050	2	0.14 ±0.015						
B-6	20	0.50	4	13.3±1.79	2	7.6±0.14	4	30.1±0.964	2	7.95±0.184	1	0.41	2	0.17 ±0.10						
B-6	21	0.25	4	13.3±1.87	1	7.6	4	30.2±1.01	2	7.97±0.170	1	0.53	2	0.072 ±0.018						
B-6	22	0.25	4	13.2±1.85	2	8.0±0.49	4	30.1±0.964	2	7.98±0.148	1	0.28	2	0.082 ±0.023						

<sup>a</sup>Site tested during first cycle of the bioassays.<sup>b</sup>Site tested during second cycle of the bioassays.<sup>c</sup>Site tested during third cycle of the bioassays.<sup>d</sup>Sample may have become contaminated.

Appendix 3. Summary of water quality analyses performed during the 48 hr exposure of oyster (*Crassostrea gigas*) larvae to elutriates to elutriates prepared from dredged sediments from nine sites in Blair and Sitcum Waterways, Commencement Bay, Tacoma, Wa.

Site	Beaker No.	Dilution (sediment: water)	Temp. (°C)	Dissolved Oxygen (mg/L)	Salinity (PPT)	pH	Ammonia-Nitrogen (mg/L)
Seawater Control	43	-	21.0	6.8	30.5	8.16	<0.050
SWC	44	-	20.2	6.9	30.7	8.08	<0.050
SWC	45	-	20.1	7.1	30.8	8.09	<0.050
SWC	46	-	20.2	6.9	30.5	8.15	<0.050
SWC	47	-	20.5	7.0	30.5	8.10	<0.050
SWC	48	-	20.6	7.1	31.0	8.13	<0.050
SWC	49	-	20.1	7.1	30.9	8.09	<0.050
SWC	50	-	20.3	7.1	30.1	8.08	<0.050
SWC	51	-	20.4	7.0	31.0	8.15	<0.050
SWC	70	-	20.0	7.0	30.7	8.06	<0.050
SWC	71	-	20.0	6.9	30.2	8.07	<0.050
SWC	72	-	20.0	7.0	30.5	8.07	<0.050
SWC	78 <sup>a</sup>	-	20.2	7.4	31.2	8.25	<0.050
SWC	79 <sup>a</sup>	-	20.2	7.5	31.2	8.19	<0.050
SWC	80 <sup>a</sup>	-	20.2	7.4	31.2	8.25	<0.050
Hollochet Bay	64	1:5	20.3	5.8	30.2	7.79	2.4 <sup>b</sup>
WB	65	1:5	20.9	5.9	30.5	8.06	1.5
WB	66	1:10	20.4	5.6	30.9	7.79	0.78
WB	67	1:10	20.5	6.8	29.8	7.87	0.75
WB	68	1:20	20.1	6.3	29.8	7.93	0.32
WB	69	1:20	20.7	6.4	30.8	8.01	0.37

Appendix 3 continued.

Site	Beaker No.	Dilution (sediment: water)	Temp. (°C)	Dissolved Oxygen (mg/L)	Salinity (PPT)	pH	Ammonia-Nitrogen (mg/L)
S-1	13	1:5	20.8	6.4	31.2	7.99	1.4
S-1	14	1:5	20.9	6.4	31.0	7.99	2.0 <sup>b</sup>
S-1	15	1:10	20.5	6.5	30.2	7.99	0.61
S-1	16	1:10	20.9	6.8	31.1	7.99	0.77
S-1	26	1:20	20.2	6.9	30.2	8.02	0.28
S-1	27	1:20	20.2	6.3	30.1	7.97	-
S-2	40	1:5	21.0	6.5	30.6	7.99	0.99
S-2	41	1:5	20.4	6.3	30.1	7.94	0.91
S-2	56	1:10	20.2	6.8	30.9	8.05	0.71
S-2	57	1:10	20.3	6.8	30.4	8.04	0.42
S-2	55	1:20	20.3	6.8	30.4	8.05	0.18
S-2	42	1:20	20.6	6.8	30.2	8.05	0.19
S-3	35	1:5	20.8	5.7	27.1	7.24	1.3
S-3	36	1:5	20.9	6.3	27.9	7.89	-
S-3	53	1:10	20.1	6.7	30.1	7.92	0.58
S-3	54	1:10	20.2	6.8	30.9	7.93	0.78
S-3	37	1:20	20.1	6.9	30.0	8.00	0.25
S-3	52	1:20	20.8	6.9	30.0	8.04	0.34
B-1	4	1:5	21.0	6.7	31.2	8.03	0.87
B-1	5	1:5	20.7	6.3	30.2	7.96	0.64

## Appendix 3 continued.

Site	Beaker No.	Dilution (sediment: water)	Temp. (°C)	Dissolved Oxygen (mg/L)	Salinity (PPT)	pH	Ammonia-Nitrogen (mg/l.)
B-1	9	1:10	21.0	6.9	31.3	8.10	0.32
B-1	10	1:10	20.1	6.2	30.2	7.91	0.37
B-1	11	1:20	20.6	7.0	31.2	8.09	0.22
B-1	12	1:20	20.2	6.4	30.8	7.99	0.16
B-2	1	1:5	20.4	6.2	31.2	8.03	1.1
B-2	2	1:5	20.2	6.0	30.1	7.88	0.95
B-2	3	1:10	20.2	6.6	31.2	8.10	0.49
B-2	6	1:10	20.0	6.8	30.4	7.98	-
B-2	7	1:20	20.5	7.0	30.2	8.07	0.14
B-2	8	1:20	20.1	6.7	30.8	8.02	0.18
B-3	20	1:5	20.9	6.5	31.1	7.99	1.3
B-3	21	1:5	20.5	6.5	29.9	7.92	1.1
B-3	29	1:10	20.5	6.6	31.1	8.02	0.45
B-3	30	1:10	20.9	7.0	31.0	8.05	0.71
B-3	28	1:20	20.9	7.0	30.4	8.11	0.26
B-3	22	1:20	21.0	6.9	31.5	8.10	0.28
B-4	58	1:5	20.5	6.4	30.0	7.87	0.41
B-4	59	1:5	20.4	6.6	30.0	7.99	0.44
B-4	60	1:10	20.2	6.7	29.8	8.00	0.20
B-4	61	1:10	20.2	6.6	30.4	7.97	0.18

## Appendix 3 continued.

Site	Beaker No.	Dilution (sediment: water)	Temp. (°C)	Dissolved Oxygen (mg/L)	Salinity (PPT)	pH	Ammonia-Nitrogen (mg/L)
B-4	62	1:20	20.4	6.7	30.9	8.08	0.10
B-4	63	1:20	20.8	6.9	30.0	8.07	0.15
B-5	31	1:5	21.0	6.6	30.2	7.94	1.5
B-5	32	1:5	20.2	6.4	30.0	7.87	0.96
B-5	33	1:10	21.0	7.0	30.3	8.06	0.67
B-5	34	1:10	20.2	7.0	30.2	7.97	0.42
B-5	38	1:20	20.9	7.0	31.2	8.09	-
B-5	39	1:20	20.9	6.9	31.2	8.11	0.22
B-6	17	1:5	20.0	6.7	27.0	7.87	0.82
B-6	18	1:5	20.2	6.6	27.5	7.93	1.3
B-6	24	1:10	20.8	6.8	28.8	8.05	0.46
B-6	25	1:10	20.6	7.1	28.3	8.04	0.35
B-6	19	1:20	20.2	7.0	30.1	8.01	0.25
B-6	23	1:20	20.7	7.0	29.2	8.08	0.14
WB, 1 <sup>c</sup>	85	-	20.2	0.2	26.2	7.74	-
S-1, I	84	-	20.4	0.9	29.1	8.02	-
S-2, I	83	-	20.4	3.8	26.7	7.96	-
S-3, I	76	-	20.3	1.8	27.1	7.86	-
B-1, I	74	-	20.7	3.1	27.9	7.80	-

## Appendix 3 continued.

Site	Beaker No.	Dilution (sediment: water)	Temp. (°C)	Dissolved Oxygen (mg/L)	Salinity (PPT)	pH	Ammonia-Nitrogen (mg/L)
B-2, 1	75	-	20.2	4.2	26.2	7.79	-
B-3, 1	82	-	20.4	5.0	24.0	8.05	-
B-4, 1	73	-	20.2	4.4	28.6	7.64	-
B-5, 1	77	-	20.3	3.3	26.9	7.94	-
B-6, 1	81	-	20.4	3.3	26.8	7.76	-

<sup>a</sup>Water quality beakers that were not inoculated with oyster larvae.

<sup>b</sup>Estimated ammonia-nitrogen concentration. The highest standard used was 2.0 mg/L ammonia-nitrogen.

<sup>c</sup>Elutriate samples poured from the bucket of sediment after the sediment had thawed (see footnote on page 13).

Appendix 4. Summary of water quality analyses performed during the 204 hr exposure of phoxocephalid amphipods (*Grandifoxus grandis*) to sediments dredged from nine sites in Blair and Sitcum Waterways, Commencement Bay, Tacoma, Wa.

Site	Beaker No.	Dissolved Oxygen (mg/L)	pH	Ammonia-Nitrogen (mg/L)
Seawater Control	15 <sup>a</sup>	8.3	8.14	<0.050
SWC	15 <sup>b</sup>	8.4	-	<0.050
SWC	19 <sup>a</sup>	8.3	8.14	0.13
SWC	19 <sup>b</sup>	8.2	-	<0.050
SWC	27 <sup>a</sup>	8.2	8.14	<0.050
SWC	27 <sup>b</sup>	8.2	-	<0.050
SWC	35 <sup>a</sup>	8.2	8.15	0.12
SWC	35 <sup>b</sup>	8.1	-	<0.050
Eagle Cove Sand	1 <sup>a</sup>	8.1	8.13	<0.050
ECS	1 <sup>b</sup>	8.1	-	<0.050
ECS	2 <sup>a</sup>	8.0	8.12	<0.050
ECS	2 <sup>b</sup>	8.1	-	<0.050
ECS	3 <sup>a</sup>	7.2	8.05	<0.050
ECS	3 <sup>b</sup>	8.1	-	<0.050
Grayland Sand	4 <sup>a</sup>	8.0	8.10	0.057
GS	4 <sup>b</sup>	7.4	-	<0.050
GS	5 <sup>a</sup>	8.1	8.12	0.057
GS	5 <sup>b</sup>	5.4 <sup>c</sup>	-	<0.050
GS	6 <sup>a</sup>	8.3	8.14	<0.050
GS	6 <sup>b</sup>	8.2	-	<0.050
Wollochet Bay	10 <sup>a</sup>	8.1	8.15	0.081
WB	10 <sup>b</sup>	8.2	-	<0.050
WB	20 <sup>a</sup>	7.9	8.13	<0.050
WB	20 <sup>b</sup>	8.2	-	<0.050
WB	30 <sup>a</sup>	8.4	8.15	0.052
WB	30 <sup>b</sup>	8.0	-	<0.050
S-1	12 <sup>a</sup>	7.9	8.12	0.057
S-1	12 <sup>b</sup>	7.1	-	<0.050
S-1	18 <sup>a</sup>	8.1	8.14	<0.050
S-1	18 <sup>b</sup>	7.3	-	<0.050
S-1	29 <sup>a</sup>	8.1	8.14	0.057
S-1	29 <sup>b</sup>	8.2	-	<0.050
S-2	16 <sup>a</sup>	8.4	8.15	<0.050
S-2	16 <sup>b</sup>	8.0	-	0.11
S-2	32 <sup>a</sup>	8.0	8.12	0.057
S-2	32 <sup>b</sup>	7.9	-	0.11
S-2	39 <sup>a</sup>	7.8	8.14	0.081
S-2	39 <sup>b</sup>	7.9	-	<0.050

## Appendix 4 continued.

Site	Beaker No.	Dissolved Oxygen (mg/L)	pH	Ammonia-Nitrogen (mg/L)
S-3	8 <sup>a</sup>	8.3	8.16	<0.050
S-3	8 <sup>b</sup>	8.2	-	<0.050
S-3	22 <sup>a</sup>	6.3 <sup>c</sup>	7.92	0.16
S-3	22 <sup>b</sup>	1.4 <sup>c</sup>	-	0.94
S-3	37 <sup>a</sup>	8.4	8.14	0.062
S-3	37 <sup>b</sup>	7.8	-	<0.050
B-1	7 <sup>a</sup>	8.2	8.14	<0.050
B-1	7 <sup>b</sup>	8.3	-	<0.050
B-1	28 <sup>a</sup>	8.2	8.14	0.057
B-1	28 <sup>b</sup>	8.2	-	<0.050
B-1	40 <sup>a</sup>	7.9	8.13	<0.050
B-1	40 <sup>b</sup>	3.6 <sup>c</sup>	-	<0.050
B-2	21 <sup>a</sup>	8.1	8.14	0.052
B-2	21 <sup>b</sup>	8.3	-	<0.050
B-2	31 <sup>a</sup>	8.4	8.15	<0.050
B-2	31 <sup>b</sup>	5.4 <sup>c</sup>	-	<0.050
B-2	38 <sup>a</sup>	7.3	8.11	<0.050
B-2	38 <sup>b</sup>	8.1	-	<0.050
B-3	23 <sup>a</sup>	8.2	8.14	0.095
B-3	23 <sup>b</sup>	8.2	-	<0.050
B-3	25 <sup>a</sup>	8.3	8.14	0.090
B-3	25 <sup>b</sup>	8.2	-	<0.050
B-3	36 <sup>a</sup>	8.2	8.15	0.057
B-3	36 <sup>b</sup>	8.2	-	0.071
B-4	13 <sup>a</sup>	8.5	8.16	<0.050
B-4	13 <sup>b</sup>	7.2	-	<0.050
B-4	33 <sup>a</sup>	8.0	8.14	0.052
B-4	33 <sup>b</sup>	8.2	-	<0.050
B-4	34 <sup>a</sup>	8.2	8.15	<0.050
B-4	34 <sup>b</sup>	8.1	-	<0.050
B-5	17 <sup>a</sup>	8.2	8.13	<0.050
B-5	17 <sup>b</sup>	7.8	-	<0.050
B-5	24 <sup>a</sup>	7.5	8.13	0.076
B-5	24 <sup>b</sup>	5.3 <sup>c</sup>	-	<0.050
B-5	26 <sup>a</sup>	8.4	8.14	0.057
B-5	26 <sup>b</sup>	7.9	-	<0.050
B-6	9 <sup>a</sup>	8.4	8.16	0.057
B-6	9 <sup>b</sup>	8.1	-	0.071
B-6	11 <sup>a</sup>	8.2	8.14	-
B-6	11 <sup>b</sup>	8.1	-	<0.050
B-6	14 <sup>a</sup>	8.4	8.15	0.057
B-6	14 <sup>b</sup>	8.1	-	<0.050

<sup>a</sup>Analyses performed 12 hr into the bioassay except for ammonia-nitrogen analyses which were performed at 36 hr.

<sup>b</sup>Analyses performed 204 hr into the bioassay except for ammonia-nitrogen analyses which were performed at ~ 185 hr.

<sup>c</sup>These beakers had slightly reduced water flows. Beaker 22 had essentially no water flow.