Pier 53–55 Sediment Cap and Enhanced Natural Recovery Area Remediation Project

Elliott Bay/Duwamish Restoration Program

Prepared for the
Elliott Bay/Duwamish Restoration Program Panel
by the
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Benthic Taxonomy Identification	Marine Taxonomic Services
Diving for Core Samples and Video Survey	Global Diving
Sediment-Profile Camera Survey	SAIC
Duwamish River Sediment Report	SAIC
Pre-Cap Bioassay	EVS Consultants
Total Organic Carbon Analysis	AMTest
Particle Size Distribution Analysis	AMTest

EXECUTIVE SUMMARY

The Pier 53-55 sediment cap and enhanced natural recovery area (ENR) is a remediation project intended to clean up contaminated bottom sediments offshore of downtown Seattle in Elliott Bay. The cleanup involves covering contaminated sediments, located near a historic untreated sewer outfall, with a layer of clean sand. The Pier 53 project, as it is called, covers 4.5 acres. It is composed of a sediment cap, which is 3 feet thick and covers 2.9 acres, and an enhanced natural recovery area, which is 1 foot thick and covers 1.6 acres. The project also includes a 10-year monitoring plan that will determine how stable the cap is, how well it is functioning to isolate the contaminated sediments, whether the cap continues to meet Washington State sediment standards for the cleanup action, and how the cap is biologically recolonized.

This report has two purposes. First, it is intended as a source of information relating to the Pier 53 project. And second, it contains the results of the first year of monitoring required by the 10-year monitoring plan.

BACKGROUND

Sediment capping is a relatively new method for remediating contaminated bottom sediments, having been developed within the past 10 years. A forerunner of capping is confined aquatic disposal or CAD. CAD involves dredging and relocating contaminated sediments and then isolating them from the marine environment with a clean layer of sediment. One of the disadvantages of CAD is that the initial dredging of the contaminated sediments can redistribute the contamination into the water column and surrounding sediments. Capping the contaminated sediments in place eliminates the expense of dredging the contaminated sediments and the possibility of contaminating the area surrounding the project. In this report, "sediment capping" or "the sediment cap" refers to this simpler process as distinct from CAD.

A 3-foot-thick cap was initially proposed for the Pier 53 site. A 3-foot cap is considered to be sufficient to prevent benthic organisms from burrowing through the clean layer into the contaminants below. In shallower areas, however, a 3-foot sediment cap may have the disadvantage of decreasing navigational depth and destroying benthic habitat. This concern led to a proposal to study the feasibility of thinner layers of sediment in shallow areas. The enhanced natural recovery area is an experimental 1-foot-thick layer that will initially isolate contaminated sediments but is thin enough to allow benthic organisms to mix small amounts of the contaminated sediment up into the clean sediment. Some contaminants that are mixed into the oxygenated layer of the clean sediments may biodegrade at an accelerated rate.

PRE-CAP STUDIES

Several preliminary studies provided the groundwork for the Pier 53 capping project. Section 2 discusses four of the pre-cap studies: Waterfront Sediment Studies: 1988 and 1989; Pier 53 Pre-Cap Sediment Study: 1992; Pre-Cap Biological Toxicity Study; and the Duwamish River Sediment Study.

Waterfront Sediment Studies: 1988 and 1989

Metro collected and analyzed sediment samples from along the Seattle waterfront in 1988 and 1989. The analysis showed elevated levels of polychlorinated biphenyls (PCBs), metals, and low and high molecular weight polycyclic aromatic hydrocarbons (PAHs) in the samples collected at the Pier 53 site. As a result, Piers 53 and 54 were ranked 14 and 15 on a list of 68 sites being considered for remediation by the agencies concerned with Elliott Bay and Puget Sound cleanup (Parametrix 1992).

Pre-Cap Sediment Study: 1992

Shortly before the Pier 53 sediment cap was placed in 1992, the sediment chemistry was analyzed to obtain carbon normalized samples that could be compared to the state sediment standards adopted in 1991. The study, conducted by Metro, showed the same types of chemicals measured in the 1988-89 waterfront study, but at lower dry-weight concentrations. In several cases, organic carbon normalized levels exceeded the state sediment quality standards (SQS), including PCB exceedances at all stations except one. All sample stations exceeded the state cleanup screening levels (CSLs) for mercury, three stations exceeded the CSLs for silver, and one station exceeded the CSLs for cadmium.

Biological Toxicity Study

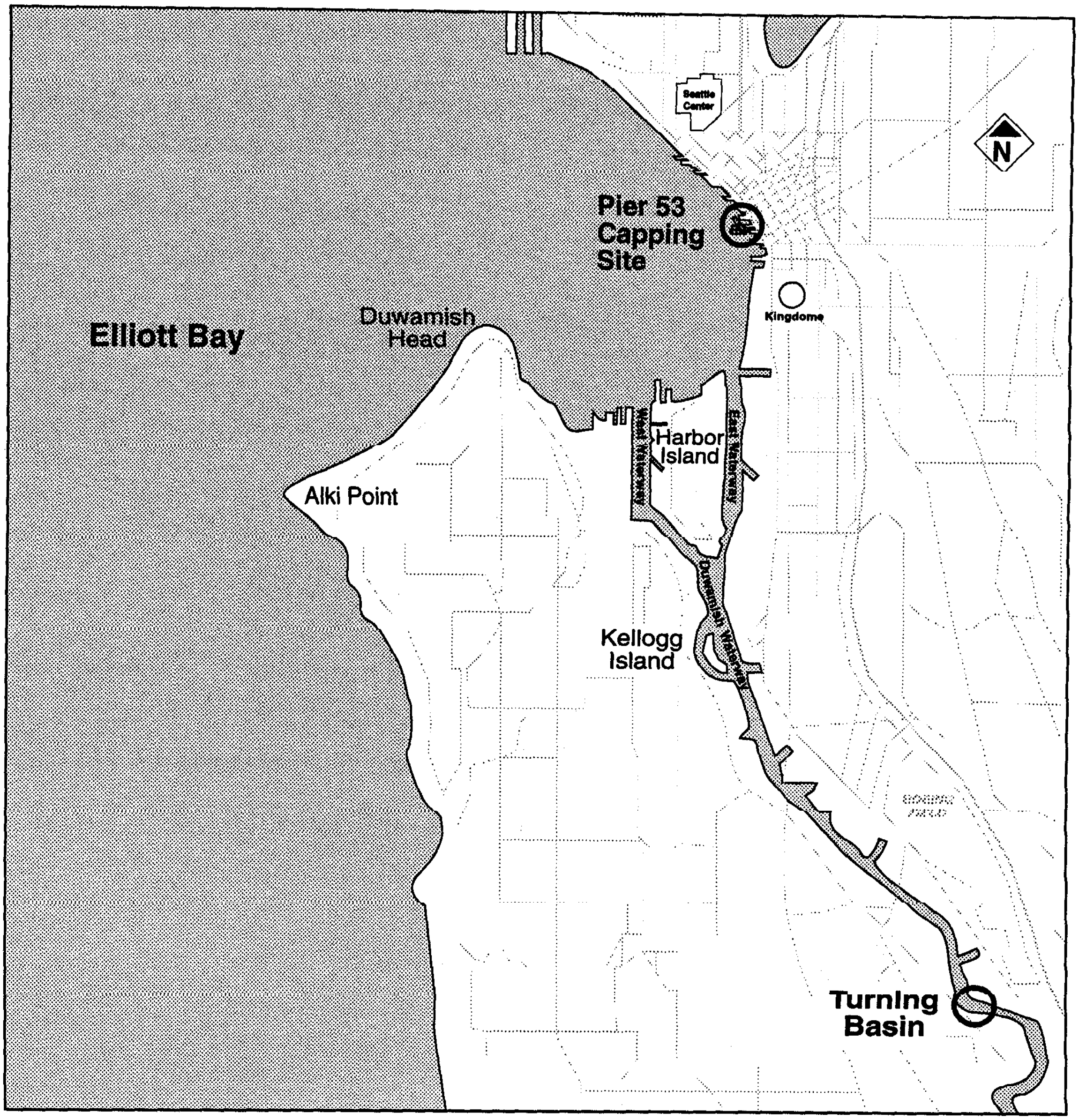
Part of the Pier 53 pre-cap sediment study involved conducting a biological toxicity study shortly before the cap was placed. E.V.S. Consultants conducted the bioassay tests, which involved exposing amphipods (*Rhepoxynius abronius*) and bivalves (*Mytilus edulis*) to the Pier 53 sediments. The amphipod test showed that three samples out of six had mean survival rates significantly lower than the control. However, none of these exceeded the state standards because they did not exceed the minimum mortality of 25 percent. The bivalve test showed that all six samples had survival rates significantly lower than the control. However, there was no reference sample so it was not possible to verify that the samples exceeded the state sediment standards for this test.

Duwamish River Sediment Study

The sediment used for the Pier 53 cap came from the turning basin at the upstream end of the dredged navigation waterway of the Duwamish River (see Map 1). Before the sediments could be dredged, they were sampled and analyzed for Puget Sound Dredged Disposal Analysis (PSDDA) chemicals of concern. The U.S. Army Corps of Engineers (the Corps) conducted the sampling with Science Applications International Corporation (SAIC) support. Four sediment core samples were taken from the area where the capping sediments were to be dredged and two composite samples were made. The first composite passed all PSDDA sediment screening levels for chemistry. The second composite exceeded a PSDDA screening value for 4-methylphenol at 140 ppb, which meant that biological testing was required. Technicians then collected a new composite sample for biotoxicity testing. The new composite passed PSDDA disposal guidelines for amphipods and sediment larval bioassays, but failed a test involving echinoderms. PSDDA staff evaluating the data concluded that the toxicity may have been caused by something other than chemicals of concern, such as ammonia produced by bacteria in the sediments. Since the new composite passed the amphipod and bivalve tests, the sediment was approved for use in sediment capping based on the best professional judgment of the PSDDA agency technical reviewers.

CAP PLACEMENT

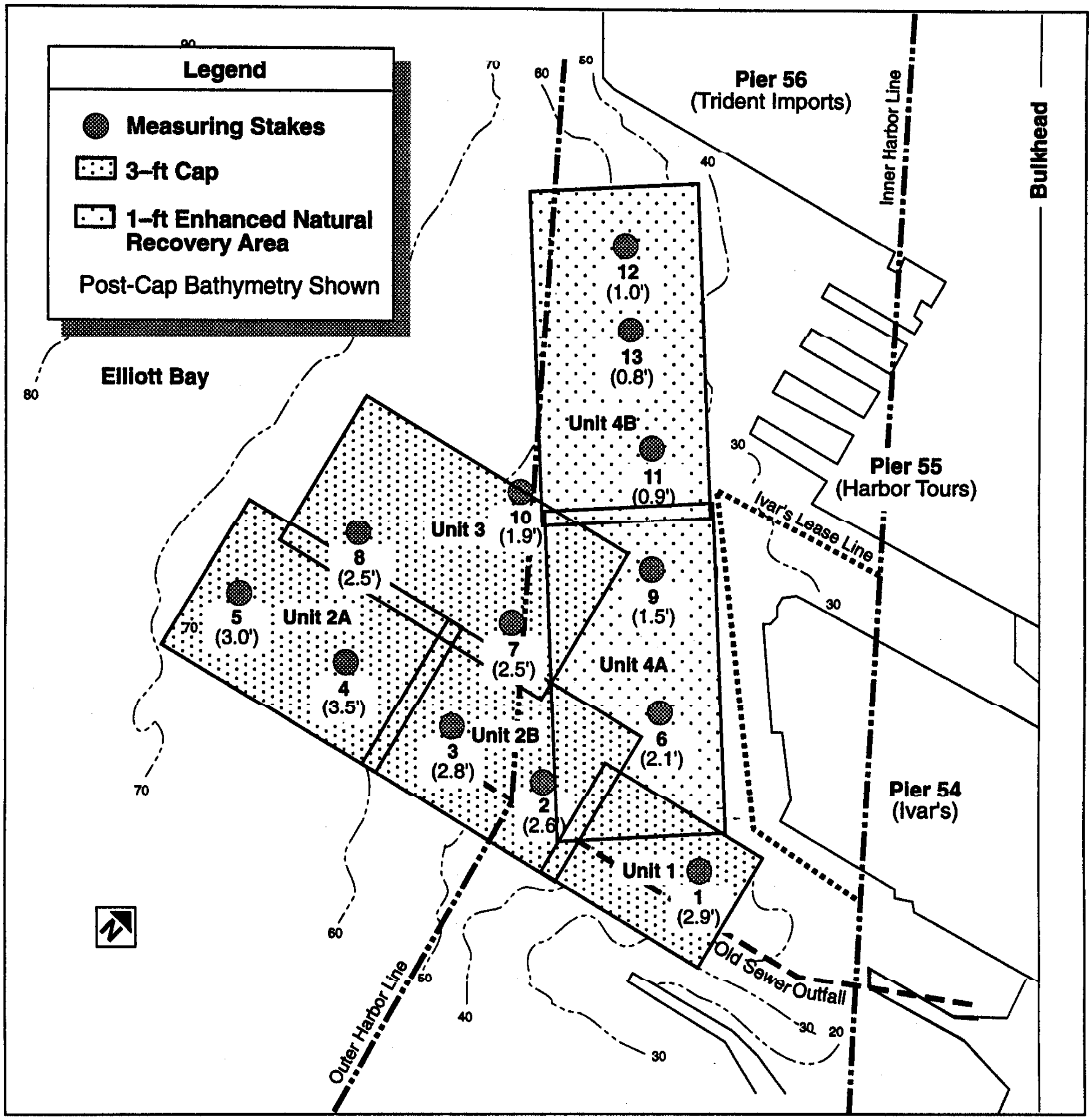
Prior to capping, the Corps project engineers divided the project site into six working units, called barge tracks, that represented the area one barge-load of sand would cover (see Map 2). Divers from Global Diving then installed stakes, for measuring the thickness of the cap and ENR, in each of the barge tracks. Thirteen stakes were placed to achieve spatial coverage over the cap and ENR and to provide one to three stakes for each barge track. A diver measured the exposed length of the stakes once before construction began, once during cap construction to guide placement, and then again after installation to verify the final cap thicknesses. Cap thickness also will be measured once each year of the scheduled post-cap monitoring to determine whether there is any erosion or movement of the cap.



Map 1. The Duwamish River Dredge Site and the Pier 53-55 Capping Site

Cap Placement

The Corps contractors placed the sediment cap at the Pier 53 site by distributing the sand with a bottom-dump barge. A total of 10 barge-loads were



Map 2. Barge Tracks and Measuring Stakes

placed on the six barge tracks. Using a bottom-dump barge to install the cap and ENR was an efficient method of applying large amounts of capping material at one time, and allowed available equipment to cover the largest area of chemically contaminated bottom sediments to desired thicknesses. This method also eliminated the expense of a crane to transfer the sediment from the barge to the bay floor.

Cap Thickness

The actual thicknesses of the cap and ENR were very close to the planned thicknesses. While some sediment drifted from some barge tracks onto adjacent ones, the overall amount of sediment drift was minimal. A minimal amount of sediment drifted off the project site. The 3-foot cap ranged from 2.5 to 3.5 feet thick, and the 1-foot ENR ranged from 0.8 to 2.1 feet thick. It was felt that the measured thicknesses were satisfactory considering the application method.

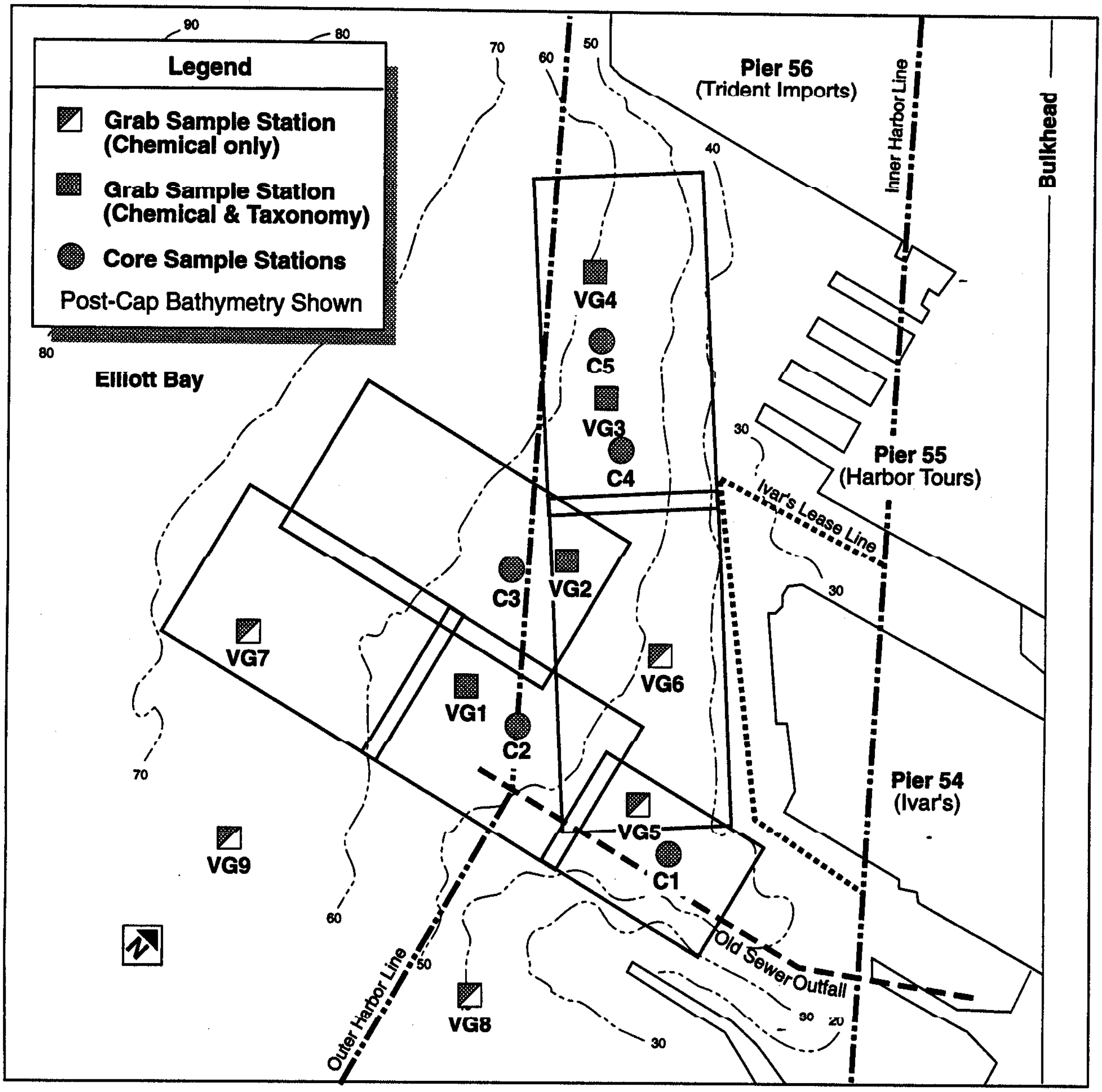
Sediment-Profile Camera Survey

The sediment-profile camera survey, conducted by SAIC, showed a thin layer of capping sand up to 300 feet beyond the project boundary in the offshore (downslope) portion of the survey area. Cap material extended 50 feet in the inshore (upslope) portion of the survey area. However, in over half of the area where sand landed outside of the barge tracks, the sand thicknesses ranged from zero to 3.5 inches. The sediment-profile camera survey and the cap thickness measuring stakes indicated that most of the capping sediments settled on the defined project site.

CORE SAMPLE ANALYSIS

Five coring stations were established to provide spatial coverage across the sediment cap and ENR (see Map 3). A Metro crew and Global Divers collected the sediment cores. Each core extended completely through the clean capping sediments and into the underlying contaminated sediments by about 1 foot. The cores were divided into 6-inch sections and analyzed by the Metro Environmental Laboratory for organic and metal contaminants.

The core samples showed that the capping sediments were mostly clean and that their chemical makeup was similar to the pre-dredge test results of the Duwamish River sediments, which were analyzed to gain approval for their use as capping material. Organic and metal contaminants were either undetected or in low concentrations within the sediment cap. There were no PCBs in the capping material. The core samples also showed the high concentrations of chemicals in the under-cap sediments.



Map 3. Post-Cap Sampling Stations

SURFACE SEDIMENT CHEMISTRY OF CAP AND SURROUNDING AREAS

On May 26 and 27, 1992, the monitoring team collected surface sediment samples from the cap, the ENR, and surrounding areas near the cap. The samples were analyzed for metals and organic chemicals to establish baseline data on the distribution of chemicals in the study area.

Seven surface sampling stations were established to provide spatial coverage across the sediment cap and ENR. Six surface sampling stations were established in the areas surrounding the sediment cap and ENR. Three grab samples were composited from each sampling station. Metro collected and analyzed the composites for organic and metal contaminants.

Chemical analysis of the cap surface samples showed that the cap material is mostly clean, the concentrations are uniform, and the results agree with the Duwamish River PSDDA sediment characterization study. Only eight polycyclic aromatic hydrocarbons (PAHs) were detected on the cap surface and these were below the SQS. Also, when metal contaminants were detected they were below the SQS.

Chemical analysis of the surface samples from the surrounding areas showed elevated levels of contaminants. Typically, chemical contaminant concentrations were highest closest to the shore and decreased with distance offshore even under the piers. The lead values for the under-pier samples ranged from 200 to 380 ppm as compared to an average of 6 ppm on the cap. Two sites offshore and south of the cap showed lead levels of 14 and 24 ppm, which are below the SQS. Four under-pier samples were collected and analyzed.

BENTHIC RECOLONIZATION

The post-cap taxonomy study shows that recolonization during the first 5 months after cap placement is beginning, with 134 species present; numbers and biomass are low, however, as expected because of the short time since cap placement. Biomass is slightly higher in the ENR than in the 3-foot cap. This may mean that the ENR is more productive, but the difference is small and further study is needed to determine productivity differences.

Images from the sediment-profile camera survey show that the Pier 53 cap is being recolonized by sparse benthic communities. The organisms that make up these communities are dominated by species that are usually first to recolonize a recently disturbed area.

The benthic communities before and after cap placement are very different, suggesting the pre-cap organisms did not survive burial during cap construction. Recolonization of the cap appears to be by juvenile recruitment or by the lateral migration of organisms as adults.

CONCLUSIONS

The capping method used for the Pier 53 project appears to have potential for economical remediation of some contaminated sediments as well as other less contaminated bottom areas. Because the contaminated sediments are not dredged but left in place, capping reduces the possible spread of contamination to surrounding areas and to the water column. The cost of remediating contaminated bottom sediments by capping can be 1 to 20 percent of the cost of dredging the contaminated material and disposing of it in an acceptable facility, assuming an acceptable facility can be found. Finally, this project demonstrated that conventional dredging and disposal equipment can be used in an innovative way to cap contaminated bottom sediments.

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

MAPS

Map

ILLUSTRATIONS

Figure

ILLUSTRATIONS (continued)

TABLES

Table

TABLES (continued)

SECTION 1

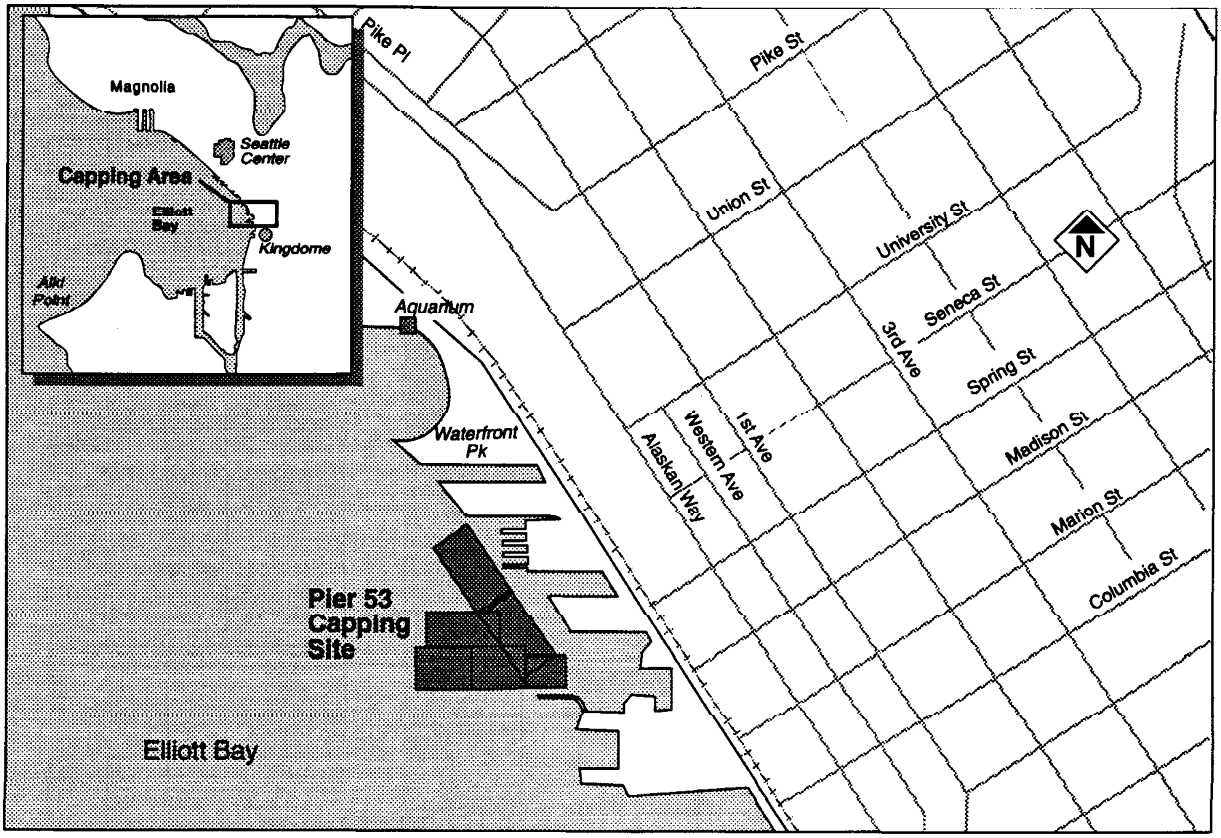
INTRODUCTION

In March 1992, contractors for the US Army Corps of Engineers slowly placed 22,000 cubic yards of clean sand offshore of Piers 53, 54, and 55 in Elliott Bay on Seattle's downtown waterfront, capping 4.5 acres of chemically contaminated bottom sediments. This action (known as the Pier 53 project) was the culmination of over 4 years of study and planning by many agencies, including the City of Seattle Department of Engineering, the Municipality of Metropolitan Seattle (Metro), the U.S. Army Corps of Engineers (the Corps), State of Washington Department of Ecology (Ecology), State of Washington Department of Natural Resources (DNR), Washington Department of Fisheries, and the U.S. Environmental Protection Agency (EPA).

The capped sediments are in an east-west-running rectangular and trapezoidal area located offshore of Piers 53, 54, and 55. The site is west and slightly north of the intersection of Madison Street and Alaskan Way in downtown Seattle (see Map 1-1). The cap is designed to be 3 feet thick over the 2.9 acres farthest offshore and 1 foot thick over 1.6 acres nearshore. The thinner part of the cap is known as the "enhanced natural recovery area" (ENR).

Planning for the Pier 53 project began as part of Metro's Toxic Sediment Remediation Program. This program is designed to coordinate and plan multiagency efforts to clean up contaminated sediment in Elliott Bay and the lower Duwamish Estuary. An interagency committee was formed to provide guidance for the Toxic Sediment Remediation Program. Through this program, the City of Seattle sponsored the Pier 53 project in cooperation with Metro. The project is now under the administration of the Elliott Bay/Duwamish Restoration Program Panel, created as part of a negotiated settlement between the National Oceanic and Atmospheric Administration (NOAA), the U.S. Fish and Wildlife Service, the Muckleshoot Indian Tribe, the Suquamish Tribe, the Washington State Department of Ecology, the City of Seattle, and Metro.

The Pier 53 remediation project report has two purposes. First, it is intended as a source of information relating to the Pier 53 sediment cap and ENR. And second, it fulfills requirements set forth in the *Monitoring Plan for Pier 53* (Appendix A). The report contains the following information pertaining to the first year of activities for the project:



Map 1-1. Location of the Pier 53 Capping Site

- The placement and thickness of the sediment cap and ENR based on barge dump records, bottom stake measurements, and a sediment profile camera survey.
- Baseline chemical information from core samples of the sediment cap to document the vertical-contaminant-concentration profiles.
- Baseline chemical information from the surface of the sediment cap and ENR and surrounding bottom sediments to document existing chemical concentrations and possible sources of recontamination.
- Initial evidence of recolonization of the project area by benthic organisms.

BACKGROUND

Several sediment monitoring studies have identified the Seattle waterfront and Harbor Island areas as problem spots because of elevated levels of toxic chemicals in bottom sediments. In 1980, D.C. Malins, B.B. McCain, D.W. Brown, A.K. Sparks, and H.O. Hodgins wrote *Chemical Contaminants and Biological Abnormalities in Central and Southern Puget Sound.* In 1984, P.G. Romberg, S.P. Pavlou, A.E. Crecelius, P. Hamilton, et al. published the *Presence, Distribution, and Fate of Toxicants in Puget Sound and Lake Washington.* In 1988, Tetra Tech, Inc. prepared *Analysis of Toxic Problem Areas* as part of EPA's Puget Sound Estuary Program. In 1988 and 1989, Metro conducted further sediment studies along the Seattle waterfront as part of its Elliott Bay Toxic Hot Spot Program (see Appendix B). Using these and other data collected in Elliott Bay, Parametrix, Inc. compiled the report, *Metro Toxic Sediment Remediation Project* (Appendix C), which prioritized potential cleanup sites. The Parametrix report was the first major step toward conducting a sediment cleanup project in Elliott Bay by an interagency planning group composed of the Corps, EPA, DNR, Washington State Department of Fisheries, Ecology, the City of Seattle, and Metro.

Site Selection

For the sediment remediation report, Parametrix developed a risk assessment evaluation of potential remediation sites and prioritized a list of 49 potential sites. The list was later expanded to include sites up the Duwamish River for a total of 68 sites. The sites were ranked on the basis of the number and types of chemicals present and the maximum concentration of these chemicals. This list was further screened by using four additional criteria established by the interagency planning committee to identify projects with the greatest potential for successful near-term implementation. These four criteria are the following:

1. The site must be publicly owned or have a public lessee.
2. Contamination source control efforts must be completed or sufficient to prevent unacceptable levels of recontamination.
3. The site must not be under consideration for remediation by another party.
4. The site must not be on the EPA National Priority List (Superfund).

Background

There were three reasons for the first criterion. First, the regulatory agencies assumed that the likelihood of obtaining permits in the near future would be greatly enhanced if only public agencies were involved in the remediation project. Second, if Metro funds were used to remediate private property, there could be a precedent for requests from private parties for remediation funds in the future. Third, it was not clear what liability Metro might incur from a cleanup project on private property. At the time, this criterion simplified the project; it will not, however, be used as a primary screen for future potential remediation projects.

The second criterion was added because source control would be a remediation option, if the site could be expected to recover naturally. Otherwise, the sediments would remain contaminated even after the source was removed. A combined source control and site remediation project would exceed the funds available for this project in the near future. Therefore, it was decided that completion of source control efforts was necessary.

The last two criteria listed are related. The interagency committee decided that initiating new sediment remediation programs was more important than contributing monies to existing plans or programs, such as Superfund.

Of the initial 49 sites, the two highest ranking were Seacrest Park, located south of the Seacrest Marina on the West Seattle side of Elliott Bay, and the Pier 53 site. A preliminary remediation plan was developed for these two sites as part of the Parametrix report. Planning for remediation was suspended when NOAA filed a lawsuit against the City of Seattle and Metro. The lawsuit alleged damages to natural resources resulting from hazardous substances released in and around Elliott Bay and the Duwamish River from combined sewer overflows and storm drains. About a year passed before planning for remediation was revived. The Pier 53 site was chosen when the City of Seattle expressed a willingness to take the lead in implementing a capping project at the site and the Corps was willing to provide capping sand from routine maintenance dredging in the Duwamish River.

There was no effort to reassemble the initial planning group. Instead, the City of Seattle and Metro decided to develop plans and coordinate agencies during the permit process. The Corps was committed to complete dredging in the Duwamish River by the end of March 1992 and would dispose of the sand at the open water disposal site in Elliott Bay if no beneficial capping project was possible. Because of this dredging schedule, the time frame for acquiring the necessary permits and the review period for the permitting agencies was very short. All permitting agencies were very cooperative and all permits were obtained, but future projects should be given more lead time for permit review.

The NOAA lawsuit was settled out of court in 1991. The settlement created a fund designated for the cleanup of Elliott Bay and the lower Duwamish River, and a panel, the Elliott Bay/Duwamish Restoration Program Panel, to administer the fund. The panel is composed of the City of Seattle and Metro and five natural resource trustees: NOAA, the U.S. Fish and Wildlife Service, the State of Washington Department of Ecology, the Muckleshoot Indian Tribe, and the Suquamish Tribe. The settlement stipulated that money for the fund would come from the City of Seattle and Metro.

After the Pier 53 sediment cap was installed, the project was presented to the Elliott Bay/Duwamish Restoration Program Panel. The panel reviewed the project, and after deciding it met certain criteria, declared that the project was eligible for reimbursement from the restoration fund. The management of the Pier 53 project then proceeded under the direction of the restoration panel with the City of Seattle as project sponsor. Metro was designated to conduct the monitoring plan established during the permitting process.

Contamination Sources

Researchers believe that contamination at the Pier 53 site came from a few sources. Before 1969, a continuous untreated wastewater outfall discharged offshore of the foot of Madison Street. After 1969, combined sewer overflows also discharged untreated wastewater but at a greatly reduced and declining rate. Also, pier activities conducted over the last century may have contributed to the toxicant loading of the marine sediments, but it is not in the scope of this report to address specifically the pier activities that produce contaminants or their reduction and control. The continuous untreated sewer outfall discharge has been stopped, CSO volumes have been controlled and reduced, and the pier activities that produced the sediment contamination have been reduced.

The now abandoned combined sewer outfall was first constructed by the City of Seattle in 1910 to continuously discharge untreated sewage and stormwater into Elliott Bay. This outfall was originally made of wood and emptied 60 feet offshore.

During the winter of 1928-29, the City replaced the original wood pipe with a cast iron, deep-water outfall and a nearshore overflow. The two adjacent discharge pipes continuously drained wastewater and stormwater from the 53-acre Madison Street basin. The deep-water outfall emptied approximately 600 feet offshore, while the overflow emptied just past the seawall. In later years, tides and storms were known to have broken the deep water outfall, which was never repaired, so the offshore distance of the actual discharge was a matter of speculation.

Background

Starting in the 1960s, the City of Seattle and Metro have worked to reduce the Madison Street outfall volume. In 1969 Metro constructed the 10-foot-diameter Elliott Bay interceptor sewer line along Seattle's waterfront. The Elliott Bay interceptor was designed to capture wastewater from all sewer lines along Elliott Bay and transport it to the newly constructed West Point Treatment Plant. At this time, most continuous wastewater discharge outfalls, including Madison Street, were converted to combined sewer overflows (CSOs). During dry weather and light rain the interceptor line would continue to transport stormwater and wastewater for treatment. If the rain was heavy enough, the additional stormwater would fill the interceptor line. Because the flow from the sewer lines could not enter the interceptor, the sewer line flow was diverted into the bay in what is called a combined sewer overflow event.

To further reduce the number of wastewater overflows, the City of Seattle installed a separate storm drain system in the Madison Street drainage basin. The separate stormwater system reduces both the volumes of wastewater in the Elliott Bay interceptor and the number of combined sewer overflow events by carrying stormwater directly into Elliott Bay. The stormwater drainage system and a new Madison Street CSO–stormwater outfall were finished in 1988. The new CSO and stormwater drain is a 5-foot-diameter pipe that ends at the bulkhead under the Seattle City Fire Department's Station Number 5. This new outfall is located 100 feet to the south of where the now abandoned deep-water combined sewer outfall and overflow pipes passed through the bulkhead.

Under major storm conditions, an overflow of the combined sewer system may still occur. Combined sewer overflow events from this outfall are calculated to occur no more than an average of once a year. The total stormwater drainage and combined sewer overflow is estimated at 700,000 gallons per year. Actual sewer overflow volumes are presently unknown, but the City of Seattle recently installed telemetry devices upstream of the outfall to provide discharge data. Further volume reduction is expected through the implementation of requirements for on-site stormwater detention for all future development and redevelopment within the drainage basin.

Remediation Method Selection

The Parametrix report considered several possible remediation methods for contaminated sediments at Pier 53 and Seacrest Park in West Seattle. It concluded by recommending capping the sediments at both sites. The report recommended a 3-foot-thick cap over the entire area and armoring in the shallower and under-pier areas to prevent erosion. A sediment cap design should isolate contaminated bottom sediments and provide a clean substrate for marine life; it may address other factors or constraints.

Subsequent design of the Pier 53 remediation project focused on the offshore area where sediment capping could be accomplished by spreading sand from a barge. Further consideration of navigation depth resulted in the decision to reduce the covering to 1-foot-thick inshore in the shallower areas.

Alternatives to Capping. The alternative remediation methods Parametrix considered but did not recommend for the two sites were nearshore confined disposal, upland confined disposal, and natural recovery.

Nearshore and upland confined disposal, both involving dredging, were not selected because of their high cost compared to capping and, in the latter case, the absence of an approved disposal site for contaminated dredged material within a reasonable distance of the project.

The natural recovery alternative was not selected because it means that no cleanup actions are undertaken and site conditions are left to improve over time by the two natural processes of chemical breakdown and burial by accumulation of new cleaner sediment. Natural recovery is an acceptable alternative when chemical levels decrease below Ecology's Marine Sediment Quality Standards in less than 10 years. At the Pier 53 site, metals exceed the standards, but they do not chemically degrade over time; consequently, waiting for natural degradation to occur is not adequate to remediate the site.

The natural accumulation of enough new clean sediment to reduce sediment chemical concentrations is essentially a natural capping process. At Pier 53, however, it would take many years for enough clean sediment to accumulate to reduce surface layer contaminants to levels below the sediment standards. For the report titled *Toxicant Reduction in the Denny Way Combined Sewer System* prepared in 1987 by Metro, sediment cores were taken and historical sedimentation rates were calculated for the area along Seattle's downtown waterfront at the foot of Denny Way. The report concluded that it would take 20 to 60 years before 6 inches of new sediment would accumulate. Since similar conditions are expected to exist along the whole waterfront, waiting for a new layer of sediment to accumulate is not adequate to remediate the Pier 53 site. In addition, it is currently unclear what the chemical makeup of the new sediment might be.

Capping. The capping method of slowly releasing sand from a bottom-dump barge was developed under the direction of Alex Sumeri at the Corps and used the first time in 1984 for confined aquatic disposal (CAD) of contaminated dredged material in the lower Duwamish west waterway. This project involved dredging a small contaminated shoal from the navigation channel, disposing of the dredged material in a deeper area in the waterway, and covering it with a layer of clean sediment. The difference between CAD and capping is that CAD first involves the dredging and relocation of contaminated sediments, which are then covered with clean sediment to isolate the contaminants. This relocation of sediments can cause contamination of the water column, which does not occur in capping projects. The term "capping" was chosen in this report to refer to projects in which contaminated sediments are isolated without being dredged first. The Duwamish CAD project, the oldest in Washington, has shown no evidence of chemical contaminants migrating up into the clean-sand cover, based on 5 years of monitoring (Sumeri, Romberg 1991). Two other successful Puget Sound CAD projects are at the One Tree Island Marina in Olympia, and Simpson Tacoma Kraft Company in Tacoma. Some dredging was involved at the Simpson site. Both sites are being monitored and show no signs of chemicals migrating up into the clean sand from underneath.

There have been three projects in Puget Sound where contaminated sediments were left in place and covered with a layer of clean sediment; all are in Elliott Bay. The first project was completed in 1989 by the Washington State Department of Transportation (WSDOT) as part of the ferry terminal expansion. This project involved covering the 4-acre area under the new pier with a 1.5-foot thick layer of sand to minimize disturbance of contaminated sediment during pier construction. The sediment cap was placed using a clamshell dredge. Post-cap monitoring was conducted once for this cap. The second project was completed at the Denny Way combined sewer overflow (CSO) in 1990. The Denny Way sediment cap was a cooperative demonstration project by the Corps and Metro to improve marine sediment quality offshore of the Denny Way CSO. The project involved placing 20,000 cubic yards of clean sand on 3 acres of contaminated bottom sediments to a depth of 3 feet. Ongoing monitoring at the Denny Way site indicates the cap is isolating the covered contaminated bottom sediments. The third is the Pier 53 cap described in this report.

Pier 53 Sediment Cap Characteristics

The Pier 53 project plan involved contingencies for two different types of sediment remediation. A 3-foot-thick cap was proposed for the area of highest chemical concentration, an approximately 2.9-acre primary area offshore of Pier

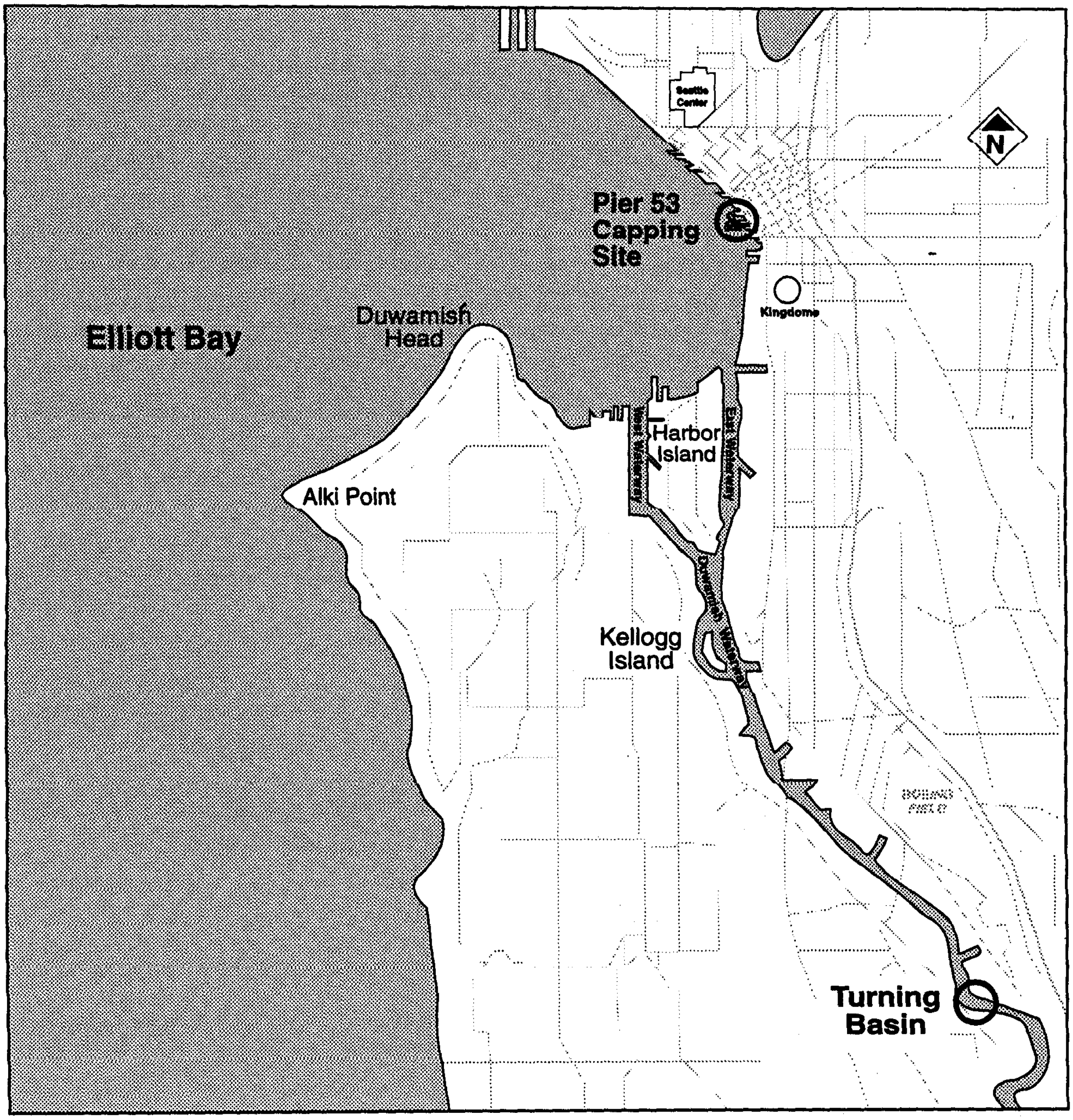
53, based on the minimum amount of cap material estimated to be available. The 3-foot cap is designed to provide a clean substrate for marine life and to isolate the underlying contaminated sediments. It is generally considered that the 3-foot cap depth is sufficient to prevent burrowing organisms from entering the underlying contaminated sediments. If more sediment were available, an adjacent, shallower, 1.6-acre area to the north and offshore of Piers 54 and 55 would be covered with a 1-foot-thick layer of sand. The 1-foot thick layer would minimize loss of navigational depth for the shallower and less contaminated northern portion of the site, and would allow studies of biological recovery under "enhanced" natural conditions–hence the name "enhanced natural recovery area." Eventually, enough sand was available for both the 3-foot-thick cap on the 2.9-acre primary area and a 1-foot-thick ENR in the 1.6-acre secondary area.

The project is known as the Pier 53 project because the minimum configuration was to cap the highest concentrations of toxic bottom sediments directly offshore of Pier 53. It was not known at the outset that there would be enough clean sediment to cap the areas offshore of Piers 54 and 55.

If the ENR part of the project failed to work as designed it would not be interpreted to mean that the practice of sediment capping had failed. Sediment capping is a technique that is slowly gaining a positive reputation for isolating toxic sediments, because of the evidence accumulating from long-term monitoring.

Source of Cap Sediment. The dredge contractor, under the direction and using procedures developed by the Corps, placed 22,000 cubic yards of clean sand at the Pier 53 site. The contractor dredged clean sand from the upper Duwamish River during routine maintenance for navigation (see Map 1-2). The City of Seattle arranged a reimbursement agreement with the Corps for transporting and spreading the sediment at the Pier 53 site instead of disposing of the sand at the open water disposal site in Elliott Bay. This cooperation substantially reduced the cost of the project. The contractors delivered a total of 10 barge loads and slowly distributed the sand over the site to generally achieve project design depths.

Enhanced Natural Recovery Area. The ENR is intended to provide a clean substrate for marine life, cause minimal reduction in navigational depth, and provide preliminary data on the feasibility of this type of remediation in shallower areas.



Map 1-2. The Duwamish River Dredge Site and the Pier 53-55 Capping Site

Natural recovery occurs either when contaminants degrade naturally through oxidation or other processes, or when enough new clean sediment is deposited to cover the contaminants and reduce chemical concentrations through dilution. Enhanced natural recovery speeds up dilution and may increase degradation.

When a thin layer of clean sediment is placed on contaminated sediments, organic chemicals, which degrade over time, are likely to break down at an accelerated rate because of increased oxidation. As bottom dwelling or bottom feeding organisms colonize the clean sediment, they mix it up a bit–a process called bioturbation. Bioturbation oxygenates the sediment. As more mixing occurs, contaminated underlying sediments are likely to be brought up into the oxygenated zone. In contaminated sediments without a clean surface layer, the numbers of benthic infauna are likely to be reduced, which decreases the chances of bioturbation. This in turn causes decreased oxygen levels in the sediment and reduces the chances for breakdown of organic chemicals.

The second component of natural recovery is dilution. It is anticipated that enhanced natural recovery will initially isolate the contaminated sediments. Then when bioturbation occurs, chemicals that do not break down, such as metals, are dispersed among the clean sediments and reduced in concentrations.

MONITORING PLAN

The monitoring program is designed to determine how stable the cap is, how well it is functioning to isolate the contaminated sediments, whether the cleanup continues to meet state sediment standards, and how the cap is biologically repopulated. It is also a means to evaluate the rate of possible recontamination.

The cleanup standards selected by the restoration panel are Washington Administrative Code Chapter 173-204 Table I, Marine Sediment Quality Standards (SQS). The Pier 53 sediments will be analyzed for the chemicals listed in Table I and will be compared to the SQS to determine whether the site continues to meet the cleanup levels.

Metro began conducting the field work for the 10-year post-cap monitoring program in 1992 with the collection of baseline benthic taxonomy and sediment chemistry data. Surveys of the cap were conducted by diver and underwater camera, and sediment samples were collected and analyzed for metal and organic chemicals and benthic populations.

The first year's baseline data will be compared to studies conducted in subsequent years to establish trends regarding chemical contamination and marine life. The monitoring program also could help pinpoint any new sources of contamination along the central waterfront of Elliott Bay. Finally, the information gained through this project will help determine if the thicker cap and ENR should be used in future remediation projects in this area.

LIST OF PERMITS AND AUTHORIZATIONS

The following is a list of governmental approvals or permits that the City of Seattle obtained for the Pier 53 capping project.

- City of Seattle: Shoreline Substantial Development Permit
- State of Washington Department of Ecology: Water quality certification, short-term water quality exemption
- Washington Department of Fisheries: Hydraulic Project Approval
- Washington Department of Natural Resources: Leasing agreement
- U. S. Army Corps of Engineers: Section 10 and Section 404 Permits regulating the placement of dredged material and a memorandum of agreement for the City's sponsorship of the capping project approved by the assistant secretary of the Army

The Corps substantially complied with the regulatory requirements of the Clean Water Act Section 404 process for the dredging of sediment used as capping material and arranged for all sediment sampling needed to satisfy the Puget Sound Dredged Disposal Analysis requirements for determining whether the sediments were suitable for capping material.

One common feature of the shoreline permit, the Corps permit, and the DNR lease is that they all require a monitoring plan for the capping project. The monitoring plan developed for 1992 Pier 53 capping project includes not only the components of the monitoring plan used for the 1990 Denny Way capping project, but a provision to evaluate the ENR. Sampling locations and frequencies for the monitoring plan were established by a committee including representatives from the regulatory agencies listed above plus the EPA, City of Seattle, and Metro.

SECTION 2

PRE-CAP SEDIMENT STUDIES

Several studies of Elliott Bay sediments and a study of Duwamish River sediments contributed information needed for the Pier 53 capping project. They are discussed in this section.

In 1988 and 1989 Metro researchers collected sediment samples from along the Seattle waterfront. The samples were analyzed for toxic chemicals to better define contaminated areas. These studies led to the Pier 53 site becoming a candidate for remediation (Romberg personal communication).

In 1992, shortly before placement of the cap, another Metro research team collected sediment samples for a bottom surface chemistry study and a biological toxicity test. These studies were an effort to get further information on the sediments that were to be capped. In addition, a study of the offshore currents at Pier 53 was conducted by Brown and Caldwell for the City of Seattle (Appendix D).

The sediment for the cap came from the upper navigable waterway in the Duwamish River. Corps contractors collected and analyzed the river sediments for chemical contamination (Appendix E), and verified its suitability for use either as capping material or for disposal at the Puget Sound Dredged Disposal Analysis (PSDDA) clean dredged material disposal site in Elliott Bay.

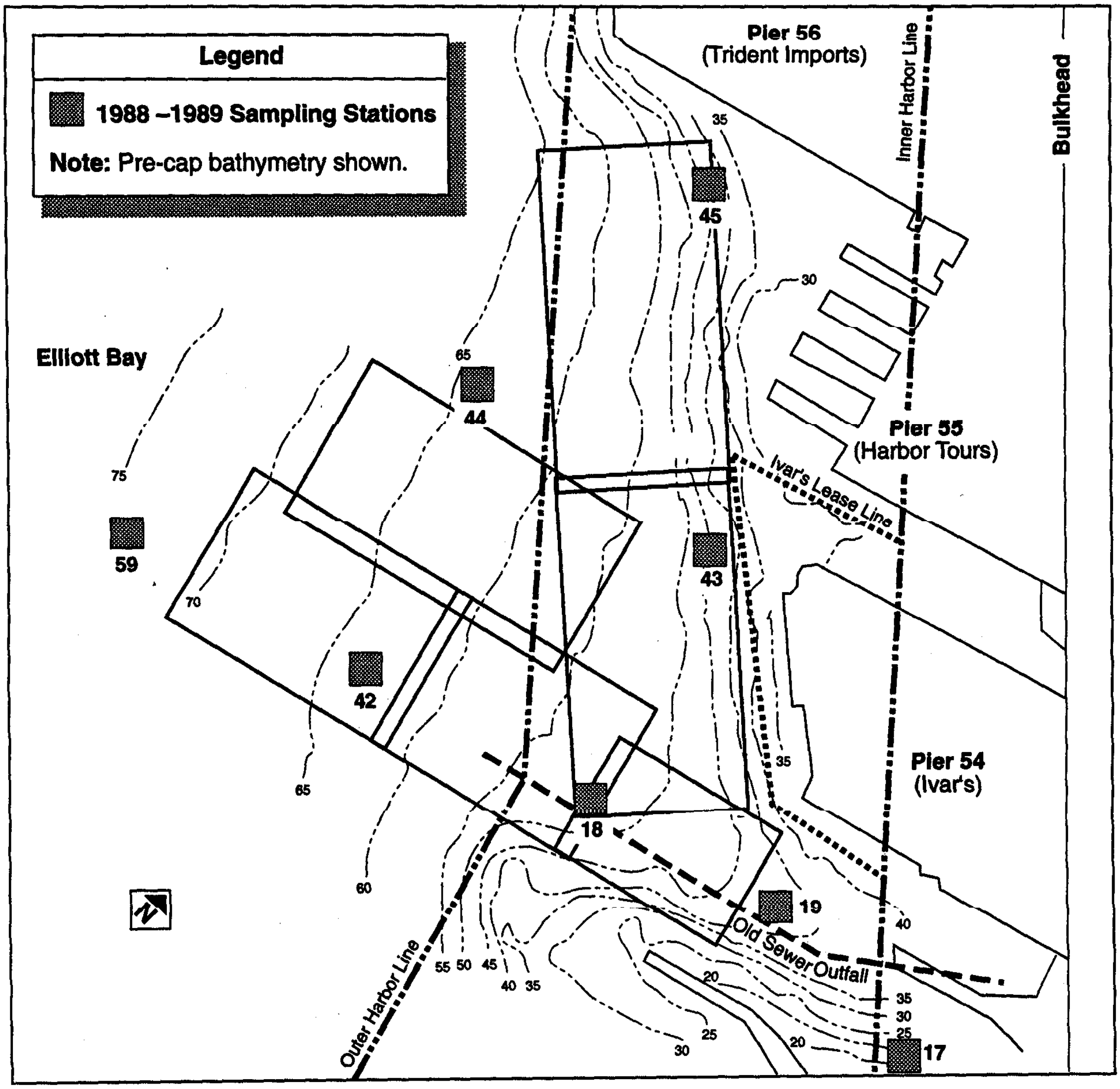
WATERFRONT SEDIMENT STUDIES: 1988 AND 1989

Metro conducted sediment studies in 1988 and 1989 with the intention of identifying potential remediation sites. Development and implementation of remedial actions such as capping and dredging of contaminated sediments required that sediment chemistry data be obtained to characterize the contamination in the area. Metro researchers collected three surface samples in the Pier 53 area in 1988 and five surface samples in 1989 (see Map 2-1) (Romberg personal communication).

Selection of the Sampling Area

The following criteria were used for selecting specific sites for further investigation:

Waterfront Sediment Studies: 1988 and 1989



Map 2-1. 1988-89 Sampling Stations

- Areas that were known to have sediment contamination problems
- Areas located near Metro discharges
- Areas with a high potential for development activities that could lead to disruption or contamination

- Areas that were not being regulated by enforcement agencies (to avoid duplication of effort)

Methods

The monitoring team collected the surface sediment samples with a 0.1-square-meter Van Veen grab sampler, which they operated from the research vessel, the *RV Liberty*. The Van Veen sampler is a steel box divided diagonally with a hinge allowing the halves to work like jaws. The jaws are propped open and lowered to the bottom. When the sampler hits the bottom, a release mechanism is tripped, allowing the jaws to close. The winch operator then pull the sampler back onboard the boat. The action of pulling the sampler off the bottom forces the jaws to close, grabbing a sediment sample.

Once the sample was on board the team used a stainless-steel "cookie cutter" sampler to remove a 2-centimeter-deep subsample from the top of each grab sample. Typically, they collected three grab samples at each station, taking one to two subsamples from each grab. These three to six subsamples were composited in a 4-liter beaker that had been cleaned in a muffle furnace at 500° C. The Metro laboratory then analyzed the samples for metals and organic priority pollutants. Samples were sent to a contract laboratory to be measured for particle size distribution. These samples were not tested for total organic carbon.

Results

Individual sediment chemistry values are included in Appendix B, and detected chemicals are listed in Table 2-1. At the time the studies were conducted, there were no state approved sediment standards. A general indication of sediment quality was obtained by comparisons with a standard then proposed by Ecology, the dry-weight low apparent effects threshold (LAET). The LAET levels are roughly equivalent to the current sediment quality standards (SQS).

Organics. The three 1988 samples in the Pier 53 area showed the inshore site to be clean and the two offshore sites to be contaminated. The clean site (17) was in an area that was dredged in 1986 and is close enough to the northern ferry loading ramp that it receives ferry-boat propeller wash. The two offshore sites (18 and 19) exceeded LAET values for high-molecular-weight polycyclic aromatic hydrocarbons (HPAH), low-molecular weight polycyclic aromatic hydrocarbons (LPAH), and polychlorinated biphenyls (PCB).

Waterfront Sediment Studies: 1988 and 1989

TABLE 2-1. Detected Chemicals at 1988-89 Sample Stations

Station #:	**18***	**19**	**42**	**43**	**44**	**45**	**59**
Sample #:	**8801129**	**8801130**	**8906413**	**8906414**	**8906415**	**8906416**	**8908183**
Date:	**5/25/88**	**5/25/88**	**6/19/89**	**6/19/89**	**6/19/89**	**6/19/89**	**8/17/89**
% Solids:	**40**	**38**	**48**	**38**	**47**	**52**	**45**
Compound Name	**Values in Dry-Weight**						
LPAH (ppb)							
Acenaphthylene	350	E 170	380	500	<200	T 200	240
Acenaphthene	500	E 290	200	1,300	<100	440	220
Fluorene	800	E 610	460	630	<200	540	310
Phenathrene	3,000	E 3,400	2,500	3,400	720	3,500	2,400
Anthracene	2,300	E 1,900	2,300	2,500	400	1,300	1,300
HPAH (ppb)							
Fluoranthene	6000	E 7,400	6,300	18,000	1,100	4,000	6,200
Pyrene	12,000	E 15,000	5,000	14,000	1,300	3,500	4,900
Benzo(a)anthracene	6,250	E 5,500	5,200	5,800	850	2,300	2,700
Chrysene	7,000	E 9,700	9,800	8,700	1,400	3,700	4,200
Benzo(b)fluoranthene	5,500	E 7,600	5,000	5,500	900	2,500	4,000
Benzo(k)fluoranthene	4,750	E 8,200	4,000	6,100	1,200	3,100	3,300
Benzo(a)pyrene	4,750	E 5,000	4,600	5,000	850	2,500	3,100
Indeno(1,2,3-cd)pyrene	3,000	E <100	2,700	2,900	600	1,500	1,000
Dibenzo(a,h)anthracene	1,925	E <200	T 700	T 1,000	<500	<500	270
Benzo(g,h,i)perylene	2,500	E <100	2,100	2,500	600	1,200	870
PCB (ppb)							
Aroclor-1248	350	E 370	E 130	E 250	E 120	E 290	<30
Aroclor-1254	1,100	E 500	E 160	E 390	E 150	E 480	130
Aroclor-1260	1,000	E 680	E 200	E 390	E 160	E 330	180
Metals (ppm)							
Antimony	0.77	0.079	0.19	<0.2	0.2	1.2	0.17
Arsenic	25	32	23	26	18	25	13.6
Beryllium	NA	0.13	<1	<1	<1	<1	1.16
Cadmium	6.1	L 3.2	0.58	1.7	<0.4	1.2	0.33
Chromium	110	79	B 48	B 110	B 51	B 71	48.9
Copper	170	170	140	160	91	270	84.4
Lead	310	250	150	280	180	420	116
Mercury	2.1	1.6	<0.02	<0.02	<0.02	0.11	0.38
Nickel	44	E 42	38	61	36	52	33.3
Selenium	NA	0.63	0.19	0.42	0.4	0.17	0.67
Silver	12.	B 7.9	<2	2.9	<2	1.9	<1.67
Thallium	NA	E 0.53	0.38	0.42	0.4	0.35	0.67
Zinc	250	B 220	B 160	B 280	140	B 350	120

NA = Not Available B - Result corrected for blank contamination. E - Estimate

L - Value is less than maximum shown. T - Detected below quantification limit.

* This data is provided for information purposes only. Archived raw data is not sufficient to qualify these sample results.

The five 1989 samples in the Pier 53 area exceeded the LAET values for PCBs. The two highest PCB concentrations of 1.0 ppm and 1.1 ppm were at Stations 43 and 45, close to the piers. Concentrations of both PAH groups showed a steady decrease going offshore from Station 18 to Station 59. The HPAH values went from 54 ppm to 45 ppm and then to 31 ppm at Station 59, while LPAH values went from 7.0 ppm to 5.8 ppm and then to 4.5 ppm (Metro, Water Quality Status Report for Marine Waters, 1988 and 1989).

Station 43, located approximately 80 feet offshore from Pier 54, had the highest overall organics concentrations for stations sampled during both 1988 and 1989 in the vicinity of Pier 53. The next highest concentrations were at Stations 18 and 19, which were both located farther inshore. Typically, concentrations drop off rapidly when moving west of the ends of the piers, but Stations 42 and 18 are quite west of the piers and still high in concentrations. One possibility is that the stations are influenced by the old sewer outfall and would receive higher chemical concentrations even though they are beyond the ends of the piers. Another possibility is that the entire area is influenced by chemicals from south of Pier 53 being stirred up by docking ferries. Because the old sewer outfall pipe was known to have broken offshore, chemical concentrations can be expected to be elevated along the entire old pipeway. A plume caused from the old outfall may also account for higher organic concentrations at Station 59. Station 59 is located farthest offshore, but does not have the lowest concentrations. Station 44 has the lowest overall concentrations and is located approximately 300 feet offshore of Pier 54 to the north of the old pipeway.

Metals. None of the five stations sampled in 1989 exceeded LAET values for metals. Stations 18 and 19, sampled in 1988, however, exceeded the LAET standards. When later compared to the current state sediment standards, both stations exceeded the Marine Sediment Cleanup Screening Levels for mercury and silver.

Metals, at all the stations for both years, followed a pattern of decreasing concentrations going offshore. Stations 18, 19, and 43 had the highest overall concentrations and were the closest inshore. Stations 42 and 44 had the second and third lowest concentrations and were the second and third farthest offshore. Station 59 was located farthest offshore and had the lowest concentrations.

PIER 53 PRE-CAP SEDIMENT STUDY: 1992

Metro conducted a sediment study in early March 1992, shortly before the cap was installed. This study's objective was to obtain sediment chemistry information that could be compared to Ecology's newly adopted state sediment standards. This information and the biological toxicity data can also be used as part of a risk assessment of the site.

In 1991, Ecology finalized the state's sediment standards with a list of 47 chemicals. All 47 chemicals appear on the longer EPA Priority Pollutant List. The state sediment standards use two sets of concentration values for regulation. One set is called the Sediment Quality Standard (SQS). The SQS established concentration levels that are considered acceptable in marine sediments anywhere in Puget Sound. The second set of numbers are typically higher values and are used as the Cleanup Screening Level (CSL), which signify whether a cleanup study should be conducted at a site. The CSLs are also used as the minimum cleanup level (MCUL) for any cleanup site.

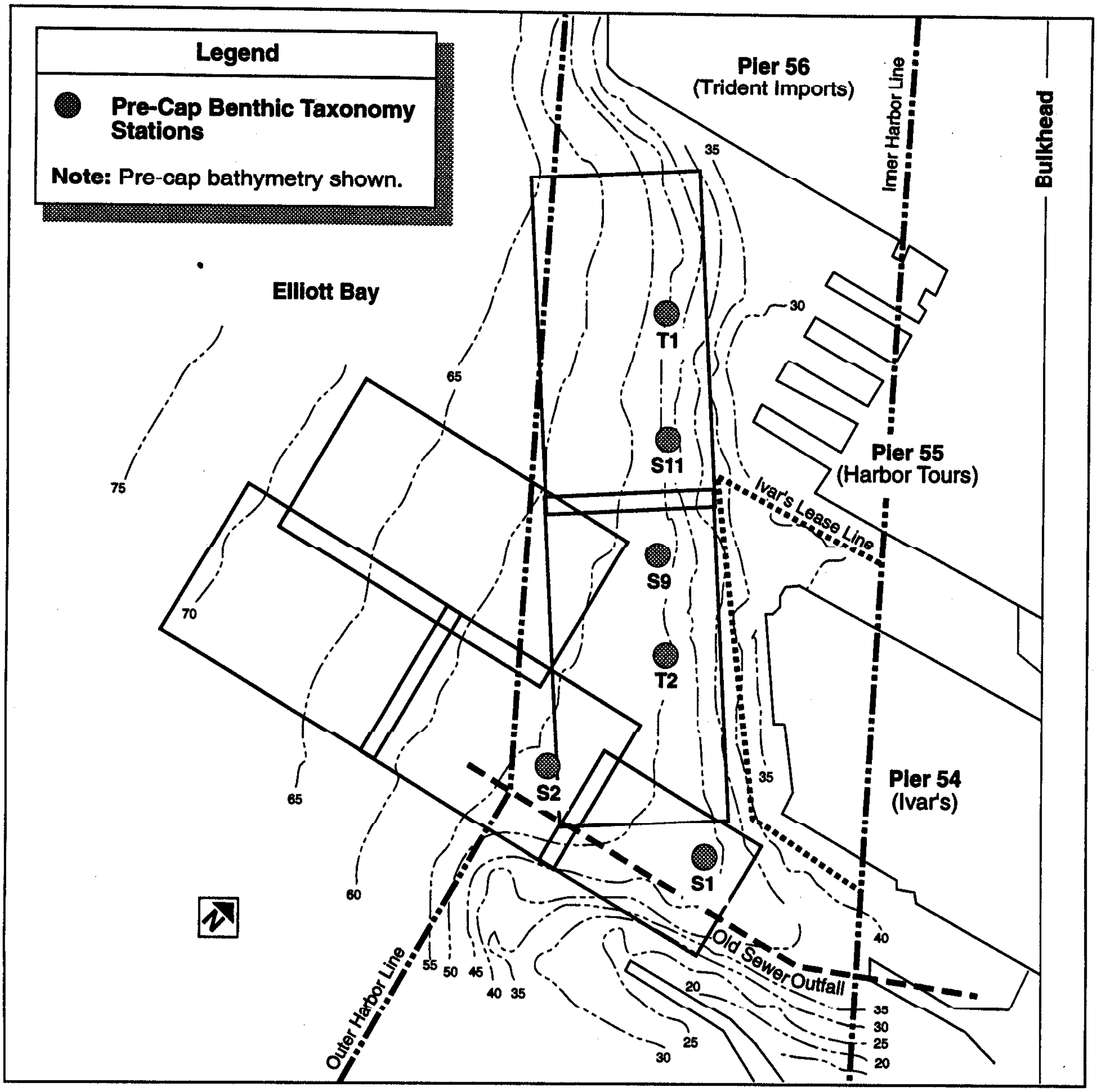
The research team defined six surface sampling stations, which provided spatial coverage over the proposed Pier 53 capping site (see Map 2-2). Five of the six sample stations (S1, T1, T2, S9, and S11) were spaced along the inshore area directly beyond the pier because chemical concentrations were anticipated to be highest inshore. Station S2 is farther offshore, near the end of the old sewer outfall. All sampling stations are at water depths of 45 to 55 feet.

Methods

Subtidal sediment samples were collected with a 0.1-square meter Van Veen grab sampler operated from the research vessel, *R V Liberty*. When possible, three individual grabs were taken at each station. Field personnel then used a stainless-steel "cookie cutter" to remove two to three 2-cm-deep subsamples from the top of each sample. Six subsamples were homogenized in a 4-liter beaker that had been cleaned in a muffle furnace at 500°C. Subsamples were placed in cleaned glass containers and analyzed for metals, organic chemicals, particle size distribution, and total organic carbon.

Results

Complete sediment chemistry values are included in Appendix B; detected chemicals appear in Table 2-2.



Map 2-2. 1992 Sampling Stations

Organics. The Metro laboratory analyzed the sediment samples for 97 organic chemicals and reported the results in parts per billion (ppb). In all, there were 17 organic compounds detected at the pre-cap sample stations. Higher dry-weight values were generally found at Station S1. The highest number of detected compounds (17) were also found at Station S1. Concentrations varied among the stations and showed no pattern of change in concentrations along the shore.

Pier 53 Pre-Cap Sediment Study: 1992

TABLE 2-2. Detected Chemicals at Pre-Cap Sample Stations						
Station:	**S1**	**S2**	**S9**	**S11**	**T1**	**T2**
Sample #:	**9200294**	**9200295**	**9200299**	**9200297**	**9200298**	**9200296**
Date:	**2/26/92**	**2/26/92**	**2/27/92**	**2/26/92**	**2/27/92**	**2/26/92**
% Solids:	**39.00**	**39.00**	**44.00**	**48.00**	**44.00**	**39.00**
Compound Name ***(ppb)***	**Values in Dry-Weight**					
Acenaphthylene ***LPAH***	400	300	T 300	T 200	T 300	<200
Acenaphthene	330	<200	<100	T 200	<100	T 300
Fluorene	590	T 400	T 300	T 200	400	T 300
Phenanthrene	2,600	1,900	1,800	1,100	2,000	1,900
Anthracene	2,100	1,700	1,400	750	1,400	1,200
Fluoranthene ***HPAH***	5,100	4,100	4,100	2,900	3,400	3,300
Pyrene	5,100	4,400	3,600	3,500	3,200	2,500
Benzo (a) anthracene	3,300	2,400	2,200	1,400	2,100	1,700
Chrysene	5,400	4,100	4,500	2,300	3,400	2,400
Bis (2-ethylhexyl) phthalate	BT 1,200	BT 1,100	BT 710	BT 750	BT 570	BT 540
Benzo (b) fluoranthene	5,400	4,900	5,200	3,500	4,300	3,600
Benzo (k) fluoranthene	3,100	2,800	2,500	1,300	1,500	1,500
Benzo (a) pyrene	3,800	3,100	2,700	2,100	3,000	1,900
Indeno (1,2,3-cd) pyrene	3,600	1,400	1,100	940	1,100	T 800
Benzo (g,h,i) perylene	2,800	1,000	840	940	1,200	T 700
Aroclor-1254 ***PCB***	490	1100	270	230	250	330
Aroclor-1260	590	590	250	290	220	330
Metals ***(ppm)***						
Aluminum	17,000.	15,000.	16,000	11,000.	19,000.	14,000.
Antimony	G <8	G <8	G <7	G <6	G <7	G <8
Arsenic	26	26	23	17	45	21
Beryllium	B 0.51	B 0.51	B 0.45	B 0.21	B 0.45	B 0.51
Cadmium	2.6	9.0	1.6	1.3	1.4	2.1
Chromium	74	110	55	38	55	51
Copper	150	150	170	90	220	130
Iron	25,000	21,000	NA	16,000	25,000	21,000
Lead	E 280	E 220	E 320	E 140	E 300	E 230
Manganese	240	200	NA	170	270	200
Mercury	EL 1.9	EL 2.6	EL 2.1	EL 1.8	EL 2.3	EL 3.8
Nickel	36	33	34	23	36	28
Selenium	<10	<10	<10	<10	<10	<10
Silver	E 7.7	E 10	E 7.7	E 4.2	E 4.5	E 5.1
Thallium	<50	<50	<50	<40	<50	<50
Zinc	280	330	210	130	250	210

B - Result corrected for blank contamination. E - Estimate G - Estimate is greater than value shown.
L - Value is less than maximum shown. NA - Not available T - Detected below quantification limits.
For more information on qualifiers see Appendix B.

Concentrations were elevated along the abandoned untreated sewer outfall pipeway and off the end of Pier 54. Fluoranthene, pyrene, chrysene, and benzo(b)fluoranthene were found in the highest concentrations. Phenanthrene and anthracene were the most abundant low molecular weight polycyclic aromatic hydrocarbons (LPAHs) in all the samples.

The PCBs Aroclor-1254 and 1260 were found in all the samples. The highest concentration of Aroclor 1260 was 590 ppb at both Stations S1 and S2. The highest concentration of Aroclor 1254 was 490 ppb at Station S1.

Figure 2-1 shows the relative chemical concentrations of the six pre-cap stations. In the 1992 samples, like the 1988-89 samples, chemical concentrations were higher inshore and decreased offshore. The 1988 Stations 18 and 19 were similar to the 1992 stations S1 and S2; in both cases the inshore station was slightly higher in organics concentrations. This supports observations that high chemical values extend beyond the end of Pier 54. Stations S1 and S2 had the highest levels of contamination and were likely influenced by both the contamination associated with the end of Pier 54 and the old abandoned sewer outfall.

Moving away from the outfall area, concentrations drop off slightly but remain elevated along the waterfront to the north. Station S11 had the lowest concentrations of detected chemicals for the six stations, while Station T2 had the second lowest concentrations. It appears that Station S11 had the lowest chemical values because it has less fines (clay) present based on lower aluminum and iron concentrations and a higher percentage of solids (48 percent). Generally, clay will have higher chemical concentrations.

Station S9, located off the end of Pier 54, had the third highest concentrations of the six stations. The station farthest north, T1, had the fourth highest concentrations. There is no consistent concentration gradient among the stations. However, the three stations with the highest concentrations were located offshore from Pier 54, while the two stations off Pier 55 were lower in concentration.

Metals. The Metro Environmental Laboratory analyzed the sediment samples for metals and reported them in parts per million (ppm). A total of 16 metals appear in Table 2-2.

Station S11 had the lowest concentrations for each metal, probably because this sample had the least clay. Station S1 had the highest overall metals

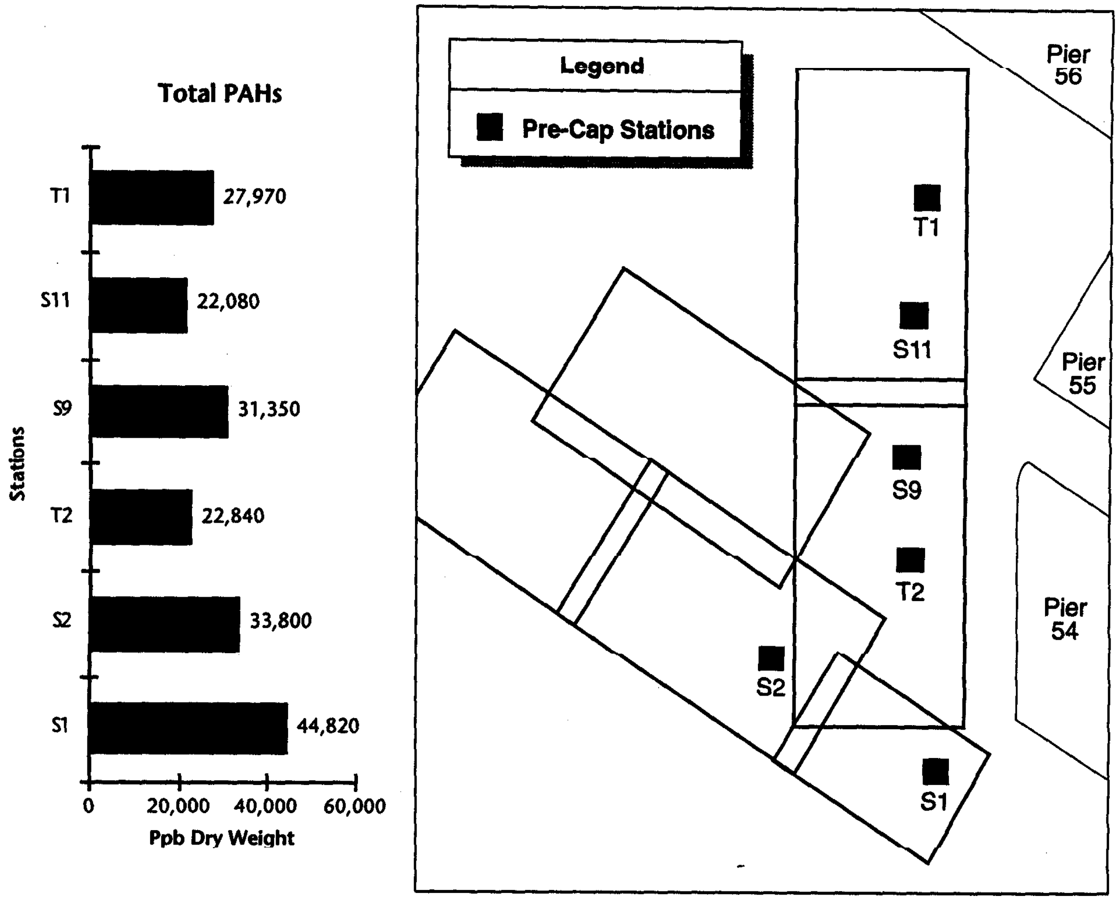


Figure 2-1. Total PAHs at Pre-Cap Sampling Stations

concentrations. The same pattern held for the metals as for the organics; Stations S11 and T2 had the lowest concentrations and Stations S1 and S2 had the highest concentrations. Station T1, the farthest north, had the third highest concentrations, showing that there was no consistent concentration gradient while moving along shore in the sampling area. However, higher concentrations occurred in the area offshore from Pier 54 than occurred offshore from Pier 55.

Comparison to State Sediment Standards. The sediment samples were analyzed for total organic carbon for comparison to the state sediment standards. The state sediment standard list of 47 chemical parameters includes eight metals for comparison in ppm dry-weight, seven organic compounds for comparison in ppb dry-weight, and 32 organic chemicals that are normalized using the total organic carbon content of the sample (see Table 2-3).

TABLE 2-3. State Sediment Standard Comparison at Pre-Cap Sample Stations

Station:	Standards		S1	S2	S9	S11	T1	T2
Sample #:	Sediment Quality Standards	Cleanup Screening Levels	9200294	9200295	9200299	9200297	9200298	9200296
Date:			2/26/92	2/26/92	2/27/92	2/26/92	2/27/92	2/26/92
% T.O.C. dry:			4.7	4.7	4.4	5.3	4	4.2
% Solids:			39	39	44	48	44	39
Naphthalene *LPAHs ppm OC*	99	170	< 13	< 13	< 14	< 9.4	15	< 14
Acenaphthylene	66	66	T 9	T 6	T 7	T 4	T 8	< 4.8
Acenaphthene	16	57	7	< 4.3	< 2.3	T 4	< 2.5	T 7
Fluorene	23	79	13	T 9	T 7	T 4	10	T 7
Phenanthrene	100	480	55	40	41	1.9	50	45
Anthracene	220	1,200	45	36	32	14	35	29
2–Methylnaphthalene	38	64	< 13	< 13	< 14	< 9.4	< 15	< 14
Total LPAHs	370	780	155	121	117	46.7	136	120.8
Fluoranthene *HPAHs ppm OC*	160	1,200	110	87	93	55	85	7.9
Pyrene	1,000	1,400	110	94	82	66	80	60
Benzo (a) anthracene	110	270	70	51	50	26	53	40
Chrysene	110	460	110*	87	100	43	85	57
Total benzo fluoranthenes	230	450	180	160	175	91	150	120
Benzo (a) pyrene	99	210	81	66	61	40	75	45
Indeno (1,2,3-cd) pyrene	34	88	77	30	25	18	28	T 20
Dibenzo (a,h) anthracene	12	33	< 15*	< 15*	< 14*	< 9.4	< 15*	< 17*
Benzo (g,h,i) perylene	31	78	60*	21	19	18	30	T 20
1,2–Dichlorobenzene	2.3	2.3	< 4.3**	< 4.3**	< 4.5**	< 3.8**	< 5**	< 4.8**
1,4–Dichlorobenzene	3.1	9	< 4.3*	< 4.3*	< 4.5*	< 3.8*	< 5*	< 4.8*
1,2,4–Trichlorobenzene	0.81	1.8	< 4.3**	< 4.3**	< 4.5**	< 3.8**	< 5**	< 4.8**
Hexachlorobenzene	0.38	2.3	< 4.3**	< 4.3**	< 4.5**	< 3.8**	< 5**	< 4.8**
Total HPAHs	960	5,300	628	596	605	366	586	369.9
ppm OC								
Dimethyl phthalate	53	53	< 2.1	< 2.1	< 2.3	T 4	< 2.5	< 4.8
Diethyl phthalate	61	110	< 8.5	< 8.5	< 9.1	< 5.7	< 10	< 9.5
Di–n–butyl phthalate	220	1,700	B < 8.5	B < 8.5	B < 9.1	B < 5.7	B < 10	B < 9.5
Butyl benzyl phthalate	4.9	64	< 4.3	< 4.3	< 4.5	< 3.8	< 5*	< 4.8
Bis (2-ethylhexyl) phthalate	47	78	BT 30	BT 20	16	BT 10	BT 10	BT 10
Di–n–octyl phthalate	58	4,500	< 4.3	< 4.3	< 4.5	< 3.8	< 5	< 4.8
Dibenzofuran	15	58	< 8.5	< 8.5	< 9.1	< 5.7	< 10	< 9.5
Hexachlorobutadiene	3.9	6.2	< 8.5**	< 8.5**	< 4.5*	< 5.7*	< 10**	< 9.5**
N–nitrosodiphenylamine	11	11	B < 8.5	B < 8.5	B < 23**	B < 7.5	B < 10	B < 9.5
Total PCBs	12	65	23*	15*	12*	9.9	12*	16*
Phenol *ppb dry*	420	1,200	<1,000*	<1,000*	<1,000*	<1,000*	<1,000*	< 1,000*
2–methylphenol	63	63	< 400**	< 400**	< 400**	< 300**	< 400**	< 400**
4–methylphenol	670	670	< 400	< 400	< 400	< 300	< 400	< 400
2,4–dimethyl phenol	29	29	< 400**	< 400**	< 400**	< 300**	< 400**	< 400**
Pentachlorophenol	360	690	< 400*	< 400*	< 400*	< 300	< 400*	< 400*
Benzyl alcohol	57	73	< 400**	< 400**	< 400**	< 300**	< 400**	< 400**
Benzoic Acid	650	650	B <1,000**	B <1,000**	B <1,000**	B <1,000*	B <1,000**	B < 1,000**
Arsenic *Metals ppm dry*	57	93	26	26	23	17	45	21
Cadmium	5.1	6.7	2.6	9**	1.6	1.3	1.4	2.1
Chromium	260	270	74	110	55	38	55	51
Copper	390	390	150	150	170	90	220	130
Lead	450	530	E 280	E 220	E 320	E 140	E 300	E 230
Mercury	0.41	0.59	EL 1.9**	EL 2.6**	EL 2.1**	EL 1.8**	EL 2.3**	EL 3.8**
Silver	6.1	6.1	E 7.7**	E 10**	E 7.7**	E 4.2	E 4.5	E 5.1
Zinc	410	960	280	330	210	130	250	210

B - Result corrected for blank contamination.
G - Estimate is greater than value shown.
**Exceeds Marine Sediment Cleanup Screening Levels.
*Exceeds Marine Sediment Quality Standards.

E - Estimate
T - Detected below quantification limits.
For further information on data qualifiers see Appendix B.

For the organic chemicals, four parameters exceeded the SQS but not the CSLs: indeno (1,2,3-cd) pyrene, dibenzo (a,h) anthracene, benzo (g,h,i) perylene, and total PCBs. All four compounds exceeded the SQS at Station S1, PCBs exceeded at all stations except S11, and chrysene exceeded at S9.

In 71 cases, detection limits exceeded at least the SQS. Of the total, 46 detection limits exceeded the CSLs, while the remaining 25 exceeded the SQS. Detection limits for dibenzo(a,h)anthracene exceeded the SQS at five stations. 1-4 dichlorobenzene detection limits exceeded the SQS at all stations, while butyl benzyl phthalate detection limits exceeded the SQS at one station and pentachlorophenol exceeded the SQS at five stations. Detection limits for hexachlorobutadiene exceeded the SQS at two stations and the CSLs at four stations. Detection limits for 1,2-dichlorobenzene, 1,2,4-trichlorobenzene, hexachlorobenzene, 2-methylphenol, 2,4-dimethylphenol, benzyl alcohol, and benzoic acid exceeded CSLs at all stations.

Three metals exceeded the CSLs; cadmium, silver, and mercury. Cadmium exceeded the standards at S2. The next closest concentration level was at Station S1 and it was a decrease by over a factor of three. Silver exceeded the standards at Stations S1 and S2. Station S2 had the highest concentrations of silver. At Stations S11, T1, and T2, silver was present in about half the concentrations of S1 and S2.

Mercury exceeded the CSLs at all stations. The highest concentration was at Station T2, which had the second lowest concentrations of all other metals compared to the other stations. In contrast, S1 had the second lowest concentration of mercury but had the highest overall concentrations of metals. A previous study indicated that concentrations of copper, lead, mercury, and zinc were among the most elevated of the metals detected along the Seattle waterfront. During this study, maximum mercury levels were seen at a few non-adjacent stations superimposed upon the otherwise elevated levels along the waterfront. This pattern suggests that a few local sources were present, possibly in conjunction with a more diffuse source (PTI, Tetra Tech, 1988).

Comparison of 1988-89 and 1992 Sediment Samples

Comparing dry weight concentrations of the 1988-89 sediment samples to the 1992 sediment samples showed noticeable differences between the two years for organics, but no differences for metals. Four stations from similar locations in each study were used to possibly identify area-wide trends. The four station pairs, with the 1988-89 station listed first, were as follows: Station 19 and Station S1; Station 18 and Station S2; Station 43 and Station T2; Station 45 and Station T1.

These comparisons between sampling periods can suggest a trend but cannot yield conclusive results because samples were not taken from exactly the same location. Even if sample collection from the same spot was attempted, differences in chemical concentrations could still be expected based on variability seen in duplicate samples.

Comparisons for four metals, arsenic, antimony, selenium, and thallium, were compromised because analytical methods changed between sampling periods. In 1988-89 the four metals were analyzed using the graphite furnace atomic absorption (GFAA) method. In 1992 the metals were analyzed using the inductively coupled argon plasma spectroscopy (ICP) method. The GFAA technique yielded lower detection limits and made any comparison of these four metals uncertain.

All other metals were analyzed using techniques common to both sampling events, and showed only small differences between events with no consistent pattern of increase or decrease. At each station some metals values would be higher and some lower than the previous sampling. For individual metals, the direction of change was not the same for all stations. With the exception of mercury at Stations T1 and T2, all metal concentration changes were within a range of 10 to 40 percent. The generally small differences in concentrations of metals between the two sets of samples can largely be attributed to differences in location of the sampling stations compared.

Organics values showed a different trend than metals. Three out of the four station pairs had lower concentrations of two LPAH and many HPAH compounds in 1992, by at least a factor of 2 and in some cases as much as a factor of 6.

The station pair with the greatest difference was 43 and T2. All LPAHs were lower in the 1992 sample, ranging from a factor of 2 to 6. All HPAHs were lower by factors ranging from 2 to 5, with most compounds lower by a factor of 4.

The two station pairs 19 and S1 and 18 and S2 had similar changes. The LPAHs fluorene, phenanthrene, and anthracene and all detected HPAHs were lower in the 1992 samples, with many lower by a factor of 2.

The station pair 45 and T1 did not show the differences observed for the other three station pairs. LPAH values varied up and down by 40 percent and HPAH values were similar in concentrations.

The observation that three out of four pairs of stations have substantially lower organic concentrations in 1992 suggests that there may have been an overall reduction of organic values in the area. However, the possibility still remains that the differences in concentrations are due to spatial differences in the paired stations. The three station pairs that showed differences were all in the project area that has the highest values and could reflect the highest concentration gradients.

If a decrease in organic values truly occurred, several factors could have had an influence. Natural accumulation of new cleaner sediment could cause a drop in measured values. However, if this were the cause, the metals values would be expected to have dropped as well.

Another factor that can reduce organic values is natural degradation. Because metals do not degrade, their concentrations would remain the same while organic values would decline over time. It is uncertain whether 3 to 4 years would be enough time to produce the observed decrease.

Another factor that could affect sediment concentrations is a reduction in the influx of organics. A stormwater separation project was completed for the Madison Street basin in 1988 by the City of Seattle. Prior to the separation project, the now-abandoned Madison Street sewer outfall and overflow pipes were still in use as a CSO until 1988, when separate storm drain systems in the Madison Street drainage basin were connected to the newly built Madison Street CSO. The old sewer pipes emptied offshore closer to the sampling stations, whereas the new CSO empties through the sea wall approximately 100 feet to the south of the old pipes. It is possible that there was a reduction in the influx of organics into the study area as a result of decreased CSO volumes and the relocation of the CSO outfall. However, it is unclear why a reduction would occur for organics but not metals.

PRE-CAP BIOLOGICAL TOXICITY STUDY

The monitoring team collected sediment samples on February 26 and 27, 1992 for a biological toxicity test of the Pier 53 sediments. The test sediments were subsamples from the composite samples taken for chemical analysis at the six stations S1, S2, S9, S11, T1, and T2 (see Map 2-2). EVS Consultants conducted the tests, and their report appears in Appendix F. The toxicity test involved exposing amphipods (*Rhepoxynius abronius*) and bivalves (*Mytilus edulis*) to the Pier 53 sediments. Appendix F includes a description of the test methods, the raw data sheets, and statistics.

Methods

Control sediments for both the amphipod and bivalve tests were collected from West Beach, a relatively remote site on Whidbey Island, Washington. A control sediment is collected from the area where the organisms are collected. During a test, very little mortality is expected in a control sediment as it duplicates conditions the organisms had been living in. The control sediment is used to determine the viability of the test organisms and certify the test conditions. A reference sediment was not collected for these tests. A reference sediment is collected from an area that is physically similar to the area of the test sediments but without local pollution influences. A reference sediment is similar in texture to the sediment being tested and can be used to factor out mortality that is caused by sediment grain size and other physical characteristics.

Amphipods. EVS technicians collected test amphipods from West Beach by using a benthic sled. They sieved the amphipods from the sediments, counted them, and then transferred them to clean 20-liter buckets. The amphipods were transported on ice to the EVS laboratory within 8 hours of collection. In the laboratory, the amphipods were acclimatized in fresh seawater before testing.

The day before testing, laboratory personnel measured 2 cm of test sediment into a 1-liter jar and then filled the jar with 800 ml of clean sea water. The jars were fitted with clean plastic lids and aeration lines and left to equilibrate overnight. The following day, each jar was seeded with 20 amphipods. Two clean control jars containing sediment from the amphipod collection site also were seeded with 20 amphipods each. Laboratory personnel checked each jar daily for 10 days to establish trends in mortality and sediment avoidance, and also to gently re-submerge any amphipods that had left the sediment overnight and become trapped by the surface tension at the air/water interface.

Bivalves. The bivalve test consisted of exposing developing mussel larvae to the Pier 53 sediments. On February 27, 1992, EVS laboratory personnel obtained blue mussels from a commercial supplier in California and held them in a static renewal seawater system prior to testing. They then induced the mussels to spawn by placing them in warm water. Once the mussels started spawning, they placed them in individual dishes to continue spawning. Laboratory personnel combined the mussel eggs and sperm to achieve fertilization. The resulting embryos were kept in suspension prior to testing by aeration and frequent agitation with a perforated plunger.

While the mussels were spawning, the laboratory personnel measured 20 grams of Pier 53 sediments into 1-liter polyethylene jars and filled them with 1 liter of clean seawater. The test sediments were then left to settle for 4 hours before they were inoculated with the test larvae. Within 2 hours of fertilization, approximately 30,000 embryos were added to each test container. The test was allowed to proceed undisturbed for 48 hours.

Results

Amphipods. Amphipod toxicity test results are summarized in Table 2-4. Mean survival in the test jars ranged from a low of 17.6 organisms out of 20 (88 percent) to a high of 19.6 (98 percent). Mean survival in the control jar was 19.8 out of 20 (99 percent). Samples S1, S2, and T2 had mean survival rates significantly lower than the control, indicating the sediments may have had a toxic effect. However, the state sediment standards require that survival be less than 75 percent (15 individuals) before the sample is considered to have failed the test.

Bivalves. Bivalve toxicity test results are summarized in Table 2-5. The mean abnormality, or the average number of bivalve larvae that developed abnormally in the test sediments, ranged from 19.6 percent to 35.8 percent. The mean abnormality in the control sediment was 1.2 percent. A negative value for mortality indicated that the number of larvae recovered at the end of the test was greater than the estimated initial density.

TABLE 2-4. Summary of Amphipod Toxicity Test

	Mean Value		
Station	Survival[1]	Avoidance[2]	% Reburial[3]
T1	19.4 ±0.9	0.1 ±0.3	97
T2	18.2 ±1.3*	0.3 ±0.6	89
S1	17.6 ±1.7*	0.3 ±0.5	100
S2	17.6 ±0.5*	0.2 ±0.5	100
S9	19.6 ±0.5	0.2 ±0.4	97
S11	19.0 ±1.2	0.2 ±0.4	96
Pooled Control Sediments	19.8 ± 0.4	0.1 ± 0.3	100

1. n=5 (except for control, n = 10). A value of 20.0 represents 100% survival. Asterisks indicate values significantly different from the control ($P < 0.05$) with respect to survival.
2. Number of amphipods on the surface per jar per day (out of a maximum of 20.0).
3. Percentage of surviving amphipods able to rebury in clean sediment and seawater within 1 hour after a 10-day exposure.
* Values significantly different from the seawater control.

The mean net percent combined mortality (corrected for the seawater control) was 0.6 percent for the control sediment and from 45.6 to 55.5 percent for the test sediments. All six samples had mortality totals significantly higher than the seawater control. Strict comparison to the state sediment standards is not possible, however, because no reference sediment sample was tested. If the mean net percent combined mortality for a reference sediment were less than about 34 percent the test sediment would be ruled toxic. Since Ecology would disqualify a reference sediment with combined mortality this high, these sediments would have failed the test and can be considered to demonstrate an adverse effect.

TABLE 2-5. Summary of Bivalve Toxicity Test

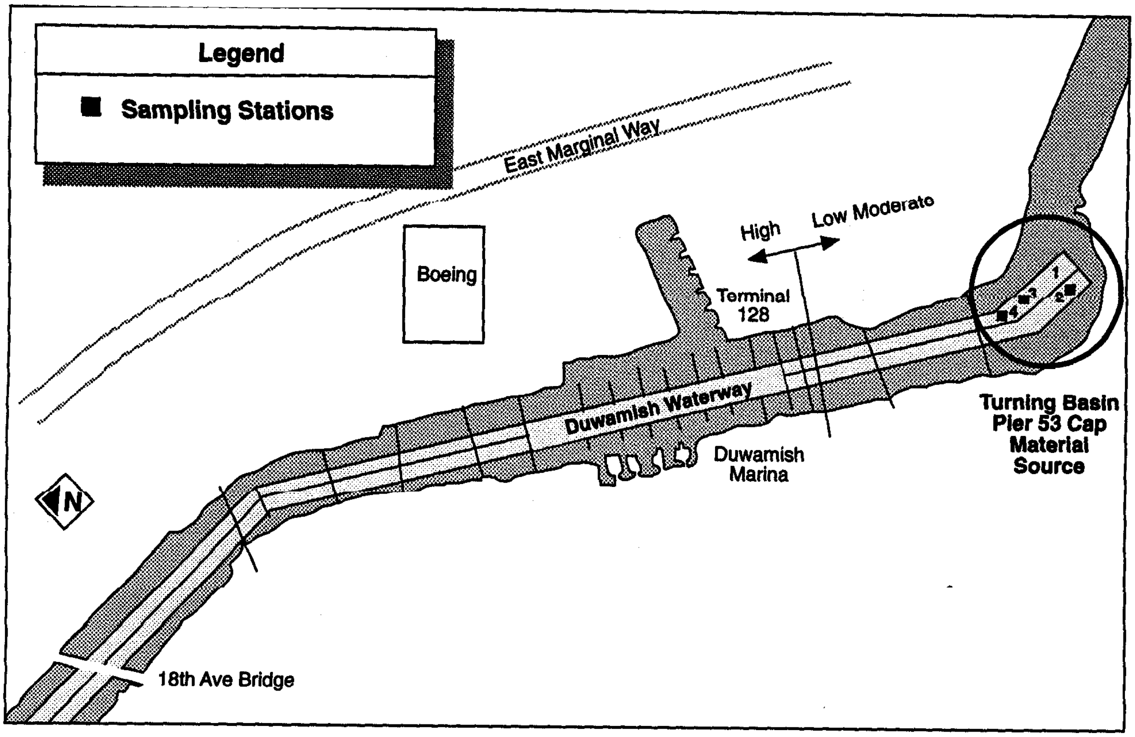
Station	Mean % Abnormality	Mean % Combined Mortality	Mean % Net Combined Mortality
T1	28.2*	43.0*	46.9
T2	26.0*	53.4*	55.5
S1	19.6*	45.5*	47.9
S2	24.2*	48.2*	50.6
S9	35.8*	50.0*	52.3
S11	25.2*	44.3	46.9
Control Sediment	1.2	-4.2	0.6
Control Seawater	0.8	-4.8	0

* Values significantly different from the seawater control.

DUWAMISH RIVER SEDIMENT STUDY

The clean sand used for the Pier 53 cap came from the Duwamish River upper waterway (see Map 2-3). As part of the routine maintenance of keeping the Duwamish waterway open and navigable, the Corps dredges sediment buildup in the upper waterway and barges it to the PSDDA open water disposal site in Elliott Bay. For sediment to be eligible for disposal at the PSDDA disposal area it must be tested and pass PSDDA disposal guidelines for dredged sediments. All testing concerning the suitability of the dredged material for the Pier 53 capping project was based on the PSDDA standards for unconfined, open-water disposal of dredged material.

The PSDDA testing procedures include sampling, testing, and test interpretation (for example, against disposal guidelines) of dredged material proposed for unconfined, open-water disposal in Puget Sound (Evaluation Procedures Technical Appendix PSDDA 1988b). These procedures were developed



Map 2-3. Duwamish River Sampling Stations

by an interagency committee, the Evaluation Procedures Work Group (EPWG), composed of representatives from each of the PSDDA agencies: Ecology, Corps, EPA, and DNR. Representatives from other federal and state agencies, Puget Sound ports, Indian tribes, and the public also assisted EPWG. The goal of PSDDA is to provide publicly acceptable guidelines for environmentally safe, unconfined, open-water disposal of dredged material, and to provide Puget Sound-wide consistency and predictability in decisions concerning dredged material disposal.

The sampling procedure developed by PSDDA to evaluate sediments is tiered. Tier 1 is an evaluation of the project area to determine if the sediments may contain chemicals of concern. If sediments are suspected to contain chemicals of concern, then chemical testing is required (Tier 2). Biological testing (Tier 3) is generally required only if chemical concentrations fall within a certain range above a screening level and below a maximum allowable level (Ecology 1989).

With the Pier 53 sediment capping project in mind, the Corps identified specific sediment sampling sites in the turning basin of the upper Duwamish River where historically the cleanest sediments have occurred and where they have been obtained for use as capping material (Sumeri 1991, Sumeri and Romberg 1991). In the turning basin area, 10 to 15 feet of sand accumulates approximately every 2 years. To test the sediments that are to be dredged, vertical cores must be taken through the deposit to adequately characterize the sediment's chemical makeup. The Corps employed SAIC to assist in sediment sampling and to analyze the sediment samples. A portion of the Duwamish River sampling report submitted by SAIC is included in Appendix E.

Methods

The Corps' shore-based survey crew positioned the sampling vessel at the sampling station by using an electronic distance measuring device. The survey crew used local Corps benchmarks, established from U.S. Coast and Geodetic Survey benchmarks, for horizontal control. Over the ship's radio, surveyors directed the captain to the desired location. Once over the station site, surveyors recorded the range and azimuth, and directed the crane operator to quickly lower the sediment core sampler.

The Corps sampled the Duwamish sediments by using a crane-operated vibracore aboard the vessel *Puget*. A vibracore is a metal tripod stand that supports a pneumatic-driven vibrating device positioned on top of a coring device. The coring device is a hollow steel pipe that is fitted with a Lexan® tube for each sample. Vibracore operators lowered the device into position and turned on the air compressor. The vibrator vibrated the coring tube into the sediment. After the core sampler reached the appropriate depth—in this case 14 feet—the operators turned off the air supply, and hoisted the vibracore onto the deck of the sampling vessel for processing.

On board the vessel, field personnel removed the Lexan tube containing the sample and placed it on a cutting trough. They gently drained excess seawater from the top of the Lexan tube, measured the length of the core sample, scored the tube with a power saw, and cut it open with utility knives, taking care not to introduce Lexan shavings into the sample. The technicians then sliced the core sample lengthwise to expose the center of the sample.

At this point, sediment was collected from the portion of the cores representing the surface of the river bottom and going down to a depth of 4 feet. In this way, the upper sections of Cores 1, 2, 3, and 4 were sampled to make the composite sample, DRC1. Next, they collected sediment from the portion of the core starting at a depth of 4 feet and going down to a depth of 14 feet. The deeper sections of Cores 1, 2, 3, 4, 5, and 6 were sampled to make the composite sample, DRC3.

Results

Table 2-6 compares detected chemicals in the Duwamish sediments with PSDDA standards. Sample DRC1, representing the near-surface sediments from the surface to a 4-foot depth, passed all the PSDDA Screening Level (SL) values. Since the sample passed PSDDA SL tests, further biological testing was not required and the sediments could be judged suitable for open water disposal or for sediment capping.

In Sample DRC3, representing the deeper sediments from the 4 to 14 foot depth, there were 16 detected organic chemicals. One compound, 4-methylphenol, at 140 ppb dry-weight, exceeded one PSDDA SL value. However, this is still below the state sediment standard value of 670 ppb dry-weight for 4-methylphenol. Technicians prepared a new composite sample, DRC3A, composed of Cores 1, 2, 3, and 4, that more closely characterized the sediments that were being dredged for the Pier 53 capping project. Composite DRC3A passed further bioassay testing involving amphipods and the *Neanthes* worm 10-day acute test, but failed PSDDA disposal guidelines for the echinoderm sediment larval test. The apparent echinoderm test failure was judged by the PSDDA agencies to be due to high ammonia levels, which have been implicated in echinoderm larvae mortalities (David Kendall, personal communication.). This result was ruled invalid, however, because it was not clear where the ammonia came from. The assumption was that it could have been generated by bacteria during sample storage prior to testing. Since the sample DRC3A passed the amphipod and *Neanthes* tests, the sediment was approved for use in sediment capping.

Table 2-6. Detected Chemicals in the Duwamish Sediments

Sample #:	PSDDA Standards		DRC1	DRC3
Date:	Screening	Maximum	8/6/91	8/6/91
% Solids:	Levels	Levels	81.2	69.7
Organics (ppb)	Values In Dry-Weight			
LPAH				
Phenanthrene	320	3200	26	57
HPAH				
Fluoranthene	630	6300	23	82
Pyrene	430	7300	21	100
Benzo(a)anthracene	450	4500	< 16	29
Chrysene	670	6700	< 16	50
Benzo(b)fluoranthene	800	8000	< 16	46
Benzo(k)fluoranthene	800	8000	< 16	38
Benzo(a)pyrene	680	6800	< 16	36
Indeno(1,2,3-cd)pyrene	69	5200	< 16	23
Phthalates				
Bis(2-ethylhexyl)phthalate	3100		< 16	180
Phenols				
Phenol	120	1200	< 16	36
4-Methylphenol	120	1200	< 16	140*
Pesticides and PCBs				
DDD	6.9	69	< 0.8	3.8
Aldrin	10		0.9	1.3
Lindane	10		< 0.5	1.1
A-1260			< 8	28
Metals				
Antimony	20	200	0.58	1
Arsenic	57	700	5.2	9.1
Cadmium	0.96	10	0.06	0.57
Copper	81	810	16	43
Lead	66	660	18	27
Mercury	0.21	2	0.158	0.096
Nickel	140		18	28
Silver	1.2	5	< 0.07	0.75
Zinc	160	1600	78	120

*Exceeds screening levels

SECTION 3

CAP PLACEMENT

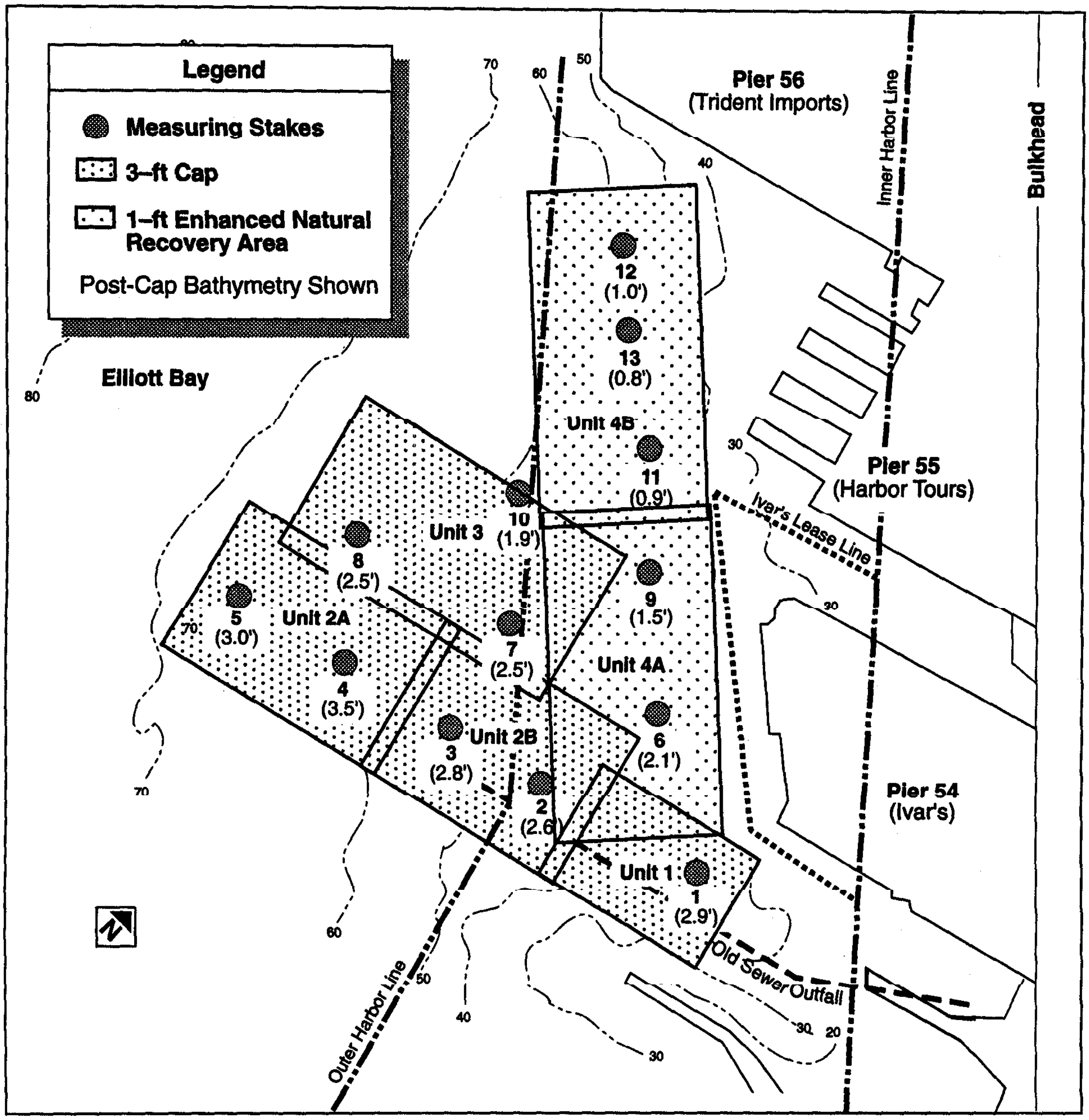
After a thorough study of the Pier 53 site and the capping methodology, the cooperating agencies agreed to cap the contaminated sediments with clean sand delivered by barge from the Corps' dredge site in the Duwamish River. This section describes how the capping material was placed and how it was measured. Also described is the sediment-profile camera survey, which documented the outer boundary of where the capping sands settled.

MEASURING STAKES

Before the sediment was placed, the Corps' project engineer divided the capping area into six working units (see Map 3-1). Metro then directed contract divers to install from one to three bottom stakes and settling plate assemblies in each working unit for a total of 13 stakes to measure cap thickness during and after cap placement. The stakes were 13 to 18 feet long, 1-inch-diameter steel pipes, pounded 8 to 13 feet into the bottom by a diver, with 4.81 to 4.9 feet left exposed. Settling assemblies are made of a 16-inch-diameter plate sitting horizontally on the pre-cap seafloor, attached to a vertical 4-inch diameter PVC-plastic cylinder long enough to remain exposed after capping (see Figure 3-1). The settling plate assembly was mounted over the exposed length of each stake and could slide down the stake as the contaminated sediments were compressed under the weight of the overlying cap. A metal clamp fastened to the stake marked the position of the PVC cylinder before capping. Settling measurements were taken from the bottom edge of the metal clamp.

Assuming that the deeply buried stake remains stationary, the distance between the bottom edge of the clamp and the top of the cylinder is a direct measurement of settling. Cap thickness was determined by measuring the length of plastic pipe exposed above the cap, then subtracting the total length of the plastic pipe measured before capping. Using a surveyor's rod, divers measured both stake height and settlement at each of the 13 stakes soon after capping and again annually.

Measuring Stakes



Map 3-1. Barge Tracks and Measuring Stakes

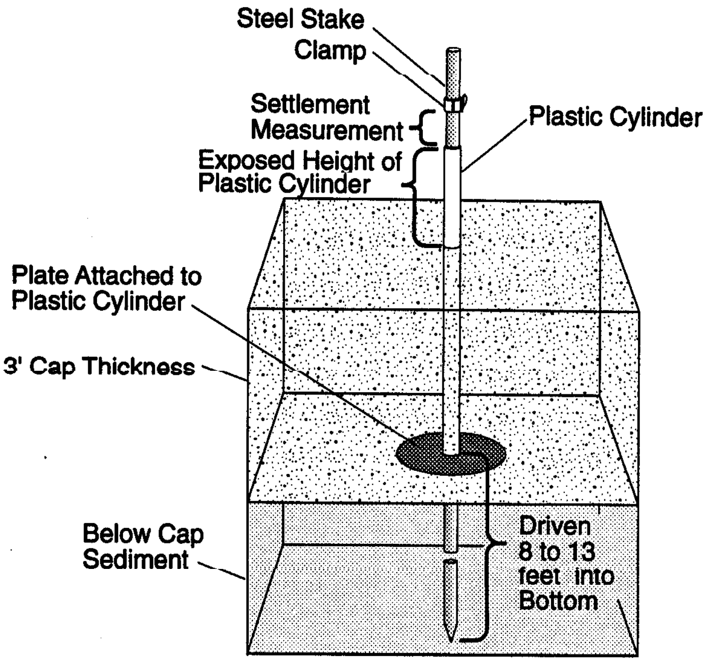


Figure 3-1. Measuring Stake Assembly

SEDIMENT PLACEMENT

The Corps and its contractor placed the sediment cap at the Pier 53 site by using the proven method of slowly releasing the sand onto the desired location with a bottom-dump barge. A total of 10 barge loads of sand were spread for this project. Cost and available equipment were major factors in the decision of how to place the sediment cap. The bottom-dump sand spreader system applies a large amount of sand over a large area at one time, cutting time spent in the application process and therefore cost. Another advantage of the system is that it eliminates the need to transfer the sediment from the transporting barge to the bay bottom with a crane. With careful planning, and because the Corps had already paid the cost of dredging and moving the dredged material, placing the cap was only $2.05 per cubic yard more expensive than dumping the sand in open water. The additional cost for capping, $41,595, broke down as follows: hydrographic survey $19,172, contract $17,828, and supervision and administration of contract $4,595. The additional cost was paid by the City of Seattle under a working agreement with the Corps.

Sediment Placement

The Corps had developed and gained experience with the capping method of sprinkling sand from a bottom dump barge during two previous projects in 1984 and 1990. This method has proven to be adequately accurate as well as cost effective. At the Denny Way capping project in March 1990, the Corps, using a split-hulled bottom dump barge, placed 20,000 cubic yards of clean sand on 3 acres of contaminated bottom sediments. The capping layer was uniform and achieved maximum coverage of the bottom sediments with the highest toxic concentrations, while avoiding kelp beds on the shore side of the cap.

For the Pier 53 project, the sediment capping crew used a seven-compartment, bottom dump barge designed for hauling dredge material. Hydraulically operated bottom-opening doors controlled the emptying of each compartment (see Figure 3-2). The Corps and the contractor were able to test this particular barge during the disposal of other Duwamish sediments at the Elliott Bay open water disposal site. The contractor provided additional hydraulic valves to allow the operator to open each of the compartments slowly and equally.

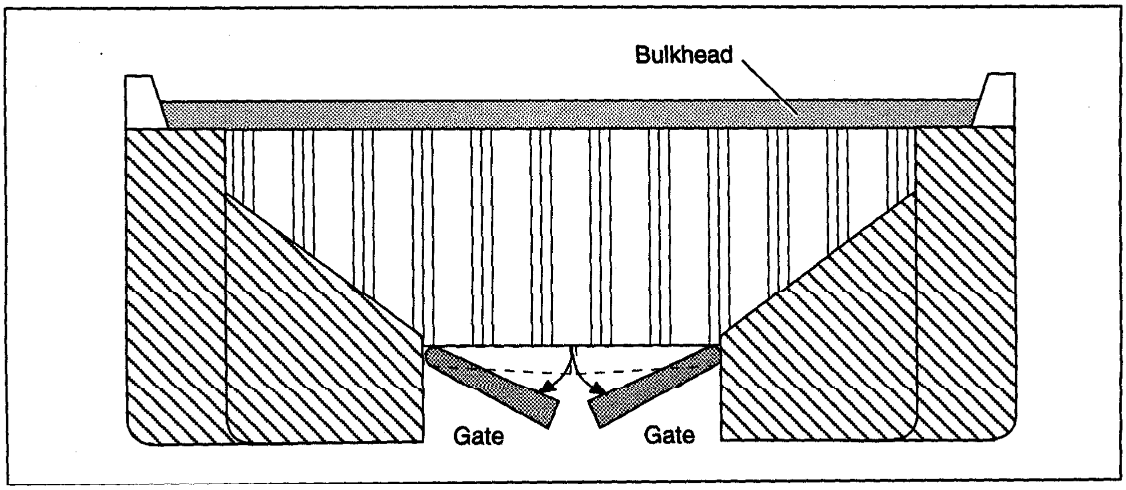


Figure 3-2. Cross Section of Seven-Compartment Barge

Two tugboats were used in cap placement. One tug pushed the barge to the Pier 53 site. At the capping site, the capping crew positioned the second tug perpendicular to the barge in the middle (see Figure 3-3). The tug in the middle pushed the barge sideways, providing the propulsion. The tug at the stern, pushing and pulling, provided steerage. As the barge was pushed sideways, the barge operator slowly released the sand in a 148-foot-wide-swath. The resulting rectangular-shaped barge tracks are shown in Map 3-1.

The Corps and contractor guided the barge into place and monitored the rate of sand deposition with the Corps' laser-range-azimuth positioning system and computer system that received signals from modified radio-transmitting tide gauges. The Corps' survey boat, with an onboard computer, was tied alongside the steering tug. The Corps' crew provided the tugboat operator with a hard-wired monitor showing the barge's position over the capping site, as well as the barge's speed and the amount of sand being released. The tugboat operator was able to accurately position the barge, and by varying the tug speed, control the amount of sand being deposited. This was accomplished by a shore-based laser tracking a prism on the barge. The survey boat's computer then calculated the position according to the known angle to a reference point on shore and the barge distance from the on-shore survey crew (see Figure 3-3). The Corps uses the laser-range-azimuth positioning system for its hydrographic surveying and did not need to modify the equipment.

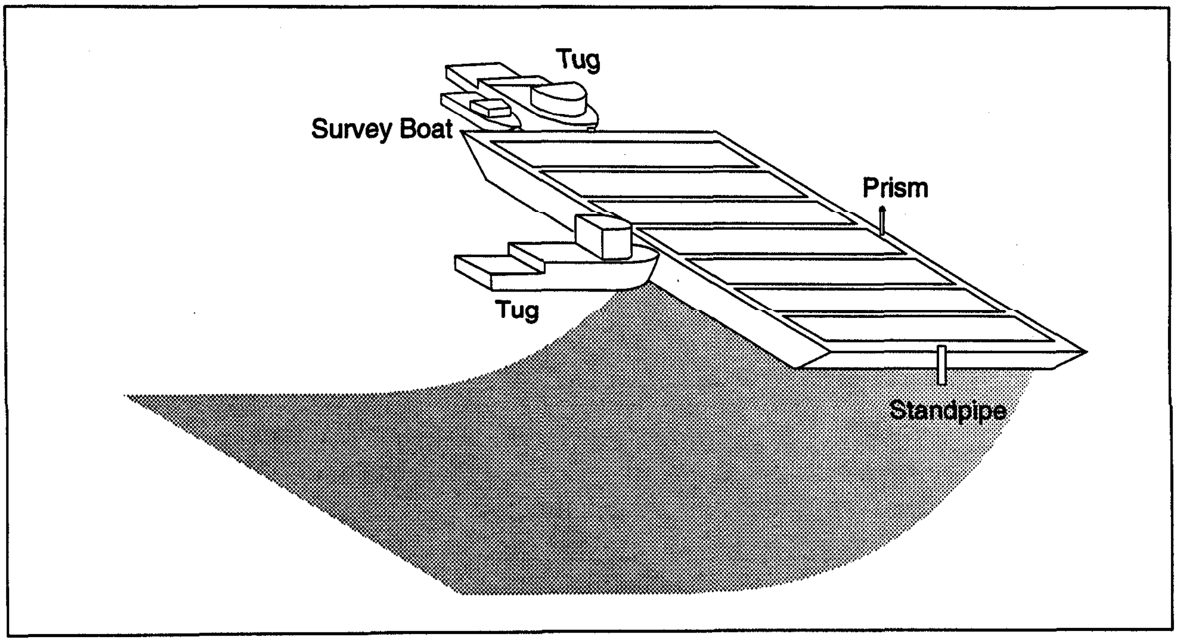


Figure 3-3. Barge Maneuvering

The capping crew monitored the rate of sand deposition with modified tide gauges that measured the change in barge draft. Corps engineers mounted one pressure transducer from Hazen radio-transmitting tide gauges in a steel standpipe at the center of each end of the barge (see Figure 3-4). The tide gauges were speeded up to send radio signals every 2 to 2.5 seconds; normally, tide gauges transmit signals every 5 to 20 minutes. The crew used government radio frequencies so as not to disrupt local communications. To prevent interference between the two gauges, each required a single radio frequency. The radio signals entered the hydrographic survey Hewlett-Packard 300 microprocessor onboard the survey boat via two radio receivers and two RS-232C ports. The capping crew modified the hydrographic survey program to read the tide gauge data instead of the depth sounder data. The computer calculated the average change in barge draft combined with the rate of change in horizontal barge position to produce the theoretical rate of sand deposition along the barge track. The computer monitor configuration provided graphic representation to the tugboat operator on the barge position, theoretical rate of sand deposition, speed, time, draft, station, range, and other information. Programming for this integrated system was developed for the Denny Way capping project with financial support from the Corps' Waterways Experimental Station in Vicksburg, Mississippi. Programming was by Gehagen and Bryant, Tampa, Florida.

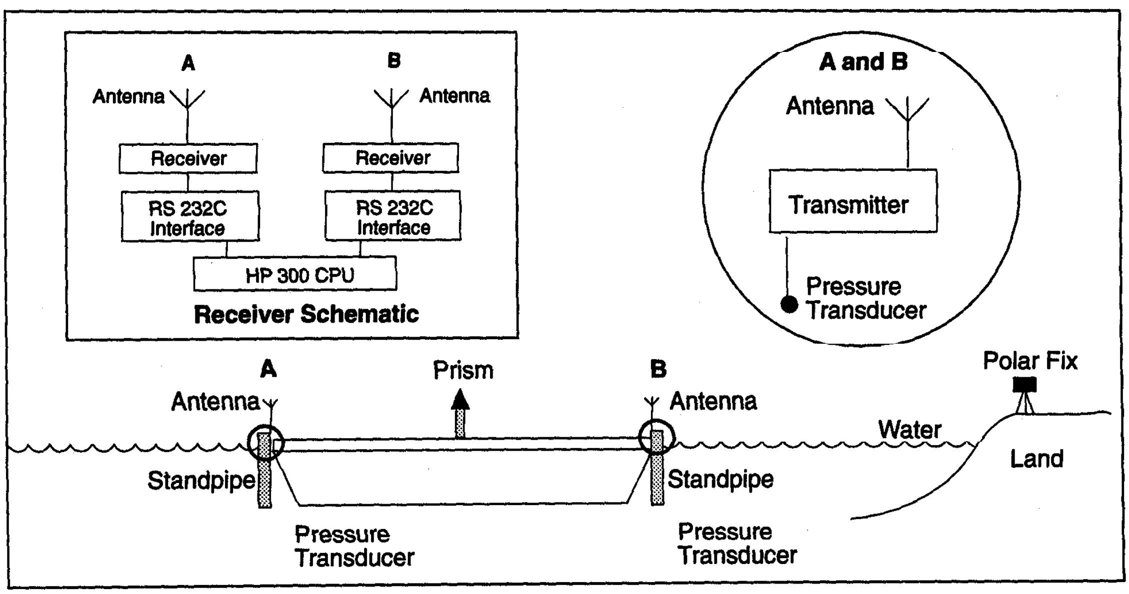


Figure 3-4. Sand Spreader System

CAP THICKNESS

By March 18, the capping crew had covered each of the six working units with at least one barge load of sand. The six barge tracks shown in Map 3-1 had the following designations: Unit 1, 2A, 2B, 3, 4A, and 4B. A diver measured the stakes in each working unit and verified that Units 2A, 2B, and 3 needed more material to make the cap the desired thickness (see Table 3-1). The last three barge dumps completed the cap and stakes were measured again to obtain the final depth.

TABLE 3-1. Cap Thickness: Stake Measurement

Unit	Stake#	Original Stake Height (Feet)	March 18, 1992		Desired Depth (Feet)	March 24, 1992	
			Exposed Stake Height (Feet)	Cap Depth (Feet)		Exposed Stake Height (Feet)	Cap Depth (Feet)
1	1	4.90	2.2	**2.7**	*3.0*	2.0	**2.9**
2A	4	4.90	2.85	**2.05**	*3.0*	1.4	**3.5**
2A	5	4.90	3.1	**1.8**	*3.0*	1.9	**3.0**
2B	2	4.90	3.0	**1.9**	*3.0*	2.3	**2.6**
2B	3	4.90	3.4	**1.5**	*3.0*	2.1	**2.8**
3	7	4.90	3.45	**1.45**	*3.0*	2.4	**2.5**
3	8	4.90	3.45	**1.45**	*3.0*	2.4	**2.5**
3	10*	4.90	3.9	**1.00**	*3.0*	3.0	**1.9**
4A	6	4.90	3.05	**1.85**	*1.0*	2.8	**2.1**
4A	9	4.90	3.6	**1.30**	*1.0*	3.4	**1.5**
						May 28, 1992	
4B	11	4.90	4.0	**0.9**	*1.0*	4.0	**0.9**
4B	12	4.90	3.9	**1.0**	*1.0*	3.9	**1.0**
4B	13	4.81	4.0	**0.81**	*1.0*	3.9	**0.8**

* Stake is located on the edge of a barge track so the anticipated depth would be less than 3 feet.

Cap Thickness

Cap thickness was determined by knowing the original stake height as constructed and then subtracting the amount of stake still exposed after cap placement. After each working unit received at least one barge load, the diver measured the amount of stake exposed above the sediments using a surveyors staff with a standard 1-foot scale divided into tenths. This measurement was recorded as the March 18 stake height. After all the sediment was placed, the diver took final measurements of the cap thickness at Stakes 1 through 10 on March 24 and at Stakes 11, 12, and 13 on May 19, as reported in Table 3-1.

Enhanced Natural Recovery Area

The enhanced natural recovery area, Units 4A and 4B, is an experimental 1-foot-thick sand covering designed to provide a clean substrate for marine life, allow toxicants to naturally degrade, and cause minimal reduction in navigation depths. The two units that compose the area were spread with one barge load of sand each. Unit 4B is close to being 1 foot thick and Unit 4A is a little thicker than 1 foot.

Measurements at all three stakes in Unit 4B were fairly uniform, ranging from 0.8 to 1.0 foot (Table 3-1). Measurements at Stakes 6 and 9 show Unit 4A to be thicker than intended. The likely cause of the added thickness is that two of the 3-foot units overlap a part of Unit 4A west of Stakes 6 and 9. Sediment probably drifted onto Unit 4A as material settled to the bay floor during placement of the thicker cap, because the thickness at Unit 4A increased by 0.2 to 0.3 feet after the last two barge loads were spread at the adjacent units. Table 3-2 shows that the adjacent working units, 2B and 3, are thinner than their calculated depth.

Three-Foot Cap

The 3-foot-thick cap was designed to isolate contaminated bottom sediments from the marine environment. Based on the types of benthic infauna living in Elliott Bay bottom sediments, a 3-foot cap of sediment should effectively prevent animals from digging through the layer and into the contaminants below. The Fisheries Research Institute, University of Washington, under contract to the Navy, attempted to document the burrowing depth limits for the burrowing shrimp *Axiopsis spinulicauda* using Kasten cores collected to a sediment depth of approximately 6-10 feet in Port Gardner. While the study was not exhaustive, and should only be considered a preliminary evaluation of burrowing depths, it documented burrow depths of less than 0.5 meters for this species. The study showed no evidence of biogenic activity, including burrow structures of any kind (for example, from *Molpadia* etc.), deeper than 0.72 meters (David Kendall, Corps, personal communication, October 13, 1993).

TABLE 3-2. Calculated and Actual Cap Thickness

Unit	Date	Cubic Yards	Calculated Depth (feet)	Actual Depth (feet)
1	3/14/92	2199	3.6 total	Stake #1—2.9
2A	3/13/92	2142	1.88	
2A	3/16/92	2214	1.94	
2A	3/21/92	2262	1.99	Stake #4—3.5
		6618 total	5.81 total	Stake #5—3.0
2B	3/12/92	2241	1.88	
2B	3/19/92	2283	1.92	Stake #2—2.6
		4524 total	3.8 total	Stake #3—2.8
3	3/15/92	2199	1.4	Stake #7—2.5
3	3/20/92	2242	1.46	Stake #8—2.5
		4441 total	2.86 total	Stake #10—1.9
4A	3/17/92	2262	1.4 total	Stake #6—2.1 Stake #9—1.5
4B	3/18/92	2242	1.3 total	Stake #11—0.9 Stake #12—1.0 Stake #13—0.8

The entire 3-foot cap area consisted of 4 units (1, 2A, 2B, 3) and took eight barge loads, or 17,781 cubic yards, of sand. The barge contractor spread one barge load of sand (2,199 cubic yards) on the smallest unit (Unit 1) located closest to shore. The first diver stake survey showed the unit to be covered with an acceptable 2.9 feet of sand. The calculated thickness for the unit was 3.6 feet. The difference in the calculated and actual thickness can be attributed to sediment drifting during placement and sloping sides of the cap not addressed in the calculation estimate. Unit 2A, which is the farthest offshore, received two loads, or 4,356 cubic yards of sand, before the first diver survey. The calculated thickness of sand after the two loads was 3.82 feet. The actual thickness was 2.05 feet at Stake 4 and 1.8 feet at Stake 5. Compounding the normal sediment drift problem was that Unit 2A is in the deepest section of the cap area. The sand, during placement, had the farthest to travel before reaching the bottom and therefore the longest time to disperse. After the first diver survey, Unit 2A received an additional barge load of 2,262 cubic yards, resulting in a measured thickness of 3.5 feet at Stake 4 and 3.0 feet at Stake 5. Unit 2A was the only area that received 3 barge loads, and it has the largest difference between actual cap thickness and calculated cap thickness. This difference is attributed to a greater loss of capping material because of deeper water.

At Unit 2B, the first barge load of 2241 cubic yards of sand resulted in an actual thickness of 1.9 feet at Stake 2 and 1.5 feet at Stake 3. Both of these were close to the calculated thickness of 1.88. The next barge load brought the area up to a thickness of 2.8 feet at Stake 3 and 2.6 feet at Stake 2.

The first diver survey showed Unit 3 to be 1.45 feet thick at Stake 8, close to the calculated thickness of 1.4 feet. The second load of sand brought the thickness to 2.5 feet at both Stake 7 and Stake 8. This thickness is a little less than desired, but all the clean sand had been removed from the Duwamish dredging site and there was no more sand available under this contract.

The stake layout was designed for barge tracks constructed using a 128-foot barge. The barge contractor, however, used a 148-foot barge. Consequently, the number and configuration of the barge tracks changed while the stake locations remained the same. Stake 10 was designed to be in the middle of a barge track in the initial configuration but ended up located on the outside edge of a barge track in the final configuration. Because Stake 10 is at the edge of the cap, the measured thicknesses would be expected to be less than in the center of the cap and cannot be used to compare with the desired thickness.

Discussion

The calculated thickness is based on a best-case scenario where all the sediments released from the barge land perfectly on site and stack up with vertical side walls. The reality is that while the sediments descend to the bottom, they diffuse into a larger area than the barge track, and the side walls slope at the angle of repose. The sloping sides of the cap are not addressed in the calculation estimate. Calculated thicknesses also presume that barge track lines did not exceed the cap outline. While every effort was made to stay on track, the very nature of barge operations made it difficult to stay exactly within the planned track outline.

On two occasions the calculated thickness matched the measured thickness, but typically the actual thickness was 0.3 to 0.7 feet less than the calculated thickness for each barge load. The deepest station had a greater difference, at 1.8 to 2.0 feet after two barge loads.

In summary, calculated thicknesses based on the volume of sand placed and barge track records were not an accurate means to determine actual cap thickness. Calculated thicknesses were best used to estimate the quantities of sand needed and as a yardstick to monitor large-scale problems with cap placement. The differences between predicted and actual measurements appear to be partly the result of using a simplified calculation estimate and also the dispersion of capping material offsite because of the action of currents and tugboats.

CURRENT DATA

In addition to the engineering considerations previously mentioned, the accurate placement of sand caps is also subject to local currents. The City of Seattle was asked to obtain current data in the vicinity of Piers 53-55, because past experience during the Denny Way capping project indicated that currents can cause a substantial loss of sediment off-site during placement. Also, waiting for slack tide, when currents are at a minimum, to place a cap is not cost effective. The City of Seattle contracted with Brown and Caldwell to obtain current data at two locations and correlate currents with tides. This current data is included in Appendix D. As a result, considerably less sand was lost during the Pier 53 capping project than at the Denny Way site. Placement of capping sand was restricted to up-current areas as much as possible.

Two InterOcean S4 current meters were placed in the area of the Pier 53 cap. The first, or inner meter, was 140 feet offshore of the northwest corner of Pier 54. The second, or outer meter, was 400 feet offshore of the southwest corner of Pier 54. Five-minute-average currents were recorded every 10 minutes for a 4-day period between February 22 and February 26, 1992. The meters were placed at mid depth in the water column at locations noted on the graphs in Appendix D.

The majority of data from the inshore meter showed a north-northeast current direction associated with the incoming tide. The direction of the individual current samples varied widely, but tended to move to the south and southeast during the outgoing tide. The speed of the current varied from 0.02 to 0.16 feet per second, with a majority of measurements between 0.04 and 0.08 feet per second.

Current Data

The general current direction for the outer meter was to the north and north-northwest during the incoming tide. The individual measurements were variable but tended to the south during the outgoing tide. The current speed ranged from 0.02 to 0.17 feet per second, with a majority of measurements between 0.06 and 0.09 feet per second.

SEDIMENT-PROFILE CAMERA SURVEY

Metro contracted with Science Applications International Corporation (SAIC) to conduct a camera survey of the Pier 53 cap. The survey was completed on October 7, 1992, with a Metro support crew and the research vessel, *RV Liberty*.

The primary purpose of the camera study was to determine the boundaries of the capping material placed at the Pier 53 site. Additionally, physical and biological data were measured from the sediment profile images to document the nature of the cap material and the benthic communities in the capped and non-capped areas. The biological aspect of the study is summarized in Section 6, and the entire report appears in Appendix G. Portions of this report are copied or summarized below.

Camera System

The photographic system used in the camera survey is a REMOTS© (see Figure 3-5). The actual camera is a Benthos Model 3731 Sediment Profile Camera. The camera has an internal strobe light and is mounted above a wedge-shaped optical prism with a Plexiglas® faceplate. The back of the prism has a mirror mounted at a 45-degree angle to reflect the profile of the sediment-water interface. The camera and prism are mounted on a frame that can be lowered from a boat to the sea bottom with a winch.

Once the camera is on the bottom, an adjustable, "passive" hydraulic piston slowly forces the wedge-shaped prism into the bottom sediment. The slow rate of penetration minimizes sediment disturbance. The prism is driven several centimeters into the sea floor by the weight of the assembly. A camera trigger is tripped on impact with the bottom, activating a 13-second time delay on the shutter release. This gives the prism time to penetrate to its maximum depth before a photo is taken.

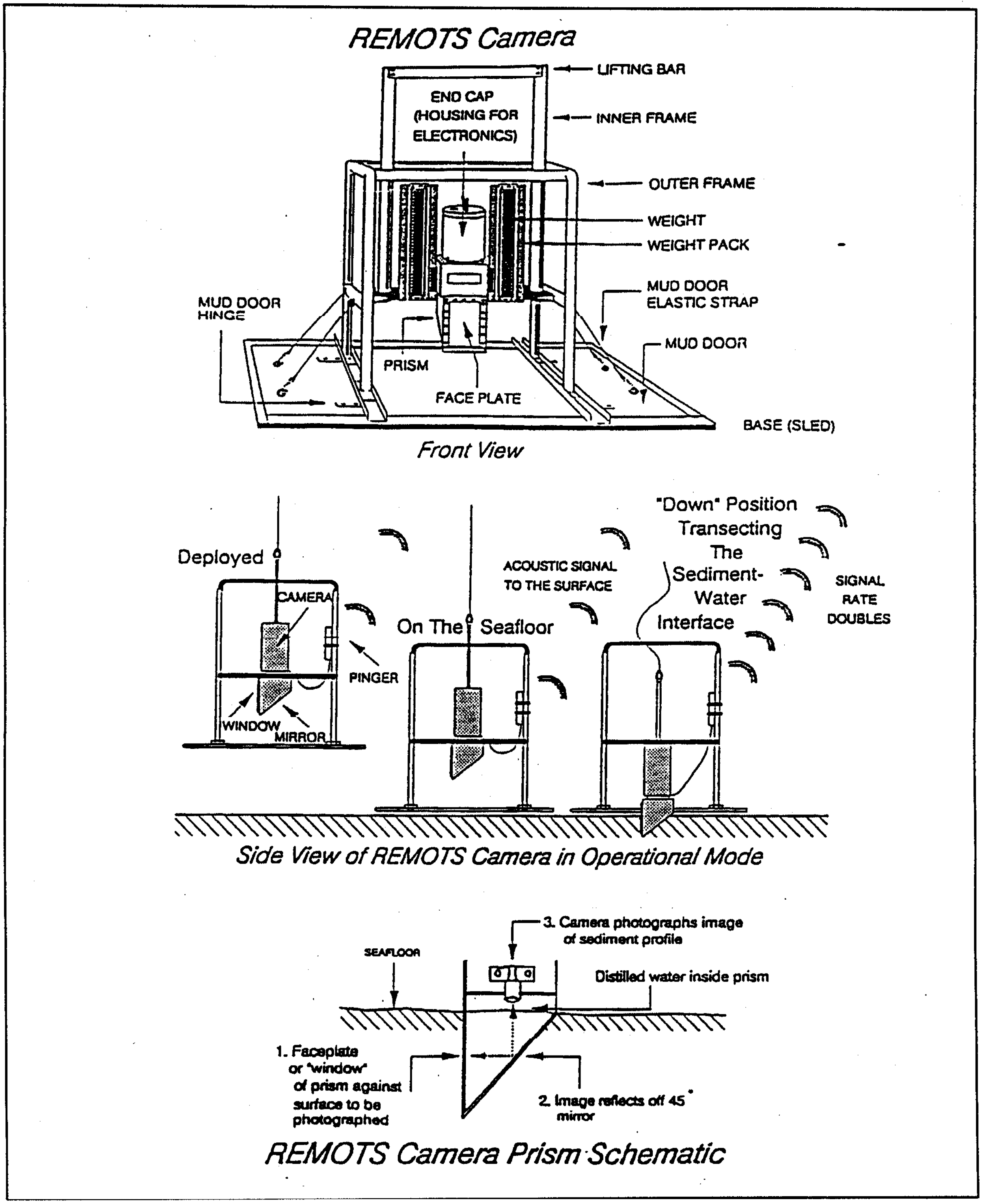


Figure 3-5. The Sediment-Profile Camera

Photographic Stations

To provide adequate spatial coverage in the delineation of cap material, the camera survey team used a sampling design composed of up-slope, along-slope, cross-cap, and cap tangential transects.

The Metro survey team used a laser theodolite range-azimuth positioning system similar to the one used for cap placement except that the Metro unit does not have automatic tracking. A shore-based survey crew aimed a laser at a prism held by a crew member on the boat and, by monitoring the range and azimuth, directed the vessel to the sampling station. Once at the station, the crew lowered the camera to the sea floor and took a picture. When the camera was on the bottom, the crew also recorded the location of the station as an angle and distance.

Results

Because the primary purpose of the camera study was to determine the boundaries of the capping material, the dredged sands placed at the Pier 53 site had to be distinguished from the native sediments. Camera images showed that typical cap sediments are coarse-grained, poorly sorted, and exhibit a chaotic sedimentary layering fabric. The pre-cap sediments are typically finer-grained, reflect more light, and have a more ordered sedimentary layering fabric. Other characteristics of the capping sands are leaf and twig debris coating the sediment surface, cohesive clasts of fine grained clay, and many golf balls, which are probably from a driving range near the Duwamish River dredge site.

The sediment cap is composed mostly of 2-1 phi (0.25 to 0.5 mm) medium sands and lesser amounts of finer 3-2 phi (0.12 to 0.25mm) sands. There is no systematic distribution of coarser and finer sands in the cap area. On the fringe of the cap, the 2-1 phi sands overlie >4 phi pre-cap silt/clay sediments. In the northwestern portion to the cap, the 2-1 phi sands overlie the >4 phi silt/clay. Moving farther out from the cap area, the overlying sands grade into finer 3-2 phi sands over the native silt/clay.

Cap surface relief or boundary "roughness" observed in the sediment-profile camera survey was generally low, between 0.5 and 1.5 cm. The "roughness" or chaotic sedimentary fabric is caused by fine-grained, cohesive clots dredged with the cap sands from the Duwamish River that stand in relief at the cap surface. These clots correspond to lumps of clay seen during cap sediment sampling and are discussed in Sections 4 and 5. Generally, the surface of the cap varied from areas of clean flat sand to debris patches of wood fiber and algae growth.

A general idea of the depth to which oxygen has penetrated the sediments can be estimated from the sediment-profile images. The apparent redox potential discontinuity depth (RPD) can be estimated because sediments that have been oxidized in an aerobic sediment layer are a different color than reduced sediments in an anaerobic layer. The apparent mean RPD depth can be considered an estimate of the extent to which benthic organisms have mixed oxygen into the bottom sediments. It has been documented that a drastic reduction in apparent RPD depths at disposal sites occurs immediately after dredged material dumping (SAIC, 1986c; SAIC, 1886d). This is followed by a progressive post-disposal apparent RPD deepening (barring further dumping activity). At Pier 53, the RPD level was generally at a greater depth outside the capped area in the native sediments. The shallowest RPD levels were seen in the center of the cap and then gradually increased in depth toward the edges of the cap. RPD levels inshore of the cap are slightly deeper than those on the cap. For most of the sediment-profile stations where capping sands were present, RPD depths were unclear and a determination could not be made. Minimal RPD depths are expected in the Pier 53 cap due to the short time after cap placement.

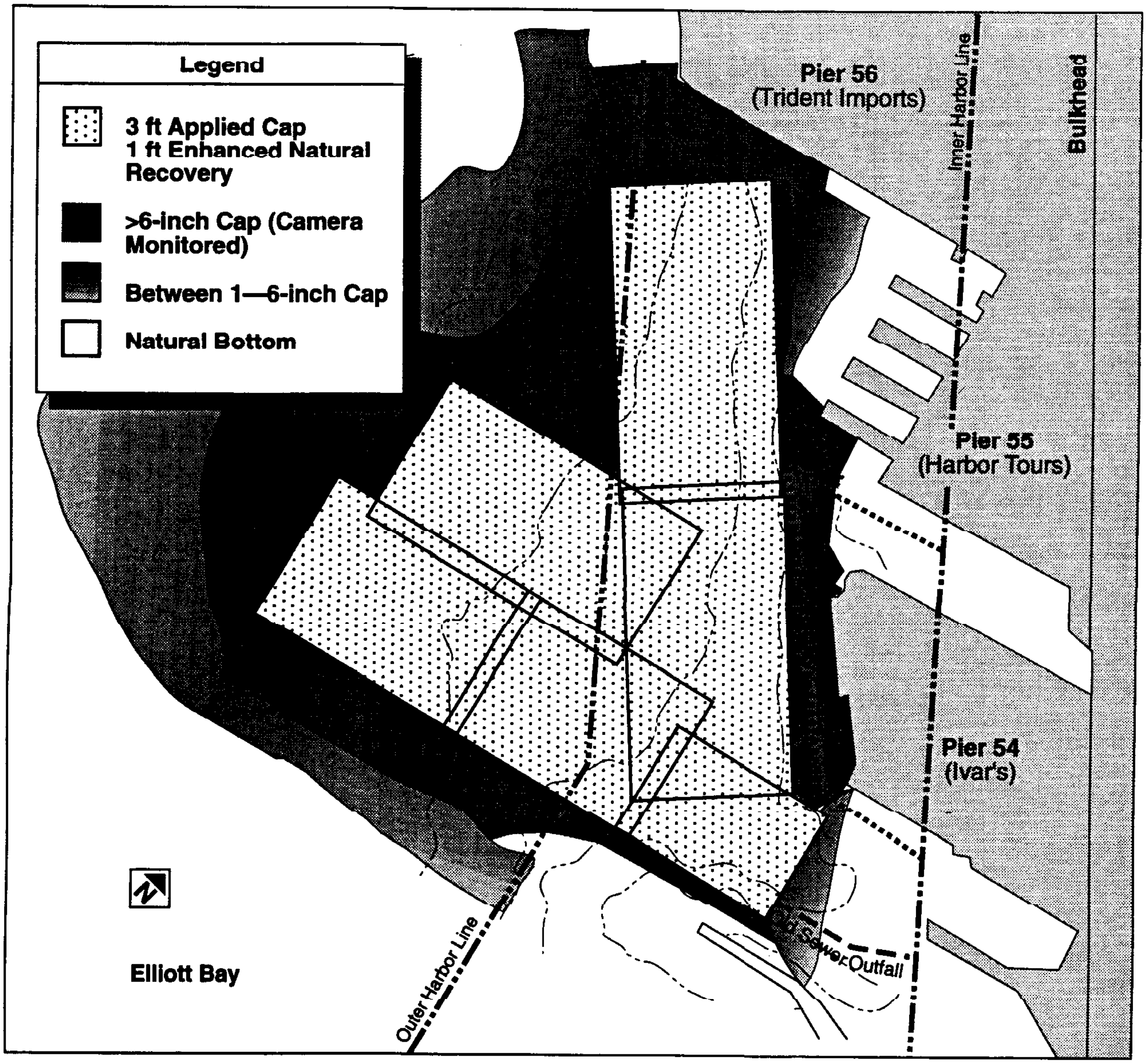
Discussion

The sediment-profile camera survey indicates the Pier 53 cap extends beyond projected boundaries (see Map 3-2). The cap extends farthest beyond the projected boundary in the offshore, or westward direction. Evidence supporting this observation includes the presence of thin layers of homogeneous cap sand overlying old benthic infauna burrows, the sharp contrasting line between the cap sands and the underlying native sediments, and the lack of sediment mixing between the two layers, even in the presence of sediment-mixing infauna.

When dredged material is disposed by barge, the descending mass typically behaves like a density current. When this current impacts the sea floor, it spreads radially. As the density current spreads along the sea floor, it constantly loses kinetic energy, and the densest (coarsest) sands settle first. The dredged material would travel farther in a downslope direction as the density current would more readily flow along a potential gradient. Camera survey images showed the Pier 53 sediment as a thin layer, 2 to 7.5 centimeters thick, up to 300 feet beyond the projected boundary in the western (downslope) portion of the survey area. In contrast, cap material extends only 50 feet beyond the projected boundary in the eastern (upslope) portions of the survey area.

It is important to note, however, that the maximum depth to which the camera was able to penetrate into the sands within the projected cap boundary was

Sediment-Profile Camera Survey



Map 3-2. Extent of Capping Sands as Determined by Sediment-Profile Camera Survey

9 centimeters, or about 3.5 inches. The camera survey was not able to determine cap thicknesses beyond that depth. The barge dumping records and the cap thickness measuring stakes indicate most of the capping sands settled on site.

Comparison To Denny Way Sediment-Profile Camera Survey

The sediment-profile camera survey at Pier 53 was in many ways similar to the Denny Way sediment-profile camera survey. The Denny Way survey was conducted a year after cap placement, while the Pier 53 survey was conducted shortly after the cap was placed. Both caps are composed of medium (0.25 to 0.5mm) to fine (0.12 to 0.25mm) sands. Capping sediments at both projects are characterized by leaf and twig debris coating some areas of the cap surfaces and cohesive clasts of fine-grained clay distributed throughout the capping sands. Also, there are flat clean areas without any surface debris.

Cap surface relief or boundary roughness at both caps mostly ranged from 0.5 to 1.5 centimeters. These values are low, indicating a lack of biologic activity. When benthic communities are established, feeding activities can cause boundary roughness measurements of several centimeters.

Both surveys indicated that capping sands were present outside of projected capping boundaries. Capping sands were present a greater distance offshore in the downslope direction than in the onshore or upslope direction at both sites.

At Denny Way, it appeared that a west-northwesterly current may have caused large amounts of sand to drift off the capping site in the offshore direction. Also, the inshore edge of the Denny Way cap is thinner than anticipated. At Pier 53, the City of Seattle conducted a study of the local currents which aided the placement of capping sands. This current data plus the use of barge tracks that were half the length of the ones at Denny Way resulted in much less sand drifting offsite.

At Denny Way, sediment-profile stations extended 210 feet beyond the west boundary but this was not far enough in the offshore direction to determine the farthest extent capping sands settled. At the station farthest offshore, the capping sands are 9 cm or 3.5 inches thick. At Pier 53, the station grid extended 300 feet beyond the cap; however, a thin layer of sand extended even beyond this distance. Between 140 feet and 300 feet offshore, where the thickness of the sand layer could be measured, the thickness ranged from 2 cm to 3.2 cm (0.75 to 1.25 inches thick). From this it would appear that most of the sand settled nearer to the capping boundaries than 140 feet and very little additional sand would be found had some stations been located farther offshore.