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Remedial Investigation Report
Sediments Operable Unit
Cascade Pole Site
Olympia, Washington

Volume I of III

January 22, 1993

Prepared by

Landau Associates, Inc.
P.O. Box 1029
Edmonds, WA 98020-9129
(206) 778-0907

LANDAU
ASSOCIATES,
INC.
Environmental and Geotechnical Services

January 25, 1993

Mr. Charles Pitz
Department of Ecology
7272 Cleanwater Lane
M/S LU-11
Olympia, WA 98504-6811

RE: **SEDIMENTS REMEDIAL INVESTIGATION REPORT**
CASCADE POLE—OLYMPIA CONSENT DECREE

Dear Mr. Pitz:

Enclosed please find five copies of the *Remedial Investigation Report, Sediments Operable Unit, Cascade Pole Site, Olympia, Washington* submitted on behalf of the Port of Olympia and Cascade Pole Company (the Parties) under the provisions of Task 17 of the Cascade Pole—Olympia Consent Decree. Please note that two copies of the document are submitted for placement in public information repositories as described in Section XXVI of the Consent Decree.

This document has been revised in response to your comments that were provided to the Parties in a letter dated October 15, 1992. Your comments pertaining to the draft report have been reiterated in the new Appendix K and are followed by a summary of the Parties' response.

The changes to Volumes 2 and 3 are minor (for Volume 2, replacing old Appendices C and E, adding new Appendices J and K, and updating the cover sheet; and for Volume 3 simply updating the cover sheet). Therefore, for three of the five copies being sent to you, we have not replaced those volumes in full, but are instead transmitting the replacement appendices and new covers, which can be inserted into the three volumes that you received as draft.

In response to your request, new or revised text is shown as shaded text in this document. Deletions are not highlighted, but generally were associated with new or revised text.

LANDAU ASSOCIATES, INC.

By: Leslee Matthews

Leslee C. Matthews

LCM/sms
No. 21015.54
01/25/93 OLY\RI\SED-RI.LET
cc: R. Malin, Port of Olympia
A. Mackie, Owens Davies Mackie
L. Lonning, Cascade Pole Company
R. Haney, Environmental Science and Engineering
R. Palumbo, Heller Ehrman White McAuliffe

P.O. BOX 1029 • EDMONDS WA 98020-9129 • (206) [illegible]
SPOKANE (509) 327-9737 • FAX (509) 327-9691 • TACOMA (206) [illegible]

EXECUTIVE SUMMARY

The Cascade Pole Site is located on the northeastern section of a peninsula that extends northward into Budd Inlet at the Port of Olympia in Olympia, Washington. The Site is the location of a former wood-treatment facility that was operated since the early 1940s by a number of different companies, the most recent of which was Cascade Pole Company (CPC). Wood-treating operations, first using creosote and later using both pentachlorophenol (PCP) and creosote, ceased in 1986, and the wood treatment plant and associated aboveground structures were removed in mid-1990. The chemicals associated with former wood-treating operations that potentially pose a threat to either human health or the environment include polynuclear aromatic hydrocarbons (PAH, the primary constituents of creosote), PCP, and dioxins and furans, which are commonly found in technical-grade PCP as a by-product of manufacturing.

A remedial investigation (RI) was conducted in the intertidal and subtidal sediments north and east of the former wood treatment plant (the Sediments Operable Unit) in 1990 and 1991, to characterize the extent of contamination in the sediments that may be related to former wood-treating activities at the Site, and to assess the impacts of the contaminants to human health and the environment. The results of the characterization of the nature and extent of contamination are reported in this document; those related to the assessment of the potential impacts of the contaminants to human health and the environment are reported in the Sediments Risk Assessment Report (Landau Associates 1992). The RI was conducted under the terms of a Consent Decree signed between CPC, the Port of Olympia, and the Washington State Department of Ecology on May 29, 1990.

The RI included two separate field programs: Phase I, conducted in December 1990 and Phase II, conducted in July and August 1991. The field programs consisted of the following activities:

- *Sampling of sediments in the intertidal and offshore zones during both phases of the RI to characterize contamination that may be related to the CPC Site*
- *Sampling of surface water, during Phase II of the RI to assess potential contaminant impacts on water quality*
- *Sampling of biological organisms, during Phase II of the RI, to determine any adverse impacts on the environment from Site contaminants.*

Phases I and II included the collection of 281 sediment samples from a total of 49 stations in the Sediments Operable Unit, and 4 sediment samples from background areas within Budd Inlet. These samples ranged in depth from the surficial sediments (the upper 10 cm) to depths greater than 4 m. Of these, 127 samples from the Sediments Operable Unit (and the 4 background samples) were analyzed for the chemicals of concern, and the remaining 154 were archived.

Phase II also included collection of four samples of water ponded on the surface of the sediments or flowing in a drainage channel within the Sediments Operable Unit, three samples of tidal water above the Site sediments, and four samples of tidal water above sediments in three other areas of Budd Inlet.

Samples of sediments for evaluation of the abundance and diversity of the benthic organisms within the sediment (an indication of the environmental "health" of the sediment) and for use in bioassays were collected during Phase II from two locations at the Site and from two reference stations within Eld Inlet (the Eld Inlet reference stations are located approximately 5 miles to the northwest of the Site and represent a relatively uncontaminated area of Puget Sound). Clam samples were also collected at two site locations to provide data regarding tissue concentrations for the Risk Assessment; a sample of clams was also collected in Eld Inlet to provide the basis of comparison of the Site to a relatively uncontaminated area.

The data collected during the RI was evaluated to identify the soil types that occur in the sediments, the areal and vertical extent of contamination in the sediment, the potential for sediment resuspension and transport, and the depth of the biologically active zone.

The RI distinguished three geologic units in the Sediments Operable Unit: 1) recent deposits consisting of fill and recent intertidal sediments, 2) marine sediments that comprise the upper aquitard, and 3) alluvial sands that comprise the Lower Aquifer. The recent deposits in the Sediments Operable Unit range in thickness from greater than 13 ft in the west to approximately 0.3 ft in the east, and consist of varying amounts of sand; silty sand; sandy silt; silt; clayey silt; and silty clay with shells, shell fragments, and wood debris. The upper layer of the recent deposits typically consists of black to olive-black organic silt and clayey silt up to 2.3 ft thick. This upper layer of intertidal sediments is thickest in the eastern nearshore area and thins to the west and north, which is consistent with Site oceanographic characteristics.

Underlying the recent deposits are tidal and subtidal marine deposits that comprise the upper aquitard. The upper aquitard encountered in the RI is typically olive-gray to dark olive-gray in color, consisting of stiff clay and silty clay. This unit has occasional silty and sandy zones with frequent but variable shells, shell fragments, and wood fragments. The upper aquitard was encountered throughout the Sediments Operable Unit, and generally ranged in thickness from 16.1 to 17.4 ft (490 to 530 cm) [at Boring A2, the thickness of the aquitard was found to be significantly less (8.2 ft), due to dredging for the East Bay Marina]. Beneath the upper aquitard lie the silty sands and sands of the Lower Aquifer.

The topography of the Sediments Operable Unit at the Site was found to influence contaminant distribution. The surface of the sediments consists of gently sloping surfaces that begin at the base of the riprap along the shoreline, and extend out into the subtidal zone. East of the former wood treatment *plant, the shoreline slopes downward to the east, and north of the former wood treatment plant, the surface of the intertidal sediments slopes downward to the north and northeast. Several erosional channels exist in the sediment surface.*

The current topography of the Sediments Operable Unit is altered from its historical surface as a result of dredging and fill activities associated with the building and development of the Port peninsula. The most recent major alteration to the sediment surface occurred in the early 1980s when the area south and immediately east of the wood treatment plant was filled as part of the Port's East Bay development. Offshore dredging of a channel for marina access also occurred at that time.

Tides, winds, and vessel traffic all contribute to sediment erosion, deposition, and resuspension at the Site. The mean tidal range for lower Budd Inlet is 10.5 ft. Tides in Budd Inlet are mixed diurnal tides, with a significant diurnal inequality and a fortnightly cycle (a 2-week cycle in which tides of extreme highs and lows gradually change to shallow tidal variations). Winds at the Site are predominantly from the south and southwest; therefore, the Sediments Operable Unit is relatively protected from the prevailing winds. The western portion of the Sediments Operable Unit is most likely to be subject to the occasional storms with northerly winds and waves, and the predominance of coarser grained sediment in that area supports this model. Sediments resuspended by these storm waves would be expected to move easterly along the shore and to the offshore. To the southeast, near the breakwater, the sediments grade finer, suggesting a significantly more quiescent environment. Vessel traffic occurs in both the East and West bays of Budd Inlet; however, the contribution of this to sediment processes at the Site was determined to be insignificant.

Net sediment deposition (or loss) rates cannot be calculated precisely for the Site without long-term, controlled monitoring. The Sediments Operable Unit is a low-energy environment, and in general, the greatest sediment resuspension is expected to occur in areas with elevation generally greater than +5 ft mean lower low water (MLLW). Pb-210 data was collected during the RI to evaluate the depth of the surface mixed layer (which can be used as an indicator of the vertical extent of the predominant biologically active zone) and the rate of sediment accumulation. The data from the Site was found to be influenced by interferences that prevented precise definition of these parameters. However, in general, benthic activity in coastal marine sedimentary environments is highest in the upper few centimeters of the sediment column, although burrowing organisms can go as deep as 1 meter. Typically, the very deep burrowers are rarer, and given the types of fauna observed at the Site, the majority of biological activity is estimated to be within the upper 0-25 cm interval of the Site sediment. This estimate is not contradicted by the rough estimate of 25 cm for the mixing zone that was postulated from the data from Station H4 (the station with Pb-210 data least subject to interferences) and also is consistent with direct *(though limited) observations at the Site. Very rough estimates of maximum sediment accumulation rates from the Pb-210 data range from 0.2 to 0.3 gm/cm^2/yr. These rates are comparable to those measured in other shallow bays in Puget Sound.*

The field investigations and chemical and biological data evaluations conducted as part of the Sediments RI result in the following findings:

- *Sediment offshore of the former wood treatment plant at the CPC Site contains contaminants associated with historical wood-treating activities at the Site.*
- *The highest levels of creosote-related contaminants are located just offshore, east of the former wood treatment plant, at the 10-55 cm depth interval. The highest levels of PCP-related contaminants are located nearshore, to the north/northwest of the former wood treatment plant, in the upper 10 cm.*
- *The lateral distribution of contamination is primarily to the east of the former wood treatment plant, with some spreading to the north and northeast. This distribution is consistent with current, and reasonably postulated, past Site characteristics (e.g., the historical and current aquitard surface, historical and current shorelines, and offshore topography) and with contaminant migration mechanisms.*
- *The vertical distribution of the contamination is such that the highest concentrations are found in the depth intervals 10-55 and 55-100 cm below the surface. The vertical extent of contamination generally is limited by the presence of the silts and clays of the original intertidal surface (the aquitard).*
- *The contamination exists in sediments primarily as sorbed chemicals, with some occurrences of nonaqueous phase liquid (NAPL; the NAPL appears to be limited to the area east of the former wood treatment plant).*
- *Current State Sediment Management Standards chemical criteria (both SQS and CSL) are exceeded for PAH, dibenzofuran (constituents of creosote), and to a lesser degree, several metals (cadmium, chromium, copper, and zinc), in sediments north and east of the former wood treatment plant. The highest exceedances were at stations located nearshore, east of the former wood treatment plant. Bioassays from two locations (approximately 150 ft offshore to the north and northeast of the former wood treatment plant) indicate exceedances of the Sediment Management Standards Sediment Quality Standards biological criteria at both locations, and the Cleanup Screening Level biological criteria at one location (C3, east/northeast of the former wood treatment plant).*
- *Current State Sediment Management Standards chemical criteria for PCP were not exceeded for any of sediment samples collected during the RI.*
- *There currently exist no State Sediment Management Standards for dioxins and furans; however, these chemicals were detected at levels that are considered elevated [dioxins and furans are evaluated with respect to human health in the Sediments Risk Assessment (Landau Associates 1992)].*

- *Surface water ponded on or flowing in channels in the surface of the sediments, and in the water column above the sediments, does not appear to be affected by contamination from the Site at levels that exceed the current Federal and State marine acute and chronic criteria for protection of the environment (and Federal criteria that address human consumption of fish from the marine environment). The only exceptions to this are 1) all Site and Budd Inlet background water samples contained dioxin above the Federal criteria that addresses human consumption of fish from the marine environment, and 2) one drainage channel just east of the former wood treatment plant in which flowing water in the channel at low tide contained chemical concentrations that exceeded health-based water quality criteria for six PAH.*

- *Clams obtained from an area of elevated sediment chemical concentrations contained levels of wood-treating chemicals significantly above concentrations in clam samples obtained from Eld Inlet (a south Puget Sound location that is removed from sources of contamination). Clams obtained from an area at the Site with lower sediment contaminant concentrations contained contaminant levels above those reported for the Eld Inlet sample, but significantly below those in the clams from the more contaminated sediments.*

- *Differences in benthic infaunal abundance and diversity were found between the two sediment samples obtained from the Site and between the Site samples and the reference sample obtained from Eld Inlet (a south Puget Sound location that is removed from sources of contamination). The Site sample collected from the northwest portion of the Sediments Operable Unit approximately 400 ft offshore exhibited minor differences from the reference sample; the differences may be related to site-specific chemicals or may, to some degree, reflect the differences between an urban embayment and the more pristine environment of a reference area. In contrast, the results for a station approximately 100 ft offshore, northeast of the former wood treatment plant, indicate decreases in abundance and diversity relative to both the Site sampling location in the northwest portion of the Sediments Operable Unit and to the Eld Inlet sample that are indicative of sediment adversely affected by organic contamination.*

The sampling and data evaluations conducted during the Remedial Investigation provide information sufficient to conduct the Risk Assessment, and to evaluate both the need for remedy and the remedial alternatives available for the contaminants in the Sediments Operable Unit. The results of this RI and the companion Risk Assessment indicate the need for remedial action in the sediments nearshore, generally east and northeast of the former wood treatment plant. These sediments cover an area of approximately 3-5 acres. A detailed evaluation of the ability of the sediment to recover naturally, and the identification of the boundaries of the sediments requiring remedy to protect human health and the environment will be presented in the Feasibility Study Report.

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1.0 INTRODUCTION

This report presents the findings and conclusions of the Sediments Remedial Investigation conducted at the Cascade Pole Site in Olympia, Washington. The Remedial Investigation (RI) was conducted under the terms of the Consent Decree between Cascade Pole Company (CPC) and the Port of Olympia (the Parties) and the Washington State Department of Ecology (Ecology), which was filed with the Thurston County Superior Court on May 29, 1990 (the Consent Decree). This report is prepared for submittal to Ecology on behalf of the Parties, in accordance with Task 17 of the Consent Decree.

Under the terms of the Consent Decree, Ecology requires the Parties to complete a Remedial Investigation/Feasibility Study (RI/FS) for the intertidal and subtidal sediments that lie north and east of a former wood-treatment plant (the Sediments Operable Unit) at the Port of Olympia, Washington. The general objectives of the Sediments RI/FS are as follows:

- Evaluate the nature and extent of contamination in the Sediments Operable Unit that may be directly associated with past activities at the former wood-treatment plant or that may result from residual contamination that remains onsite.
- Evaluate potential contaminant migration pathways, and the fate and transport of contaminants in the Sediments Operable Unit such that potential remedial alternatives may be identified.
- Develop a database that allows for a comparison of potential remedial alternatives in the Sediments FS.
- Evaluate potential threats to human health and welfare, and the environment associated with contamination in the Sediments Operable Unit.

The Sampling and Analysis Plan submitted to Ecology in October 1990 (Landau Associates 1990a) and the Phase II Work Plan submitted to Ecology in June 1991 (Landau Associates 1991a) described a two-phase approach to the Sediments RI:

- Phase I was designed to provide preliminary data on the areal and vertical extent of contamination related to wood-treatment chemicals in the sediments. Phase I sampling and analyses were limited to sediments only.
- Phase II was identified as a follow-up program to provide refinement of information in areas in which more specific data would be needed to meet the objectives of the Sediments RI/FS. Phase II was designed to build upon the information obtained in Phase I, so as to better focus investigative efforts to areas of concern.

The RI Phase I field program was accomplished in December 1990. The data from that program were used to develop the Phase II field program, which was completed in August 1991. This report presents the data obtained in both phases of the Sediments RI and directly addresses the first three overall objectives of the Sediments RI. A concurrently submitted Sediments Operable Unit Risk Assessment (Landau Associates 1992) addresses the fourth overall objective of the Sediments RI.

1.1 SITE BACKGROUND

1.1.1 Site Description

The Cascade Pole Site (Site) is located on the northeastern section of a peninsula that extends northward into Budd Inlet in Olympia, Washington (Figure 1). The Site is the location of a former wood-treatment facility that was operated since the early 1940s by a number of different entities, the most recent of which was CPC. Wood-treating operations at the Site ceased in 1986, and the wood treatment plant and associated above-ground structures were removed in mid-1990.

The Sediments Operable Unit at the Site is comprised of the intertidal and subtidal sediments that lie north and east of the former wood-treatment plant. Figure 2 shows the relationship of the Sediments Operable Unit to the site and other significant features (e.g., the East Bay Waterway), as well as the property boundaries and navigational channels in the vicinity of the Sediments Operable Unit.

1.1.1.1 Geographic Setting

Budd Inlet is a shallow estuary in the extreme southern end of Puget Sound, in an area known as the southern Puget Lowlands. A constructed peninsula about 4,400 ft long and varying in width from 1,000 to 2,000 ft (the Port peninsula), extends north from the southern shore of Budd Inlet, separating the inlet into two waterways, the Deschutes Waterway (West Bay) and the East Waterway (East Bay) (Figure 1).

1.1.1.2 Current Land Use and Zoning

The Port peninsula is bounded to the south by the urban area of the City of Olympia, which is both the population center of Thurston County and the State capital. The Port peninsula is zoned primarily Industrial in the north and west central portions, and Central Waterfront along the eastern shoreline and in the south end of the peninsula (Figure 3). Current land use on the Port peninsula includes the East Bay Marina on the east shoreline; a deep water loading dock, log sort yards, warehouses, and Port offices to the west; and a restaurant, radio station, commercial office space, the Port maintenance shop, and the Cascade Pole Site to the north.

Land use surrounding the East and West Bays of Budd Inlet is primarily residential and industrial, respectively. Adjacent to and southeast of the Site is the East Bay Marina. Currently, approximately 25 people live on the boats at the marina. Based on recent estimates, approximately 2,100 boats are launched from East Bay Marina each year, with more than 75 percent of the launches taking place during the summer season (May through August). The East Bay Marina is predominantly used by recreational or pleasure cruisers or sailors, with only minor usage for fishing or other aquatic activities (Cutshaw 1992).

Fences restrict access to the Site shoreline. Warning signs are posted along the shore by the Thurston County Health Department, discouraging consumption of shellfish from the Site.

1.1.1.3 Climate

The climate in Olympia is characterized by warm, dry summers and wet, mild winters. July is the warmest month, with typical afternoon temperatures in the 70s (°F); January is the coldest, with typical afternoon temperatures in the 30s (°F). The mean annual precipitation is approximately 51 inches, most of it falling as light to moderate rain from mid-October through March. The prevailing winds are southerly during most of the year, but during the summer months, the winds generally are gentle and from the north and east (NOAA 1990a).

1.1.1.4 Natural Resources

Fisheries

The Sediments Operable Unit at the CPC Site has been identified by the State Department of Fisheries (Fisheries) as consisting of nearshore habitats that "*are critical to most resident and anadromous juvenile and adult fin fish as a migration corridor, as a producer of benthic and epibenthic food, and as a refuge from predation.*" (Finn 1990). Fin fish that have been documented in the vicinity of the Site include Shiner perch, Pile perch, dogfish, Staghorn sculpin, Buffalo sculpin, and Starry flounder (Frederick 1990). Several other fish species are present in the area, and may use habitats at the Site (Dickison 1990). Coho salmon and juvenile Chinook salmon annually migrate past the Port peninsula from the Deschutes River and Capital Lake, respectively (Dickison 1990). The habitats of the Sediments Operable Unit also "*provide substrate* *as well as similar habitat values for resident shellfish.*" (Finn 1990). Representative species documented in Budd Inlet include clams, geoduck, mussels, cockles, sea cucumber, cancer gracilis, and red rock crab (Finn 1990). Site-specific sampling for enumeration and identification of infaunal organisms conducted as part of the RI indicate the common occurrence of polychaetes, molluscs, and crustaceans (see Section 4.3.3).

The Squaxin Island Tribe and other Washington Treaty tribes retain the right to harvest fish and have fish habitat protected throughout the Puget Sound area. Although commercial fishing is restricted from Budd Inlet, this waterway is a "*usual and accustomed place*" under the Treaty of Medicine Creek, principally for the Squaxin Island Tribe, which has a net fishery in Budd Inlet (Corps of Engineers 1980).

As part of an Inventory of Potentially Protected Resources at the Site, the U.S. Fish and Wildlife Service, the Washington Departments of Wildlife and Fisheries, and the Squaxin Island Indian Tribe were consulted in order to identify whether fish and wildlife species of concern exist on or near the Site, or if important habitat areas that could be directly impacted by remedial actions exist on or near the Site. The U.S. Fish and Wildlife Service report that it is unaware of any listed or proposed species of concern occurring within the Site area. Fisheries has not identified any threatened, endangered, or candidate species in the Site area. The Washington Department of Wildlife's Fisheries Management Division is not aware of any threatened or endangered fish species in the Site area (Landau Associates 1990b). Under the state Priority Habitats and Species program, the shoreline at the Site is included in a larger area of Lower Budd Inlet that is designated as a priority habitat for Bull trout (based on its value as a game fish and federal candidacy), Dolly Varden (based on its game value), and for anadromous fish in general (Young 1992). The Squaxin Island Tribe reports that it does not possess any information regarding the occurrence of threatened or endangered species in the area. However, the Squaxin Island Tribe did note that it considers all marine habitats in Budd Inlet to be of importance (Landau Associates 1990b).

Wildlife

Budd Inlet supports a wide variety of resident and migratory waterfowl. During the cooler months, many species of birds winter in East Bay. Wintering birds include scaup and ruddy ducks, scoters (all three species), killdeer, goldeneye, canvasbacks, coots, and cormorants. Mallards are the most abundant migrating waterfowl; more sporadically, the following waterfowl and shorebirds have been reported to feed and find refuge from storms in East Bay: pintails, green wing teals, least and western sandpipers, and dunlin (Frederick 1990).

Marine mammals are also known to use Budd Inlet, although their frequent occurrence in Olympia Harbor has been judged unlikely. Harbor seals have been observed along the undisturbed shorelines and in outer Budd Inlet (Corps of Engineers 1980).

The Washington Department of Wildlife's Wildlife Management Division reports that there are two species of concern that occur within 2 miles of the Site: the purple martin, listed as "federally sensitive" (a designation provided by the regional office of the U.S. Fish and Wildlife Service in Portland, Oregon—this designation has no legal ramifications, but reflects the species' vulnerability to change, which could potentially elevate them to threatened or endangered designations) and the great egret, which is currently under consideration for classification as either endangered, threatened, sensitive, or monitor.

Vegetation

The Port peninsula is sparsely vegetated due to its history of industrial use. Species present include grasses, weeds, and other disturbance-tolerant plants (Corps of Engineers 1980).

Patchy vegetation exists on the western portion of the intertidal region at the terminus of the Port peninsula. Vegetation is not common in the Sediments Operable Unit of the Site, which covers the eastern portion of the intertidal region. The lack of vegetation to the east may be related more to the lack of coarse substrate in this region than to contamination. In general, muddy intertidal sediments within Budd Inlet are sparsely vegetated.

1.1.2 History of the Site and the Surrounding Area

During the late 1800s, the southern shoreline of Budd Inlet was located near the present city center. The Port peninsula and some of the City of Olympia shoreline was subsequently created by filling of intertidal and subtidal lands. Filling began in the 1920s with sediment dredged from West Bay. Several fill episodes followed this initial fill episode, beginning in the 1930s and concluding in the early 1980s. The last fill involved sediment dredged for the construction of the East Bay Marina that was placed along the eastern peninsula shoreline.

Figure 4 shows the approximate fill history of the Port peninsula; details of the pre-1980 shorelines of the CPC Site are shown on Figure 5. Historical filling of nearby intertidal lands include fills along East Bay Drive (roadway) and occasional isolated landfills on the peninsula and along West Bay. East Bay also has been used extensively for community waste disposal and for log raft storage (Corps of Engineers 1980).

The Port peninsula has been used for commercial and industrial activity since at least 1930. A wood-treatment plant was reportedly first constructed at the northeastern end of the Port peninsula (the current CPC Site) in 1939, but the operator from 1939 to 1942 is unknown (AGI 1986). According to Applied Geotechnology, Inc. (AGI), Olympia Wood Preserving operated the wood treatment plant from 1942 to 1949. The wood treatment plant was leased, and then later owned by Wood Products Company of Portland, Oregon, from 1949 to 1956. Sound Treating Company operated the wood treatment plant in 1956 and 1957, and Cascade Treating Company conducted operations from 1957 to 1967. Cascade Treating Company merged with CPC in 1967, and CPC operated the treatment plant until the fall of 1986, at which time operations ceased (AGI 1986). Figure 6 shows the approximate boundary of the area leased by CPC for wood-treatment operations.

Land use on adjacent properties historically included a plywood mill to the south, which was operated by Georgia Pacific from 1930 to 1970. The Olympia Oil and Wood Company, located to the southwest, operated from 1931 to 1972, and reportedly had storage tanks for No. 6 oil, No. 5 oil, and diesel fuel. Texaco operated a bulk fuel storage facility located to the west from 1945 to 1965; the facility reportedly had storage tanks for kerosene and two grades of gasoline (AGI 1986). Figure 6 shows locations of historical land use adjacent to the CPC Site.

CPC and previous operators of the wood treatment facility reportedly used several chemical preparations to treat wood. Creosote (a mixture of creosote, coal tar, and other petroleum constituents at variable proportions) was reported to have been the primary preservative used at the wood treatment plant prior to 1967. Inorganic wood preservatives such as copper may also have been used historically at the wood treatment plant (ESE 1992a). In about 1967, the wood treatment plant also began using pentachlorophenol (PCP) solution to treat poles. The PCP treatment solution was reportedly prepared onsite by dissolving PCP in a medium aromatic oil to form a 5 percent PCP solution. Oils used in this process at CPC included P-9 (an oil consisting of 50-60 percent gas-oil extract and 40-50 percent straight-run middle distillate) and Base Oil LN (which contains approximately 65 percent aromatic hydrocarbons) (AGI 1986).

The creosote was reportedly delivered to the wood treatment plant by barge until the 1960s, after which the creosote was delivered by rail (AGI 1986). Deliveries of PCP started in the 1960s, and therefore the PCP (as solid blocks or possibly unconsolidated in sacks) and the petroleum products with which it (and possibly creosote) were mixed, were also most likely made by rail.

Environmental investigations at the CPC Site were triggered in 1983 by the discovery of soil contaminated by wood-treating chemicals along an alignment for utilities southwest of the wood treatment plant, along the present Marine Drive. Since that time, numerous sampling events and investigations have been conducted on or around the Site, including an RI onshore at the Site in 1985 (AGI 1986), followed by the original onshore FS (ERT 1988). The most recent onshore investigation was the Supplemental Site Investigation (SSI) which provided information necessary to revise the onshore FS (ESE 1992a); both of these activities were conducted under the Consent Decree. An Expedited Seep Investigation also was conducted in 1991 under the Consent Decree to evaluate whether NAPL was discharging from the Site through seeps. Data collected in the course of both the SSI and the Expedited Seep Investigation are referenced, as appropriate, in this report.

Since 1985, there have been a number of studies of contamination in the offshore area north and east of the Site. These studies were conducted both by Ecology and consultants to CPC, and are summarized in the Final Sediments Scoping Document (Landau Associates 1990c). The intent of these studies was to determine the nature, and to a lesser degree, the spatial extent of contamination in the areas offshore of the wood-treatment plant that could be associated with past wood-treating operations at the plant and with residual contamination onshore. Contamination thought to be associated with wood-treating operations was found in the offshore environment in these studies; however, a comprehensive understanding of the nature and extent of the contamination in the intertidal area was not achieved.

1.1.3 Chemicals of Concern

The chemicals associated with former wood-treating operations that potentially pose a threat to either human health or the environment, and that were identified prior to the RI as the constituents of concern for the Site, are the following:

- **Polynuclear aromatic hydrocarbons (PAH)**, the primary constituents of creosote. PAH are commonly grouped according to similar chemical and risk properties:
    - Light molecular weight PAH (LPAH) have two or three aromatic rings and include naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, and 2-methyl naphthalene.

  - High molecular weight PAH (HPAH) contain four or more aromatic rings and include fluoranthene, pyrene, benzo(a)anthracene, chrysene, the benzo(b,j,k)fluoranthenes, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene.
  - Total PAH (TPAH) is the sum of LPAH and HPAH.
  - Carcinogenic PAH (CPAH) are those PAH designated by The U.S. Environmental Protection Agency (EPA) as B2 carcinogens, and include benzo(a)anthracene, chrysene, the benzo(b and k)fluoranthenes, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, and dibenz(a,h)anthracene.
- **PCP**, which has been assigned a weight-of-evidence classification by EPA as a B2 (probable) carcinogen. Group B carcinogens include compounds for which sufficient evidence for carcinogenicity in animals exist; however adequate evidence of carcinogenicity in humans is not available.
- **Dioxins and furans**, which are commonly found in technical grade PCP as a byproduct of manufacturing, and which are considered to pose a potential carcinogenic risk.

The RI results also show that the following chemicals are potential constituents of concern in the Sediments Operable Unit:

- **Dibenzofuran**, a tricyclic organic chemical associated with creosote
- **Several metals** (cadmium, chromium, copper, and zinc).

Onshore investigations under the Consent Decree also have identified benzene, toluene, ethylbenzene, and xylene (BTEX) to be constituents of concern (ESE 1992b) for onshore soil and groundwater. On the basis of the concentrations of these chemicals detected in pre-RI sampling, and the fate and transport properties of these chemicals, they were not considered primary constituents of concern for the sediments in the Sediments Operable Unit and were not evaluated during the Sediment RI.

Creosote is primarily composed of PAH, but also contains lesser amounts of aliphatic hydrocarbons and various nitrogen- and sulfur-containing organic compounds (Ingram et al. 1982).

1.2 REPORT ORGANIZATION

The remainder of this report presents the scope of the Sediments RI and the study methodology (Section 2.0), the results of the investigations (Sections 3.0 and 4.0), and an evaluation of the results, including a discussion of release mechanisms and contaminant fate and transport processes that may have resulted in the current distribution of contaminants

(Sections 4.0 and 5.0). A summary of the study conclusions are presented in Section 6.0. The appendices provide supporting documentation of various components of the investigation, and tabulations of data collected historically and as part of the RI.

2.0 REMEDIAL INVESTIGATION

2.1 SCOPE OF THE REMEDIAL INVESTIGATION

The Consent Decree required the following specific elements of the Sediments RI:

- Sampling of sediments in the intertidal and offshore zones to characterize contamination potentially related to the CPC Site
- Sampling of surface water in Budd Inlet at background areas and above or adjacent to contaminated areas potentially related to the CPC Site to assess contaminant impacts on water quality
- Sampling of biological organisms, as deemed appropriate, to determine any adverse impacts on the environment from Site contaminants.

Sampling of sediments occurred during both phases of the RI, while sampling of surface water and biota were deferred to the second phase in order to use the Phase I data to better focus those sampling programs. The scopes of the RI sampling programs are described more fully in the following sections.

2.1.1 Phase I

2.1.1.1 Site Survey

In accordance with Task 14.6 of the Consent Decree, a topographic map of the Site was developed from an aerial photograph. The photo flight was arranged by the Port of Olympia at a tidal stage low enough to capture the majority of the intertidal sediments at the Site. The photograph was taken on July 20, 1990 at 11:14 a.m., capturing the intertidal sediments to a depth of approximately -2 ft mean lower low water (MLLW). A topographic map was then developed by DeGross of Bothell, WA, and transferred to a CAD-based system for use throughout the RI/FS. The resultant map forms the basis of the figures used in this report.

2.1.1.2 Phase I Sediment Sampling

The Phase I sediment sampling program was accomplished in December 1990, and included the collection of 70 sediment samples (this includes 7 duplicate samples) from 36 stations in the intertidal and subtidal sediments (Figure 7).

- Twenty-nine stations were arranged along six transects (A-F) north and east of the Site. Sixteen of these stations were 10-cm cores and 13 of these stations were 1-m cores.

- Two stations (G1 and G2) were located within the narrow intertidal area offshore of the East Bay Marina southeast of the Site. Ten-centimeter cores were collected from both of these stations.
- Five stations (G3 through G7) were positioned between the first pairs of stations (nearest shore) along each pair of adjacent transects. Ten-centimeter cores were collected from all five of these stations.

All sediment samples were collected by either hand-inserted core tubes or a hand-held piston corer deployed from a boat. The upper 10 centimeters (cm) of sediments were collected at each of the 36 stations. In addition, 1-meter (m) sediment cores were collected from 13 stations as indicated on Figure 7. The 1-m cores were sectioned into 0-10 cm, 10-55 cm, and 55-100 cm subsamples to evaluate the vertical extent of sediment contamination over this depth range. Details regarding sample collection and handling methodologies are presented in Appendix A and the Phase I core logs are presented in Appendix B.

The Phase I sediment samples were numbered generally in accordance with the methodology outlined in the Data Management Plan (ESE 1990), with modifications to accommodate sediment-specific needs. The generic numbering format was:

CP# - media - location + depth interval

in which the # references the phase (in this case = 1), the media was M = marine sediments. The "location + depth" identified not only sampling stations and the depth of the subsample, but also replicates, as explained in detail in the beginning of Appendix C.

All sediment samples collected during Phase I were analyzed for polynuclear aromatic hydrocarbons (PAH), chlorophenols, TOC, total solids, and particle size (PSEP 1986a). Twelve samples were also analyzed for polychlorinateddibenzodioxins (dioxins) and polychlorinated-dibenzofurans (furans). In addition, 23 samples were analyzed for total metals. The analytical methods used during the Phase I investigation are discussed in Section 2.2.

The Phase I sediment chemistry results are tabulated in full in Appendix C, and are discussed in Section 4.1.

2.1.2 Phase II

2.1.2.1 Phase II Sediment Sampling

The Phase II sediment sampling program was accomplished in July and August 1991. During that period, 57 sediment samples for general chemistry (this includes 3 duplicates) were collected and analyzed from 24 intertidal and subtidal locations onsite (Figure 7):

- One 10-cm core was obtained for surficial sediment chemistry (H10)
- Three 1-m cores were obtained for analysis of lead-210 (Pb-210) to evaluate sedimentation rates at the Site (C6, E6, and H4) and four 1-m cores were obtained at stations where 4-m cores were planned for sediment chemistry, but at which Site conditions did not allow access by the drilling rigs (H7) or where additional cores were obtained following demobilization of the drilling rigs (Stations B6, B7, and H11). These samples were obtained using a piston-corer deployed from a boat with the aid of a diver.
- Thirteen 4-m cores were obtained for sediment chemistry analyses and for lithologic logging (A2, C2, D3, D4, E1, E4, F1, G3, H1, H5, H6, H8, and H9). These samples were obtained from a hollow-stem auger drilling rig mounted on a barge or on skids. As noted previously, a 1-m core was substituted for the planned 4-m core at Station H7.
- Three cores were obtained that exceeded 4 m in depth (>4-m cores) for sediment chemistry analyses and to verify the conceptual model of the general area lithology (C1, H2, and H3). These samples were obtained using the barge-mounted hollow-stem auger rig.

Several Phase II sample locations coincided with Phase I sample locations where sediment chemistry from depth intervals greater than 1 m were desired. The remaining Phase II samples were collected from new locations generally within, or adjacent to, the area defined by the Phase I transects.

Four additional 10-cm samples were obtained from three other areas in Budd Inlet for the purpose of evaluating background sediment quality [BI1, BI11 (a duplicate of BI1), BI2, and BI3]. Figure 8 shows the locations of the background sampling stations. The background stations were selected in order to represent typical concentrations of sediments and surface water in the local urban embayment. As such, indirect influences by other urban source areas are possible. The background stations could be influenced by one or more of the following:

- Local point source discharges from storm drain outfalls (lower East and West bays of Budd Inlet). However, the sampling was not conducted during storm periods, which should preclude an undesired skew of surface water samples due to storm discharges.
- Marinas (lower East and West bays of Budd Inlet).
- LOTT overflow discharge (lower West Bay).
- Direct or indirect discharges (e.g., surface runoff) from waterfront industries (more likely lower West Bay).

The intent of the sampling was not to skew the results to any one potential source of contamination. Therefore, care was taken in locating the exact sampling sites in the field to avoid obvious point sources.

The Phase II sediment samples submitted immediately for analyses were analyzed for PAH (primarily constituents of creosote), chlorinated phenols (including PCP), and the Puget Sound Estuary Program (PSEP) conventionals of total solids, TOC, and grain size distribution. The only exceptions to this were: 1) the samples submitted for Pb-210 analyses, for which the PAH and chlorinated phenol sample aliquots were initially archived pending a review of the usefulness of the Pb-210 data, and 2) Sample CP2-M-A2A, which was submitted for dioxin and furan analysis only.

Also as part of the Phase II program, 18 sediment samples were analyzed for dioxins and furans, and 9 were analyzed for metals. The analytical methods employed during the Phase II investigation were the same as those used for the Phase I program, and are discussed in Section 2.2. The Phase II sediment chemistry results are tabulated in full in Appendix C, and are discussed in Section 4.1.

In addition to the 57 sediment samples obtained during the Phase II program that were submitted immediately for laboratory analyses, an additional 154 were archived for possible analysis at a later date.

2.1.2.2 Phase II Water Sampling

During Phase II, 11 water samples were obtained from Budd Inlet for the purpose of characterizing water quality with respect to chemicals associated with wood-treatment operations at the CPC Site. The 11 water samples included:

- Four samples of water ponded on the surface of the sediments or flowing in a drainage channel within the Sediments Operable Unit (in either natural or artificial depressions) for the purpose of characterizing exposure concentrations for the risk assessment. Figure 9 shows the locations of these sampling stations. Originally, surface water ponding in or flowing through natural depressions only were targeted for sampling during Phase II. However, during sampling, it was recognized that depressions made by sampling equipment (e.g., the vanVeen grab) could simulate recreational activities in the sediments, and therefore samples of water ponded in such features were valid for the exposure assessment. Ponded water was collected from a flowing drainage channel at Station H12, and from a natural depression at Station H13; ponded water was collected from artificially created depressions at Stations C2 (vanVeen grab hole) and H14 (hole dug by hand 2 hours prior to sampling).

- Three samples of tidal water above the sediments at the Site for the purpose of characterizing both the impact of the sediments to the water quality of Budd Inlet and to obtain exposure concentrations for the risk assessment (B3, C2, and G3). Figure 9 shows the locations of these sampling stations.
- Four samples of tidal water above sediments in three other areas of Budd Inlet for the purpose of characterizing background water quality (BI1, BI11, BI2, and BI3). These sampling stations are shown on Figure 8.

The samples from the sediment surface were collected either directly into the sample containers, or with the use of a peristaltic pump. Samples of the water column were obtained by raising a sampling tube from a peristaltic pump slowly through the water column, from the surface of the sediments to the water surface. All water samples so collected were analyzed for PAH, chlorinated phenols, dioxins/furans, salinity, and total suspended solids.

The results of the Phase II water sampling program are tabulated in full in Appendix C, and are discussed in Section 4.2.

2.1.2.3 Phase II Biological Sampling

Biological samples were collected during the Phase II program from the sediments at the Site and from reference stations within Eld Inlet (approximately 5 miles to the northwest of the Site) as follows:

- Bentnose clams were collected from two stations onsite (F5 and H2) (Figure 10) to evaluate both the impacts to biota and the exposure concentrations for the risk assessment. Bentnose clams were also collected at a reference station in Eld Inlet (Station EI shown on Figure 11) for comparison. The clams were collected by hand. Most clams collected were obtained from the upper 7 cm of the sediment column, but some were collected from as deep as 15 cm.
- Ten-cm sediment cores were collected at two locations onsite (C3 and D3) (Figure 10) and from two reference stations within Eld Inlet (EI1 and EI2) (Figure 11) for bioassays. The purpose of the bioassays is to further evaluate the level of concern represented by sediment chemical concentrations in those areas identified through Phase I data as being of potential concern.
- vanVeen sediment grabs were collected at two locations onsite (five replicates at each station) for an evaluation of benthic abundance/diversity (C2 and E4) (Figure 10). Similar reference samples were collected in Eld Inlet (EI1) (Figure 11) for comparison. The grab sampler achieved the minimum criteria for penetration (14-15 cm) except in the case of one replicate at Eld Inlet that achieved 13 cm penetration. The depth achieved in this case provided about 93 percent of the minimum sample volume and this was judged to not significantly influence the sampling results.

The clam samples were submitted for chemical analyses for PAH, chlorinated phenols, dioxins and furans, metals, and percent lipids. The bioassays were conducted in general accordance with PSEP guidelines (PSEP 1986b) and the benthic abundance/diversity samples were processed in accordance with the procedures set forth in the Phase II Work Plan (Landau Associates 1991a).

The results of the biological testing are presented in Appendix E, and are discussed in Section 4.3.

2.2 LABORATORY ANALYSES

Samples collected during the Sediments Operable Unit RI were analyzed in general accordance with the schedule and procedures proposed in the Phase I Sampling and Analysis Plan (SAP) and the Phase II Work Plan (Landau Associates 1990a and 1991a). For the analysis of PAH, chlorophenols, dioxins/furans, and metals, U.S. Environmental Protection Agency (EPA) methods (SW-846; EPA 1986d) as modified by the PSEP protocols (PSEP 1989) were used by the laboratory. The specific analytical methods used during the RI are presented in Table 1, along with the detection limit goals.

Sediment and surface water samples collected for chemical analyses from the Sediments Operable Unit were subjected to several cleanup steps [described in detail in the Phase II Work Plan (Landau Associates 1991a)] to remove naturally occurring substances (humic acids, lipids, etc.) that could interfere with the analytes of interest. By so removing the naturally occurring substances, the laboratory minimized the masking of analytes of interest or sample dilutions, both of which potentially decrease the ability of the laboratory to accurately quantify concentrations of the analytes of interest.

2.3 DATA VALIDATION

All data from the investigations of the Sediments Operable Unit were subjected to two levels of review and validation: at the laboratory and outside the laboratory.

Initial data reduction, validation, and reporting at the laboratory were conducted as described in the PSEP protocols or EPA guidance, as appropriate. Quality control data resulting from such procedures were reported by the laboratory.

The data were further reviewed outside the laboratory using EPA guidelines for Contract Laboratory Program (CLP) data (EPA 1988). The chemical data were reviewed with regard to analytical methodologies used; detection limits; holding times; blank results; accuracy, precision, and completeness; and data reduction, validation, and reporting. The results of the data validation processes are presented in Appendix D, are incorporated into the chemical data tables presented in Appendix C, and are summarized below.

In general, Phase I sediment and Phase II sediment, tissue, and water sample data were acceptable. Some data required qualification and some data were rejected, as identified on the data tables in Appendix C, and as described below.

- **Holding Times**: Most samples were extracted and analyzed within the appropriate holding times for each method of analysis. The hold time prior to extraction of several Phase I samples for chlorophenols and PAH was exceeded by 7-8 days. The hold time for chlorophenols extraction of Phase II marine water samples was exceeded by 17 days. The results of these samples might be biased low and were qualified as estimated.
- **Laboratory Field Blanks**: Some PAH, chlorophenols, and dioxins/furans were detected in laboratory method blanks. All sample data associated with these blanks were reported as undetected or at levels less than 5 times the blank concentrations and were therefore qualified as undetected. All field rinsate blanks reported all analytes as undetected.
- **Surrogate Spike Recoveries**: Surrogate spike recoveries were reported with the PAH (EPA Method 8270), chlorophenol, and dioxin/furan analyses. The PAH analysis required the addition of three surrogates (nitrobenzene, 2-fluorobiphenyl, and terphenyl). The chlorophenol analysis required the addition of two surrogates (2-fluorophenol and 2,4,6-tribromophenol). During both Phases I and II, the laboratory only added one surrogate (2,4,6-tribromophenol) to samples being analyzed for chlorophenols and only one surrogate (terphenyl) to samples being analyzed for PAH. The recoveries of these surrogates were acceptable; however, the addition of the other chlorophenol and PAH surrogate compounds would provide greater confidence in the accuracy of these data. Some surrogates in the dioxin/furan analyses were reported outside the working range of the instrument and quantitative interferences were indicated in some samples; therefore, the associated samples were qualified as estimated. This problem was not consistent between Phases I and II.
- **Matrix Spike Recoveries**: During Phases I and II, the laboratory had difficulties in recovering several matrix spike compounds. Recoveries of 2,4-dichlorophenol were inconsistent during both phases, either reported above or below the control limits. All 2,4-dichlorophenol data for Phase I and the affected 2,4-dichlorophenol data from Phase II were qualified as estimated. There also were problems during both phases recovering 2-chlorophenol. During Phase I, the spiking level was below the detection limit and the lab was unable to recover this compound. This lack of recovery data may also indicate incomplete derivatization, and therefore the data for Phase I were qualified as estimated. During Phase II, 2-chlorophenol was spiked at a higher level but was not recovered in the sediment or tissue samples. Therefore, the associated Phase II data were rejected. A low recovery of

tetrachlorophenol in sediments was also reported during Phase II. Because the recovery was only slightly low, nondetected results were not qualified and detected results were qualified as estimated. Spike recoveries for some metals were reported outside the control limits; these data were judged acceptable with some qualification.

- **Field Duplicates**: In general, field duplicate results were acceptable: below 50 percent relative percent difference (RPD). For some samples, an RPD greater than 50 percent for the chlorophenols was due to dilution of the sample or to detections of the analyte near the detection limit. Inconsistent and unacceptable variation was reported for 2,4-dichlorophenol in the Phase I samples. For PAH analyses, RPDs were greater than 50 percent in one sample but not in another for the same compound. Greater variability in sediment samples is expected. The RPD for metals and conventionals were within 50 percent. Most dioxins/furans were within 50 percent RPD; however, there was no pattern for those which exceeded 50 percent. The replicate frequency (5 percent) achieved during Phase I was consistent with PSEP guidelines and the Quality Assurance Plan, which was accepted by Ecology.

- **Confirmation**: Compound identification/confirmation was done by use of a confirmation column. Most data were acceptable without further qualification; however, some compounds were not confirmed. Pentachlorophenol was not confirmed in most of the Phase II sediments due to interferences on the chromatogram and these data were qualified as estimated. Benzo(k)fluoranthene and fluorene were not confirmed by UV detection for one Phase II marine water sample and the results were rejected.

3.0 PHYSICAL CHARACTERISTICS

3.1 SITE TOPOGRAPHY

The area between the highest tide and the lowest low tide at the north end of the Port Peninsula (referred to herein as the intertidal sediments) form a broad, gently sloping surface. The uppermost surface of the intertidal sediments is littered with partially sunken logs, old marine pilings, old tires, and other debris. The entire intertidal area covers approximately 40 acres (as measured at a -2.8 ft MLLW tide stage), and the Sediments Operable Unit at the Site (those sediments generally north and east of the Former Lease Area) covers approximately 25 acres.

Figure 12 shows the topography of the Sediments Operable Unit at the Site. Just east of the former wood treatment plant at the Site, the shoreline drops abruptly to an elevation of 5 ft (MLLW), and from there the surface of the intertidal sediments slopes downward to the east with a gradient of about 43H:1V. North of the former wood treatment plant, the shoreline drops to an elevation of 12 ft (MLLW), and from there the surface of the intertidal sediments slopes downward to the northeast with a gradient of about 53H:1V. A small rise in the sediment surface occurs approximately 250 ft offshore in the southwestern portion of the Sediments Operable Unit.

Aerial photos of the site (and the topographic map developed from the photos) show several major erosional channels in the sediment surface (Figure 12):

- One channel runs southeasterly along the shoreline at the southeast edge of the Sediments Operable Unit
- Three channels originate from areas between the NPDES outfall north of the former wood treatment plant and the alignment of the old log pond, and run due east.
- Two channels trend northeast from just to the east and north of the center of the Sediments Operable Unit
- Two additional channels are oriented in a northerly alignment off the north end of the Port peninsula; these channels appear to collect and channel permanent groundwater seepage that occurs at the shoreline and across the nearshore intertidal areas

Recent high resolution aerial photographs from the Site indicate that, except for a few minor meanders that have migrated, the drainage channels did not change their locations between July 1989 and July 1990. Land based observations in spring 1992 generally confirm this observation. Historical photographs with lower resolution indicate that the general location of the drainage channels through the intertidal area has been relatively constant since at least August 1985.

The current topography of the Sediments Operable Unit is altered from its historical surface as a result of dredging and fill activities associated with the building and development of the Port peninsula. The most recent major alteration to the sediment surface occurred in the early 1980s when the area south and immediately east of the former wood treatment plant was filled as part of the Port's East Bay development. Changes to drainage patterns likely occurred concurrently with the placement of fill along the east side of the uplands portion of the Site. Offshore dredging of a channel for marina access also occurred at that time. Figure 13 shows the intertidal topography at the site prior to the East Bay development.

3.2 GEOLOGY

The Site is located at the southern end of the Puget Sound lowland. The lowland is a broad north-south trending structural trough between the Cascade Mountains to the east and the Olympic Mountains and Willapa Hills to the west. At least 500 ft of glacial and interglacial unconsolidated sediments have been encountered beneath the area (AGI 1986).

Investigations in the Sediments Operable Unit distinguished three geologic units: 1) recent deposits consisting of fill and recent intertidal sediments, 2) marine sediments that comprise the upper aquitard, and 3) alluvial sands that comprise the Lower Aquifer. All of these units have been encountered beneath the peninsula in recent studies (AGI 1986, ESE 1992a). Seven geologic cross sections, located as shown on Figure 14, present general stratigraphic relationships (Figures 15 through 21).

The recent deposits in the Sediments Operable Unit range in thickness from greater than 13 ft at Boring E1 (west) to approximately 0.3 ft at Station G3 (east) (Figure 20). They consist of varying amounts of sand; silty sand; sandy silt; silt; clayey silt; and silty clay with shells, shell fragments, and wood debris. Recent deposits are thickest in the western nearshore area west of Stations C1, D1, and D2, where they consist of layered silty sand, sand, and silt. These recent deposits are interpreted to be predominantly fill; the thickest deposits appear to be associated with the area bounded by fill dikes installed in the 1930s that extended north from the northern shoreline (Figure 5). These deposits thin to the east and grade to predominantly gray to olive-gray silt. Where recent deposits are predominantly silt, they are interpreted to be a combination of dredged fill and recent intertidal sediments.

At most sampling stations, the upper layer of the recent deposits typically consists of black to olive-black organic silt and clayey silt up to 2.3 ft thick. This upper layer of intertidal sediments is thickest in the eastern nearshore area and thins to the west and north, which is consistent with site oceanographic characteristics (see Section 3.4.2).

Recent deposits as described in onshore studies (AGI 1986, ESE 1992a) are considerably thicker (between 17.5 and 26 feet) predominantly due to greater fill thickness related to filling the Port peninsula. Onshore, these deposits make up the fill aquifer (AGI 1986).

Underlying the recent deposits are tidal and subtidal marine deposits that make up the upper aquitard (AGI 1986). The upper aquitard encountered in the RI is typically olive-gray to dark olive-gray in color, consisting of stiff clay and silty clay. This unit has occasional silty and sandy zones with frequent but variable shells, shell fragments, and wood fragments. The upper aquitard was encountered throughout the Sediments Operable Unit and was completely penetrated at Stations C1, H2, and H3. At these borings, the upper aquitard is between 16.1 to 17.4 ft (490 to 530 cm) thick. The upper aquitard was also penetrated at Boring A2, but at this location, the aquitard thickness was significantly less (8.2 ft), due to dredging for the East Bay Marina.

As described by other studies (AGI 1986, ESE 1992a) the upper aquitard is continuous beneath the Port Peninsula, ranging in thickness from a maximum of approximately 40 ft near the center of the peninsula to approximately 10 ft to the east and 20 ft to the west. As described by AGI (1986), the upper surface of the upper aquitard is relatively flat, occurring at approximately -10 ft MSL (-2.2 ft MLLW). Based on borings by ESE (1992a), the upper surface of the upper aquitard varies in elevation locally on the uplands portion of the Site from approximately 1 ft to -6 ft MLLW. In the Sediments Operable Unit, this variation is pronounced in the vicinity of Boring C1 (Figures 15 and 20), where the aquitard forms a lip north and east of Well EW3. The extent of this lip is shown on Figure 22, which presents the interpreted upper surface of the upper aquitard in the Sediments Operable Unit and adjacent onshore area. The upper aquitard appears to reach a high point in the vicinity of Boring G3 at Elevation 2.6 MLLW, and a low point of approximately Elevation -8.8 ft MLLW at Boring A2, 125 ft to the east (Figure 20). The relatively high degree of variation in the upper surface of the aquitard in the eastern nearshore area is interpreted to be due to dredging activity. Variation in the eastern onshore area was interpreted in the SSI Report (ESE 1992a) to be due to dredging or to a possible mud wave that resulted in the lip in the aquitard upper surface.

Beneath the upper aquitard, silty sand and sand of the Lower Aquifer was encountered at Borings A2, C1, H2, and H3. These sand deposits are alluvium or possibly glacial outwash (AGI 1986). As described by AGI, the lower aquifer underlies the Port Peninsula.

3.3 HYDROGEOLOGY

The Fill Aquifer onshore at the Site discharges to Budd Inlet along the shoreline and through the nearshore sediment surface. Several distinct seeps have been identified along the shoreline at low tide; other seepage appears to occur more uniformly across broad expanses of the sediment surface. Several of the major drainage channels in the sediments become more distinct at varying distances from the shoreline, suggesting a convergence of disseminated seepage.

As part of the Expedited Seep Investigation, also conducted under the Consent Decree, several seeps along the shoreline were sampled for chemical evaluation. Four temporary piezometers also were installed in the sediments in pairs at two nearshore locations to evaluate hydraulic gradients, both vertically within the sediments, and horizontally between the Fill Aquifer onshore and the sediments. Piezometric data available from a pair of piezometers (ESE 1992a) show a downward gradient at all times over one tidal cycle (the piezometer screens ranged in elevation from 6.8 to 9.8 ft MLLW).

3.4 OCEANOGRAPHY

Saltwater enters Budd Inlet from Puget Sound via the Tacoma Narrows and Dana Passage (Corps of Engineers 1980). The surface area of Budd Inlet varies with the tides, from approximately 6 to approximately 7 mi^2 at MLLW and mean higher high water (MHHW), respectively. The mean tidal range for Budd Inlet (in West Bay) is 10.5 ft, with extreme tides recorded as low as -4.5 ft MLLW and as high as 18.2 ft MLLW (NOAA 1990b and Corps of Engineers 1980). Fresh water enters Budd Inlet from the Deschutes River, and to a lesser extent, as surface runoff.

The flushing rate in Budd Inlet is reported to be relatively fast compared to other bays and inlets in the vicinity, at approximately 2.8 tidal cycles (Corps of Engineers 1980), although data reported by URS and Evans Hamilton (1986) indicate that the flushing rate in Budd Inlet is only marginally above those for nearby Totten and Eld Inlets).

The physical action of the tides, wind, and waves at the Site affect both water circulation and sediment transport processes. Boat wakes also may affect sediment transport processes. In this section, the oceanographic features of the Site are summarized.

3.4.1 Tides

As noted previously, the mean tidal range for lower Budd Inlet is 10.5 ft. Tides in Budd Inlet are mixed diurnal tides, with a significant diurnal inequality, and a fortnightly cycle (a 2-week cycle in which tides of extreme highs and lows gradually change to shallow tidal variations).

Although tidal current data are not available specifically for the Site, the presence of fine-grained silt and sand nearshore suggests that the typical tidal currents are significantly less than 1 ft per second (fps) (Appendix F). Tidal current charts developed by NOAA are reported to show that currents in Budd Inlet are weak and variable, ranging in speed from 0.3 to 0.8 fps. Longshore currents, which run parallel to the shoreline, typically have mean values of 1 fps or less (Appendix F).

Based on grain-size data obtained during the RI, current velocities of an estimated 1.2 to 1.4 fps 3 ft above the sediment surface would be necessary to induce motion of the surface sediments (Appendix F). These velocities were calculated for a silt to sandy silt sediment with a grain size range from 0.06-0.25 mm. The density of typical clastic detrital debris is approximately 2.5 g/cm^3. In general, the finer grained the material is, the slower the current is that is required to resuspend it. In some cases, such as in the muddy deposits of Budd Inlet, fine silt and clay sized particles can exhibit cohesiveness and defy easy resuspension. This is due to particle-particle electrostatic influences and binding of sediment particles by organic matter or related biological structures.

An approximately 650-ft length floating breakwater is located immediately adjacent to the eastern boundary of the Sediments Operable Unit (Figure 12). The breakwater is held in place by wood pilings spaced approximately 50 ft apart. Approximately 4 ft of the dock extends below the water surface. The dock and pilings could attenuate the currents that cross the Site from the north or northwest to a small degree. Current velocity will also be lowered due to the change from shallower to deeper water in this vicinity. Some additional particle settling due to the attenuated currents may occur within the immediate vicinity of the breakwater (on the order of 10-20 ft) and under the breakwater.

3.4.2 Winds

Wind-induced waves are important sediment transport processes in nearshore areas. Winds at the Site are predominantly from the south and southwest; therefore, the Sediments Operable Unit is relatively protected from the prevailing winds. There are, however, occasions when storms with northerly winds generate waves along the shoreline, due to the fetch of open water (approximately 3-½ miles) north of the Site. Maximum wave heights of 2-2.9 ft have been predicted at the Site, using Corps of Engineers winds of record curves and December 1990 storm information.

The western portion of the Sediments Operable Unit is most likely to be subject to northerly winds and waves, and the predominance of coarser grained sediment in that area supports this model. To the southeast, near the breakwater, the sediments grade finer, suggesting a significantly more quiescent environment.

3.4.3 Vessel Traffic

Vessel traffic occurs in both the East and West bays of Budd Inlet. Traffic in West Bay is comprised of large ships that dock at the Port of Olympia for cargo transfers [approximately 50-70 ships annually, with no seasonal trends (Malin 1991)], and small boats that use West Bay facilities. In East Bay, the majority of the vessel traffic consists of small boats launched or docked at the East Bay Marina.

3.4.4 Sediment Accumulation and Mixing

3.4.4.1 Deposition

Sediment deposition in the Sediments Operable Unit occurs primarily as a result of sediment loading to Budd Inlet from the local watershed, and due to local resuspension and redeposition of marine sediments. The former process, input from the watershed, was predominant historically. In fact, the intertidal area upon which the Port Peninsula was constructed is interpreted as a depositional feature of the Deschutes River and Moxlie Creek. Sediment loadings from these sources have decreased dramatically over recent years, which in turn has decreased the influence of the process in the Sediments Operable Unit. Therefore, resuspension and redeposition of marine sediments is believed to be the current primary depositional influence in the Sediments Operable Unit.

3.4.4.2 Rate of Accumulation and Zone of Mixing

The distribution and inventory of excess Pb-210 activity within sediments can provide information about sediment accumulation and mixing. The typical Pb-210 distribution in deeper waters of Puget Sound consists of a surface-mixed layer (SML; due to biological or physical mixing of sediment), which has uniform Pb-210 activity, and a lower zone in which a logarithmic decay of excess Pb-210 activity occurs. The decay of Pb-210 in the lower zone is used to estimate the sediment accumulation rate. Accurate estimates of both the zone of mixing and the sediment accumulation rate using the Pb-210 technique are based on the following assumptions (Carpenter et al. 1985):

- Constant deposition rate and initial excess Pb-210 concentration during the last 150-200 years
- Loss of Pb-210 from sediment horizons is only by radioactive decay (e.g., no sediment mixing in depth horizons used to calculate accumulation rates, and no chemical mobility of Pb-210 after deposition)
- Mixing is confined to the SML and is constant with depth
- Individual intervals of sediment used for analyses have well defined depositional times and are short compared to the overall dating period
- Accurate knowledge of the decay constant for Pb-210.

As part of the RI, sediment cores were collected from three stations at the Site (C6, E6, and H4) for analysis of Pb-210 and Cs-137 as an aid to evaluation of sediment accumulation and mixing at the Site. The excess Pb-210 activity profiles (semi-log plots) from Stations C6, E6, and H4 are shown on Figure 23. These distributions do not exhibit well-defined surface-mixed zones except perhaps at Station H4 where the uniform excess Pb-210 layer is approximately 25 cm thick. The excess Pb-210 activity profiles also do not exhibit well-defined logarithmic decay of Pb-210 activity below an SML. Therefore, precise values for the depth of the mixing zone or the rate of sediment accumulation at the Site are not possible from these data.

When the Pb-210 profiles are nonclassical, and standard procedures based on the above five assumptions are not applicable, another way to estimate sediment accumulation is to compare the Pb-210 flux at the Site to other Pb-210 flux and sediment accumulation data in the Puget Sound region. Input of excess Pb-210 to Puget Sound is from suspended particulates in river water, atmospheric fallout, Pb-210 dissolved in seawater, and dissolved Ra-226 decay. The Pb-210 dissolved in sea water and Pb-210 from dissolved Ra-226 decay are scavenged from the

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water column by particles, and these particles along with the other Pb-210 associated with river borne and atmospheric particles settle to the seabed. The Pb-210 fluxes to the sediment in shallow bays are low [0.3-1.0 disintegrations per minute per square centimeter per year (dpm/cm^2/year) relative to open, deeper bays within the sound (1-10 dpm/cm^2/year) because sedimentary fluxes of Pb-210 in shallow bays or inlets, which are removed from large riverine discharges and dissolved sources, (Carpenter et al. 1984) are predominantly composed of riverine particles and atmospheric fallout. Carpenter et al. (1985) measured a Pb-210 flux of 0.3 dpm/cm^2/year in southern Puget Sound near the Nisqually River mouth.

The Pb-210 inventory for the three cores in the intertidal zone of the Site was calculated by integrating the excess Pb-210 activity (making water content corrections and assuming a supported activity of 0.3 dpm/g, based on the lowest value attained at depth) over the depth sampled. Dividing the inventory (dpm/cm^2) by the mean life of Pb-210 (22.3 years) gives a flux of excess Pb-210 to the sediment at Stations E6, H4, and C6 equal to 0.267, 0.438, and 0.497 dpm/cm^2/year, respectively (based on a particle density of 2.5 g/cm^3). As expected, these fluxes are comparable to the flux measured by Carpenter et al. (1985) in southern Puget Sound (0.3 dpm/cm^2/year), and much lower than those measured in the deeper bays (1-10 dpm/cm^2/year). Also, these values show a relative increase in flux with decreasing elevations of the sediment surface.

The sediment accumulation rate indicated by the decay of Pb-210 with depth below the surface mixed layer in data from subtidal locations throughout Puget Sound positively correlates with the excess Pb-210 flux to the seabed (see Figure 24). [The Puget Sound sediment data shown on Figure 24 are from Carpenter et al. (1985) and calculated from the data of Lavelle and Masoth (1985).] From this relationship, the sediment accumulation rate can be estimated. The regression of the data presented on Figure 24 predicts sediment accumulation rates of 0.19 ± 0.26, 0.20 ± 0.25, and 0.21 ± 0.25 g/cm^2/yr for locations E6, H4, and C6, respectively. The noted error bars identify the 95 percent confidence limits for the mean of the accumulation rate at a given Pb-210 flux (the confidence intervals are particularly large because the fluxes of Pb-210 at the Site are low). The estimates of the sediment accumulation rate based on the Pb-210 flux are considered to be upperbound estimates because a portion of the Pb-210 inventory could be due to resuspension of sediments with subsequent scavenging by these particles of Pb-210 from the water column and then redeposition, rather than input of new sediment. These accumulation rates are comparable to those measured in shallow bays of Puget Sound (Carpenter et al. 1985), but much lower than those rates measured along the axis of the Main Basin of Puget Sound (Lavelle et al. 1985).

Examination and comparison of 1979 sediment surface elevations with present bathymetry of the intertidal area shows that the locations of the core samples for Pb-210 analysis (C6, E6, and H4) have only experienced minimal changes in elevation since before the recent filling activities.

The distribution of Cs-137 from bomb testing can be used to test the validity of the Pb-210 flux-based accumulation estimates (Nittrouer et al. 1984). Cesium is particle-reactive in the aquatic environment, but less so than lead, and some mobility during diagenesis has been observed (Beasley 1982). Cs-137 is produced during nuclear fission reactions and its injection into the atmosphere peaked in the early 1960s. (Nuclear reactor operations can also discharge radionuclides such as Cs-137 and represent another possible Cs-137 source for sediment.)

The Pb-210 fluxes indicate sediment accumulation of 0.26-0.29 cm/yr at the Site. At these accumulation rates, the peak in Cs-137 would be buried 8-9 cm in 30 years (the approximate time interval since the peak in testing). This estimate assumes that mixing is not important; variability in grain size or mineralogy or nonsteady state conditions would complicate this interpretation. The highest Cs-137 activities (Figure 23) are restricted to the upper few centimeters of sediment in Cores E6 and C6 and the upper 5 cm in Core H4. Nevertheless, these distributions are generally consistent with the Pb-210 flux-based accumulation rate estimates. Burial of the Cs-137 peak by greater sedimentation rates in the past and subsequent erosion leaving the peak near the surface today is another scenario consistent with the observed Cs-137 distribution.

3.4.5 Sediment Resuspension and Transport

The influences of the various oceanographic processes on sediment resuspension and transport at the Site were evaluated as part of the RI. Storm waves were predicted using climatic data and the physical parameters of the Site, and subsequently, sediment resuspension rates were predicted (Appendix F). The results of the evaluation are as follows:

- Storm waves resulting from northerly winds refract as they move south in Budd Inlet and approach the Site. The resultant angle of attack in the Sediments Operable Unit is skewed toward the east because of the shoreline bathymetry. Therefore, sediments resuspended by these storm waves would be expected to move easterly along the shore and to the offshore.

- Wind waves from West Bay that refract around the point also will have an easterly skew. The short fetch available to the generation of these winds, combined with other factors, make this contribution insignificant.
- Ship wakes from the West Bay channel also have a skew towards the east as they reach the shoreline, resulting in an easterly transport of any sediments they resuspend. The area of resuspension for this process is immediately east of the Port of Olympia deep draft terminal. Due to the slow speeds of the vessels when approaching the terminal dock, this contribution is determined to be insignificant, relative to natural wave conditions, because of the resultant smaller waves and shorter duration of the wave train.
- Prop-wash from departing vessels and maneuvering tugs in the West Bay channel may affect the Site. This would occur after vessel loading, as the departing vessels make the turn into the outer channel. The effect of this prop-wash can not be determined with the available data; however, the localized turbulence of the prop wash during turning is estimated not to be significant because of the distance from the shoreline and the limited duration of the activity. An estimated current velocity at the Site, caused by prop-wash, is on the order of 0.5 ft per second.
- Small recreational craft in the East Bay channel leaving the East Bay Marina will provide some wake energy that could result in transport in the opposite or westerly direction. However, the small vessel transport is not expected to be significant when compared to the natural waves at the Site.

As waves approach the shore, they generate velocities throughout the water column. The velocity profile is one of decreasing velocity with depth, and at a critical depth, the velocity is no longer sufficiently high to maintain suspension of sediments. Based on the maximum storm waves predicted for the Site, sediment resuspended with the Sediments Operable Unit would be redeposited in water approximately 13 ft deeper than the tide at the time of the storm (or at elevations greater than -17 ft MLLW if the storm coincided with a tide equal to or less than -4 ft MLLW) (Appendix F). Estimates of longshore transport of sediments were made for the Sediments Operable Unit.

The estimates of long-term average annual sediment resuspension are as follows (Appendix F):

- Storm waves due to northerly winds: resuspension of approximately 1,470 yd^3 per year
- Storm waves due to northwesterly winds: resuspension of approximately 20 yd^3 per year
- Deep draft vessel wakes: resuspension of approximately less than 1 yd^3 per year.

These estimates are considered to be conservative (biased high) annual volumes, and are based on annualized storm predictions. Note that these values are not considered to be estimates of a net loss of sediments from the Sediments Operable Unit. A portion of the sediments resuspended from the intertidal area west of the Sediments Operable Unit would resettle within the Sediments Operable Unit. Similarly, a portion of the sediments resuspended in the higher intertidal areas of the Sediments Operable Unit would resettle in lower elevations within the Sediments Operable Unit.

Some erosion may also occur in the drainage channels that exist in the sediment surface. Due to the observed relative stability of the channels over time, the volume of sediment transported in this manner may not be significant compared to that resuspended and transported by wave action. The data necessary to quantify this process is not available at this time.

Net sediment deposition (or loss) rates cannot be calculated for the Site without long-term, controlled monitoring. The Sediments Operable Unit is a low-energy environment, and in general, the greatest sediment resuspension is expected to occur in areas exposed to northerly storm wave action with elevation generally greater than +5 ft MLLW (Hartman 1992).

4.0 NATURE AND EXTENT OF CONTAMINATION

4.1 SEDIMENT CHEMISTRY

All Phase I and Phase II chemical results for sediment samples are presented in two tables:

- Table C-2 in Appendix C in which the chemical results are presented as reported by the laboratory (in dry weight)
- Table C-3 in Appendix C, which is similar to Table C-2, but in which: 1) PAH and dibenzofuran concentrations have been normalized to TOC, 2) LPAH does not include 2-methylnaphthalene, and 3) dioxin and furan concentrations have been converted to 2,3,7,8-TCDD toxicity equivalents (TEQ). These conversions are explained further in Section 4.1.1.

Table C-1 in Appendix C clarifies the sample numbering system, data qualifiers, and other pertinent information to aid the reader.

Within the main body of this report, the Site data are summarized in Tables 2 (organic parameters) and 3 (metals). Table 4 presents a summary of the sediment chemistry data from the three background stations in Budd Inlet that were sampled during the RI (the RI background samples RI were collected from the 0-10 cm interval only). The locations of the RI background samples were chosen to avoid known point source discharges of contaminants through an evaluation of previous studies in Budd Inlet (Tetra Tech 1988c) and visual observations; care also was taken in the field prior to sampling to avoid obvious point sources.

Comparisons of Site data to the RI Budd Inlet background samples and to data from other sampling events within Budd Inlet and other Puget Sound locations are made in the RI to help identify areas of the Site with clearly elevated concentrations. For the purpose of this RI, use of the term "background" refers to areas that generally (unless otherwise indicated) represent the conditions that would be expected at the Site if the Site had not contributed contaminants to the environment, and therefore that are likely to be affected to some degree by urban or industrial sources of pollution in lower Budd Inlet. Conversely, use of the term "reference areas" refers to areas considered relatively pristine, not affected by urban or industrial sources of pollution. This use of the terminology "reference areas" is generally in accordance with the use of that term in the PSEP guidance, but the use of the term "background" in this RI is not intended to be synonymous with the rigorous definition of that term under the Model Toxics Control Act (MTCA).

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For these comparisons in the RI, it is recognized that the small number of Budd Inlet background samples does not support statistical treatment, nor are three samples sufficient to characterize area background under MTCA for the purposes of determining cleanup levels. However, the data is of use in a qualitative comparison of Site samples to determine which Site samples are clearly elevated, and therefore Site sample concentration are compared to the range of concentrations detected in the three Budd Inlet background samples (and the one duplicate background sample).

Data on background concentrations in other areas of Puget Sound are summarized in Table 4. The "Pollutants of Concern in Puget Sound" database (PTI 1991a) presents 90th percentile concentrations for reference areas (which consisted of seven bays in rural areas), for urban bays (which included bays in heavily industrialized areas including Elliott and Commencement Bays), and for nonreference areas (which included the urban bays and adjacent areas such as Central Puget Sound that exhibited elevated contamination above that found in more rural reference areas). The document *Reference Areas Performance Standards for Puget Sound* (PTI 1991b) presents standards with which to evaluate the suitability of an area as a reference area. Comparison of the Budd Inlet samples to the reference area concentrations (PTI 1991b) confirms the intermediate status of Budd Inlet, which is not pristine enough to be a reference area, but not industrialized enough to warrant status as an urban bay.

The Phase I and Phase II chemical results are discussed in detail in the following sections.

4.1.1 PAH

As noted earlier, PAH were analyzed for in most samples obtained during the RI due to the prevalence of PAH in creosote. For the purposes of evaluating the RI data, the following conventions were used:

- For sums, such as LPAH, HPAH, TPAH, and CPAH, nondetected PAH compounds were included and assigned the detection limit value. This approach is consistent with the criteria outlined in the Sediment Management Standards (WAC 173-204) and historical sediment quality data. The use of detection limit values for undetected compounds does overestimate the known PAH concentration and may be, therefore, a very conservative assumption. With the low detection limits achieved in the Sediment RI analytical program, this conservative assumption was deemed acceptable for the data evaluation presented in this RI. However, such a conservative approach may not be appropriate for all uses of the Sediments RI data (e.g., risk assessment). Additional PAH compounds (TICs) were tentatively identified by the laboratory at estimated concentrations but cannot be used quantitatively, and therefore were not included in the PAH sums. The presence of these PAHs may, in part, counteract the conservatism of using the detection limit for nondetects.

- Estimated values (qualified "J") were assumed to be equal to that estimated value.
- 2-Methylnaphthalene was included in calculated LPAH concentrations except in the text, figures, and tables that compare Site sediment chemistry to the Sediment Management Standards.

In addition, PAH concentrations presented in Table C-3 (Appendix C) were normalized on a TOC basis. Nonpolar organic chemicals such as PAH tend to adsorb to organic carbon (the more labile, or bioavailable, portion of the sediments). The normalization of PAH concentrations to TOC accounts for the "skew" of these chemicals toward the more bioavailable portion, and allows for regulatory criteria comparisons (e.g., to the Sediments Management Standards). Whenever normalized concentrations are used, they are reported as "milligram per kilogram (mg/kg) organic carbon."

The areal distributions of nonnormalized LPAH and HPAH are shown on Figures 25 through 27 and 29 through 31 for the top three depth intervals sampled (0-10 cm, 10-55 cm, and 55-100 cm). These intervals correspond generally to the intervals with the highest concentrations of the chemicals of concern. Concentration contour lines have been hand drawn on these figures as an aid in assessing the data. For clarity, the boring identification numbers have been omitted from these figures, but can be determined by comparison to Figure 7. The areal distributions of nonnormalized LPAH and HPAH below 100 cm in depth (the D, E, and F Zones) are shown on Figures 28 and 32, respectively.

4.1.1.1 Concentrations of LPAH

As shown in Figure 25, the highest LPAH concentration in the upper 10 cm (the A Zone) was 87,170 µg/kg at Station C1 near the shore. Two other stations, D3 and G3, also contained LPAH concentrations above 10,000 µg/kg in the A Zone. In total, 34 of the 43 stations sampled in the A Zone contained LPAH concentrations above the highest of the background concentrations (which ranged from 700 to 1,100 µg/kg DB and three station sampled in the A Zone contained LPAH concentrations within the range of background LPAH. Lastly, 9 of the A Zone samples (less than 8 percent) were reported to contain LPAH at levels that exceed the

90th percentile from nonreference areas in Puget Sound, and 6 of these exceeded the 90th percentile for urban bays (Table 4). When the LPAH concentrations were normalized to TOC, there was no change in the relative distribution of LPAH. The highest normalized concentration in the A zone (1,900 mg/kg organic carbon) was at Station C1.

The concentrations of LPAH in many 10-55 cm depth interval (the B Zone) samples were increased relative to the A Zone concentrations at those stations. As shown on Figure 26, seven stations contained concentrations above 10,000 µg/kg. All but one of these were in the area between the B and D transects, and within 200 ft of the shore. The highest concentration in this zone was found at Station B3 (970,000 µg/kg). In total, 22 of the 27 stations sampled in the B Zone contained LPAH concentrations above the highest of the background concentrations and one B Zone sample fell within the range of background LPAH concentrations. The B Zone contains 5 stations with TOC greater than 6 percent. The LPAH values at the stations become relatively lower when normalized to TOC concentrations. In particular, the elevated concentration at Station D3 becomes significantly less elevated relative to other B Zone samples, whereas that for Station F1 becomes more elevated relative to other B Zone samples.

The highest concentration of LPAH in the 55-100 cm depth interval (the C Zone) was 660,000 µg/kg at Station C1 (Figure 27). Six stations contained concentrations of LPAH above 10,000 µg/kg. In total, 11 of the 26 stations sampled in the C Zone contained LPAH concentrations above the highest of the background concentrations and two C Zone samples fell within the range of background LPAH concentrations. In general, however, the concentrations in the C Zone were lower than those in the B Zone. When the LPAH data from the C Zone are normalized to TOC there is little relative change in distribution across the site, although the relative elevation of the concentration for Station D3 diminishes somewhat.

Below the 100-cm depth (but above the aquitard), sampled intervals indicated LPAH concentrations approximately equal to (Samples E1F and H6E) or lower than (Samples E4E and H8E) the LPAH concentrations reported in the 55-100 cm interval (Figure 28). Below the 100-cm level, within the aquitard, LPAH concentrations were either approximately the same (Samples G3E, H1E, H2D, H3E, H5E) or much lower than (Samples C1E, C2E, D3E, and H9F) the LPAH concentrations in samples from above the aquitard. One exception to this was Sample A2D, in which LPAH was significantly higher in the aquitard sample (18,000 ppb in Sample A2D versus 2,500 ppb in Sample A2C). Three of the stations sampled below 100 cm contained LPAH concentrations greater than the highest of the background concentrations (Samples A2D, G3E, and H9F) and two samples (C1E and E1F) contained LPAH at concentrations that fall within the range of the background LPAH concentrations. Normalization of the data to TOC did not appreciably change the distribution of LPAH below the 100 cm depth interval.

4.1.1.2 Concentrations of HPAH

The concentrations of HPAH detected in samples from the A Zone (0-10 cm) are shown on Figure 29. The highest concentration in the A Zone was found at Station C1 (61,000 µg/kg). Eight other A Zone samples had concentrations in excess of 10,000 µg/kg. Most of the stations with high concentrations of HPAH in the A Zone were located within 300 ft of the shore in the area of the B and C transects. Another area of elevated concentrations was observed closer to the shore near the F transect. In total, 32 of the 43 stations sampled in the A Zone had concentrations of HPAH above the highest of the background concentrations (which ranged from 1,400 to 2,200 µg/kg DB) and 8 samples had concentrations that fell within the range of the background HPAH concentrations. Only 3 of the A Zone samples (less than 3 percent) were reported to contain HPAH at levels that exceed the 90th percentiles for both nonreference areas and urban bays in Puget Sound. Normalization of the HPAH data to TOC did not appreciably change the relative distribution in the A Zone across the site.

The highest concentration of HPAH in the B Zone was found at Station B3 (810,000 µg/kg) approximately 200 ft from shore, near 0 ft MLLW (Figure 30). In general, the area between the B and C transects, which contained high concentrations in the A Zone, contained higher concentrations in the B Zone. Ten stations contained concentrations of HPAH exceeding 10,000 µg/kg. In all, 21 of the 27 stations sampled in the B Zone contained concentrations above the highest of the background concentrations, and one sample fell within the range of the background concentrations. As with the LPAH, normalization of the data to TOC significantly reduced the relative elevation of HPAH at D3, due to the high TOC concentration in that sample (8.2 percent).

The highest concentration of HPAH in the C Zone, as shown on Figure 31, was found at Station C1 (280,000 µg/kg). Five other stations in the intertidal area between the B and D transects contained HPAH concentrations exceeding 10,000 µg/kg in the 55-100 cm depth interval. Nine of the 26 stations sampled in the C Zone exceeded the highest of the background concentrations. At stations at which both the B and C Zones were analyzed, the concentrations of HPAH were lower in the C Zone. Normalization of the data to TOC did not change the general distribution of HPAH in the C Zone, but did diminish the relative elevation of HPAH at Station D3 and increase the relative elevation of HPAH at Station H9.

Below the 100-cm depth HPAH, concentrations were equal to or lower than those reported in the 55-100 cm interval. This trend is similar to that observed for LPAH with one exception: HPAH dropped significantly between Samples G3C and G3E, whereas LPAH concentrations in these samples were approximately the same. Figure 32 presents data on HPAH below 100 cm (in the D, E, and F Zones). The sample collected at Station A2D had higher concentrations of HPAH (30,000 µg/kg) than did either of the samples collected above it. It is unclear whether this represents an increasing downward trend or whether it represents HPAH emplaced laterally.

Only one of the samples collected below 100 cm (Sample A2D) had HPAH concentrations above the highest of the background concentrations and one sample (H9F) had an HPAH concentration that fell within the range of the background HPAH concentrations.

4.1.2 Concentrations of PCP and Other Chlorophenols

Sediment PCP concentrations in the A Zone are shown on Figure 33. The highest PCP concentrations in the A Zone were found at Stations H1 (240 µg/kg) and F1 (140 µg/kg average of Phase I and Phase II samples). In all, 37 out of 44 stations sampled in the A Zone contained PCP at concentrations above the highest of the background concentrations (which ranged from 3.0 to 6.1 µg/kg) and four contained PCP within the range of background concentrations. No site samples were detected above the 90th percentile value for nonreference areas and urban bays.

The two highest PCP concentrations in the B Zone, as shown on Figure 34, were found at Stations C1 and C2 (100 and 220 µg/kg, respectively). The concentrations at these two stations increased greatly (over an order of magnitude for Station C2) over the concentrations in the A Zone (conversely, the two stations with the highest concentrations in the A Zone contained PCP concentrations in the B Zone below (Station F1) or only slightly above (Station H1) the range of background PCP concentrations. Stations C1, C2, and H1, and an additional 11 other stations, were above the highest of the background concentrations.

While most of the samples from the C Zone contained no detectable PCP (Figure 35), one station (C1) contained PCP at 140 µg/kg. Three additional samples contained PCP above the highest of the background PCP concentrations.

In addition to PCP, five other chlorophenols were analyzed for in the sediment samples: tetrachlorophenol, 2,4,5-trichlorophenol, 2,4,6-trichlorophenol, dichlorophenol, and 2-chlorophenol. In most of the sediment samples, there were scattered detected concentrations of chlorophenols near the detection limit. Only 2,4-dichlorophenol and tetrachlorophenol were reported at concentrations more than twice the detection limit. There were six samples widely scattered across the Sediments Operable Unit at which elevated concentrations of 2,4-dichlorophenol were detected: A1A, A2C, C2A, D4B, E5A, and H9F. The detected concentrations ranged from 300 to 630 µg/kg. Only one sample (C2B) had detected concentrations of tetrachlorophenols. There did not appear to be a distinct relationship between other PCP concentrations and other chlorophenol concentrations, except that Station C2, the station at which both 2,4-dichlorophenol and tetrachlorophenol were detected, also contained 220 µg/kg PCP in the B Zone.

Below the 100-cm depth, PCP was reported either as nondetected or at estimated levels approximately equal to or lower than concentrations reported for C Zone samples, as shown on Figure 36. The highest concentration of PCP below 100 cm was at H5E (41J µg/kg DB). This sample and one other (Sample A2D) contained PCP above the highest of the background concentrations.

4.1.3 Concentrations of Dibenzofuran

Dibenzofuran, a constituent of creosote, was detected in sediment samples at concentrations ranging up to 100,000 µg/kg (Sample B3B) (Table 2). Dibenzofuran was present at concentrations exceeding the highest of the background concentrations (which ranged from 58 to 65 µg/kg DB) in approximately half of the sediment samples, and as expected, its presence coincided with areas of high LPAH and HPAH concentrations. There was no Reference Area 90th Percentile value reported for dibenzofuran, although the median value detected in the reference areas was 14 µg/kg. The 90th Percentile for urban bays was 560 µg/kg (PTI 1991b).

Below 100 cm, dibenzofuran was reported either as nondetected, or at levels approximately equal to or lower than concentrations reported for C Zone samples (Figure 40). Once again, Sample A2D was an exception to this.

Dibenzofuran concentrations in the A, B, and C Zones are presented on site maps on Figures 37 through 39. Contour patterns are similar to those presented for HPAH and LPAH.

Below 100 cm, dibenzofuran was reported either as nondetected, or at levels approximately equal to or lower than concentrations reported for the C Zone samples. Once again, Sample A2D was an exception to this.

4.1.4 Concentrations of Metals

Ten metals (antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc) were analyzed for in sediment samples from both the Sediments Operable Unit and background locations. The analytical results are summarized in Table 3. Because of the small number of background samples collected for the RI and because the data are all from the 0-10 cm interval, the Site metal data were compared to both the RI Budd Inlet background sample concentrations and to the 90th percentile of the Puget Sound Reference Areas (PTI 1991b) to determine whether concentrations in the Site samples represented concentrations elevated above background. To accomplish this, the upper bound of the concentration range for the three Budd Inlet samples (and the one duplicate) was used for comparison. In many cases, the highest Budd Inlet background concentrations were well below the 90th percentile concentrations for the Puget Sound Reference Areas (PTI 1991b), as shown in Table 4. Three of the metals (cadmium, lead, and silver) were detected in the Budd Inlet samples above the 90th percentile for the reference areas.

Two Site sediment samples (H2C and H2D) contained clearly elevated concentrations of several metals: cadmium, chromium, copper, and zinc. Chromium and copper are common components of certain wood preserving processes and may represent some influence of treated wood.

Antimony was not detected in any of the Site or background sediment samples. The detection limit (0.1 mg/kg) was well below the Reference Area 90th percentile.

Arsenic was detected in one sediment sample (C1C) above the Budd Inlet background maximum of 8.5 mg/kg, but below the Reference Area 90th percentile of 17.4 mg/kg.

As mentioned above, cadmium was clearly elevated in two samples: H2C (4 mg/kg) and H2D (12 mg/kg). One other sample (Sample A3A) exceeded the Budd Inlet background maximum of 2.2 mg/kg. The Reference Area 90th Percentile value (1.57 mg/kg) was lower than the highest concentration of the Budd Inlet samples, and seven additional samples (A1A, A2A, C1B, C1C, C2A, C2B, and G3E) exceeded this value.

Two Site samples contained chromium at concentrations clearly elevated above the rest of the samples at the Site, one in H2C (150 mg/kg) and one in H2D (350 mg/kg). The highest Budd Inlet background concentration was 28 mg/kg. Numerous Site samples slightly exceeded this, ranging up to 35 mg/kg; these probably do not represent elevated concentrations. The Reference Area 90th Percentile value is 142 mg/kg.

The highest copper concentrations were detected in samples H2C (230 mg/kg) and H2D (410 mg/kg), described above, as well as in sample C2C (240 mg/kg). Samples from 17 stations contained copper at concentrations above either the highest of the Budd Inlet background concentrations or the Reference Area 90th Percentile values (49 and 52.9 mg/kg, respectively).

The highest of the lead concentrations in the Budd Inlet samples (42 mg/kg) was above the Reference Area 90th percentile (27.5 mg/kg). Only two Site samples contained lead above either of these values (Sample H2D, which contained elevated concentrations of other metals as well, and Sample C1B, which was above the reference area value but below the background maximum).

Several Site samples exhibited mercury concentrations slightly above the highest of the Budd Inlet background mercury concentrations (0.12 mg/kg), however, only three samples also exceeded the Reference Area 90th Percentile value of 0.176 mg/kg. These three samples were C1C (0.37 mg/kg), C2B (0.33 mg/kg), and G3B (0.21 mg/kg).

Over half of the samples slightly exceeded the highest of the Budd Inlet background concentrations for nickel (23 mg/kg); however, no samples exceeded the Reference Area 90th Percentile value of 66 mg/kg. The exceedances are most probably caused by the Budd Inlet samples not representing enough variability in background sediment concentrations.

Only two sediment samples from the Site contained detectable concentrations of silver, and these were estimated concentrations that were reported at or just above the detection limit (1 mg/kg). The detection limit for the Budd Inlet background samples was slightly lower than that for most of the Site sediment samples, resulting in detected concentrations of silver in these samples. The highest Budd Inlet background concentration (0.71 mg/kg) was higher than the Reference Area 90th Percentile value of 0.38 mg/kg. Two sediment samples, C2B (duplicate only) and E1A were reported at 1.1 and 1.0 mg/kg, respectively. The distribution of silver at the Site below 1 mg/kg is not known, and the possibility remains that there may be areas with concentrations slightly greater than the Reference Area value. However, there is no evidence for high levels of silver contamination at the Site.

Two Site samples contained zinc at elevated concentrations: H2C (270 mg/kg) and H2D (580 mg/kg). Several other stations slightly exceeded the highest of the Budd Inlet background concentrations for zinc (79 mg/kg), but were below the Reference Area 90th Percentile value of 99.7 mg/kg.

In summary, the highest concentrations of metals were found in the two sediment samples H2C and H2D. Of these two, only H2D exceeded Sediment Management Standards for any metals (cadmium, chromium, and copper exceeded the CSL; zinc exceeded the SQS). Only one other sediment sample (Sample C12B, a duplicate sample from Station C2) exceeded the standards for metals, as discussed in Section 4.1.11. In comparison to measures of background and reference areas, there were some elevations of cadmium, copper, and mercury concentrations in Site sediment samples. Cadmium exceeded the Budd Inlet background range for one sample and exceeded the Reference Area 90th percentile for 6 samples. Copper exceeded both the background and Reference Area concentrations for 15 out of 29 samples collected. Mercury exceeded both the background and Reference Area concentrations for three samples.

4.1.5 Concentrations of Dioxins and Furans

As noted previously, dioxin and furan data for sediments are presented in Table C-2, as reported by the laboratory, and in Table C-3 as TEQs (both in Appendix C). The TEQs result from an adjustment of the individual congener concentrations according to a toxicity equivalency factor (TEF), which weights each congener by its toxicity relative to the most toxic isomer, 2,3,7,8-TCDD. The sum of the adjusted concentrations is referred to as the TEQ and is reported in µg/kg TEQ (EPA 1989). TEQs were developed and adopted by EPA as a procedure for assessing the health risks associated with exposure to mixtures of dioxin and furan compounds (EPA 1989). The TEQ concentrations for the RI sediment samples are summarized in Table 2, and the background sample TEQs are presented in Table 4.

Dioxins and furans were detected in all 30 of the onsite sediment samples and duplicates, as well as in the three background samples. The total dioxin and furan concentrations were dominated by the presence of hexa-, hepta-, and octa-chlorinated congeners, congeners which have been detected in abundance in technical grade PCP. Concentrations of OCDD in PCP have been reported as high as 2,500 ppm, with concentrations of hepta- and hexa-chlorinated congeners as high as 520 and 29 ppm, respectively (reported in Hackett et al., 1986). Although the TEFs for these congeners are low (reflecting their relatively low toxicity compared to that of TCDD), because the composition of congeners in Site samples is fairly uniform, the total TEQ calculated for all congeners is a fairly consistent and a good measure of both toxicity and total dioxin and furan distributions.

Dioxin and furan concentrations (as µg/kg TEQ) are presented on areal maps for the A, B, and C Zones (Figures 41 through 43) and Zones D, E, and F (Figure 44). The presence of the most toxic isomers, those containing 2,3,7,8-substitution, are best interpreted through the use of the TEQ. Only one sample (C1B) had a TEQ greater than 1 µg/kg (1.29 µg/kg TEQ). Of the five samples with the highest TEQ, three were from the top three intervals from Station C1. Samples C2B and F1A were also among the five highest TEQs. It should be noted that nondetected dioxin and furan compounds were included and assigned the detection limit value when calculating total dioxin and furan TEQ. The use of detection limit values for undetected compounds overestimates the total dioxin or furan concentration and is a conservative approach. However, because of the low detection limits, a substitution of zero would not significantly lower the resultant TEQ.

Almost half of the onsite sediment samples analyzed contained dioxins and furans above the highest reported concentrations in the background surface samples (see Table 4).

4.1.6 Tentatively Identified Compounds (TICs)

In addition to reporting the requested analytes, the laboratory also reported tentatively identified compounds (TICs) in sediment samples. TICs are compounds that the laboratory identifies through comparisons to a library of mass spectra, but for which standards were not run. Therefore, the identification is tentative, and the reported concentration is only an estimate. The TICs reported for site sediment samples were primarily aliphatic and aromatic hydrocarbons, additional PAH compounds, and water soluble constituents such as carboxylic acids, alcohols, ketones, and aldehydes. Reported concentrations were generally in the very low mg/kg (ppm) range. Individual compounds are tabulated and discussed in terms of their toxicity in the Sediments Risk Assessment (Landau Associates 1992). TIC data were not validated and may in part represent laboratory contamination.

4.1.7 Concentrations of TOC

Organic carbon in sediments can be derived from natural sources such as plants and animals, as well as from anthropogenic sources. TOC data are used in evaluating criteria for the Sediments Management Standards and can be used to estimate partitioning of hydrophobic organic constituents onto sediments. TOC concentrations (in percent) are presented for the A, B, and C Zones on Figures 45 through 47 and for depths below the C Zone on Figure 48. Onsite sediment TOC values range from 0.28 to 9.49 percent. Generally, TOC concentrations at individual sampling stations do not appear to significantly change with depth.

The upper range of TOC values are above both those measured in the Budd Inlet background samples (background concentrations range up to 4.3 percent) and the value reported as the performance standard for reference areas (2.5 percent) (PTI 1991b). Additional samples collected from Budd Inlet as part of the Puget Sound Ambient Monitoring Program (TetraTech 1989) contained 2.2 and 3 percent TOC. The detected organic contaminant concentrations at the high TOC stations are not high enough to account for a significant amount of the reported TOC. Four of the 8 samples containing the highest TOC values (greater than 6 percent), contained visual evidence of NAPL. For these stations, it is possible that the unidentified (not reported by the laboratory) NAPL constituents could have contributed to the elevated TOC values. For the other stations, the most likely contribution to TOC is localized decomposing organic matter such as wood debris.

The Sediment Management Standards require normalization of the PAH data to TOC to reflect and compensate for the affinity of PAH compounds to soil organic matter. This normalization has the effect of leveling out areas with elevated organic chemical concentration that correspond with localized high TOC values. Because this effect can potentially mask the distribution of total PAH, nonnormalized concentrations were discussed and mapped in Section 4.1.1.

4.1.8 Evidence of NAPL in Sediments

Oil-based wood-treating solutions such as creosote and the 5 percent PCP solution used at the Site, like other organic liquids of low aqueous solubility, may enter and remain in sediments and associated water as relatively pure, nonaqueous phase liquid (NAPL). NAPL may be present as pools of liquid (saturated interstitial pores) or as small globules trapped within soil or sediment pores (unsaturated interstitial pores). Mobility behavior and remediation techniques of NAPL can be very different from those pertaining to dissolved contamination, and NAPL in soil or sediment can act as long-term sources of dissolved contamination.

There are currently no analytical methods available to confirm the presence of NAPL in soil or sediment. The presence of NAPL must be inferred from physical evidence, including visual observation, or from estimation methods such as comparing individual solubility limits of the chemicals thought to comprise the NAPL with porewater concentrations that were calculated from sediment concentrations.

During the collection and logging of the RI sediment samples, visual evidence of the possible presence of NAPL, either as a visible sheen/oil or through UV light detection, was recorded in field notes. These observations are shown in Table 5. (Table 5 omits observations of oil and/or sheens on the outside of the core only, because this simply may have represented carrydown within the sampler.)

As an additional tool to evaluate the potential presence of NAPL, the concentrations of the individual PAH expected to occur in the interstitial porewater that is in equilibrium with the sediments were estimated, and these estimated porewater concentrations were compared to the individual PAH aqueous solubility limits (the PAH concentrations in porewater in equilibrium with each sediment sample were estimated using partitioning coefficients calculated from literature values of log Koc, measured TOC concentrations, and estimates of porosity and density, and were compared to literature values of aqueous solubility of PAH compounds. It is important to note that actual porewater concentrations may be somewhat different due to a number of site-specific factors; however, it is the theoretical porewater concentration as calculated that yields information concerning the presence or absence of NAPL). Estimated porewater PAH concentrations that exceeded the aqueous solubilities were assumed to be evidence of NAPL in the sediment. The results of this comparison are shown in Table 5, along with LPAH and HPAH data for each sample.

The comparison of calculated porewater concentrations directly to literature aqueous solubility values may be biased towards underestimating NAPL for several reasons. These include site-specific factors that could alter the actual solubility limit, such as temperature and salinity. Also, the maximum concentrations of individual chemicals that a multicomponent NAPL may yield to solution are expected to be less than the maximum aqueous solubilities of those individual chemicals in pure water (EPA 1992a; Feenstra et al. 1991). The "effective solubility" (calculated from multiplying the aqueous solubility by the proportion of that constituent in the mixture) becomes very small for creosote and other complex mixtures. This makes the comparison very sensitive to the value of aqueous solubility used, and literature values for aqueous solubilities vary appreciably. Also, the effective solubility values will change as the NAPL migrates and weathers. The use of effective solubilities for complex mixtures such as creosote (as opposed to mixtures with only a few components) is judged to significantly increase the chance of predicting NAPL where there is none. Therefore, interpretations of NAPL-containing sediment within this RI have been limited to comparisons of theoretical porewater concentrations to aqueous solubilities. To evaluate the sediment samples most sensitive to becoming false negatives with this approach, an accounting was made of those samples with theoretical porewater concentrations of any PAH greater than 50 percent of its aqueous solubility. These samples include A2D, B2C, D3C, and G3B. Reducing the cutoff to 30 percent adds the following samples: B2A, C2C, D1B, E2B, F1B, G3A, G7A, and H12B, and of these, E2B, G7A, and H12B are most tenuous due to only one chemical exceeding the cutoff. There is a possibility that NAPL may exist in some of these samples, but the evidence does not warrant a positive conclusion.

Table 5 lists all RI sediment samples for which there are chemical data to evaluate for the presence of NAPL, as well as those samples not sent for chemical analysis but for which there is field evidence of NAPL (note that not all samples that contained visible product were analyzed chemically). As seen in Table 5, all of the samples that had sediment concentrations which yielded exceedances of maximum aqueous solubility values also had visual evidence of NAPL. Several samples in which NAPL was recorded in the field did not yield calculated exceedances based on chemistry data. This can occur when the NAPL is present in only a small percentage of the sampled interval or it could be due to the conservatism of the evaluation. The determination of whether or not NAPL can reasonably be inferred to exist in each of these samples was determined as follows:

- Clear observations of NAPL in small intervals within the sample were identified as "spotty NAPL"
- Inconsistent observations between visual and UV light records were identified as inconclusive, unless chemical comparisons suggested NAPL as well
- Observations of NAPL associated with wood fragments within the sample, rather than with the sediments themselves, were so noted.

Figure 49 shows the areal distribution of samples in which NAPL was interpreted to be present. These samples all lie to the east of the former wood treatment plant and historical log pond.

4.1.9 Correlations Between Chemicals in Sediments

To evaluate potential relationships between the various chemicals identified in Site sediments, Spearman's rank correlation coefficients were calculated for selected constituents. Calculated coefficients are shown in Table 6, along with the sample size used to calculate the coefficient and the significance level. The Spearman's coefficient ranges from 1 to -1, and is a measure of the relationship between two variables. A coefficient of 1 represents a perfect positive correlation. A coefficient of -1 represents a perfect inverse correlation. A coefficient of 0 indicates that the two variables are independent. The significance level is analogous to the significance level used in a standard t-test (Davis 1986). Significance levels of 0.05 or less indicate a relatively high degree of confidence (95 percent or greater) that a relationship exists between two variables.

LPAH and HPAH in Site sediments show a very strong positive correlation. Both LPAH and HPAH show a moderate to strong positive correlation with PCP, dibenzofurans, and dioxins. HPAH shows a slightly stronger positive correlation with PCP and dioxins, while LPAH shows a slightly stronger positive correlation with dibenzofurans. PCP also shows a strong positive correlation with dioxins.

The only metal that correlates strongly with organic contaminants is mercury, which shows a moderately strong positive correlation with PCP and dioxins. Mercury also shows a moderate positive correlation with TOC.

The strongest positive correlation between metals in Site sediments is lead and zinc. With the exception of mercury, all metals show a moderate to moderately strong positive correlation. The only metal with which mercury shows a moderate positive correlation is lead.

4.1.10 Comparison to Other Sites in Budd Inlet

As noted previously, in addition to the chemical data available from the three background samples obtained from Budd Inlet during the Sediments RI, data have been published for historical sampling events in Budd Inlet. In Sections 4.1.1 through 4.1.7, Site data were compared to RI background data and published data regarding reference areas. In this section, Site sediment data are compared to sediment concentrations reported in five other studies of Budd Inlet: sampling events associated with the Olympia Harbor Navigation Improvement Project, One Tree Island Marina, the LOTT outfall, an EPA reconnaissance of southern Puget Sound, and the Puget Sound Ambient Monitoring Program. Table 7 lists average and maximum levels reported in Site sediments for LPAH, HPAH, PCP, and metals, as well as ranges of these values from the noted other studies in Budd Inlet. Figure 50 indicates approximate sampling locations for these other studies (both Budd Inlet samples of the Puget Sound Ambient Monitoring Program were obtained from stations located further north in Budd Inlet than shown on Figure 50).

The reconnaissance survey of chemical contamination in southern Puget Sound by EPA in April 1990 (PTI 1991c) represents the most comparable data for the Site, because sampling techniques and sampling intervals used in the survey were similar to techniques used during the RI. The LOTT, One Tree Island, and Olympia Harbor Navigation Improvement Project samplings used composite samples over intervals of up to 4 ft. Because these values essentially represent vertically averaged values, they should only be compared to average values at the Site.

The data in Table 7 indicate that LPAH and HPAH values at the Site are appreciably elevated relative to values reported for the other studies in Budd Inlet. PCP was reported as detected in only the Olympia Harbor Navigation Improvement Project samples. In the other studies in which PCP was analyzed for, the detection limits were above the average value detected at the Site. Therefore, based on the data summarized in Table 7, it cannot be concluded that PCP levels are significantly elevated at the Site relative to other locations in Budd Inlet.

With the possible exceptions of elevated cadmium and copper values, average metal values for the Sediments Operable Unit were similar to values from the reconnaissance survey and the Olympia Harbor Navigation Improvement Project. Detected concentrations of metals at One Tree Island Marina are higher than average values recorded at the Site, with the exception of mercury (the concentration detected on One Tree Island Marina may reflect contamination from nearby boat maintenance). The limited available data on PCP concentrations in sediments, summarized in Table 7, are inadequate to allow meaningful comparisons to concentrations at the Site.

4.1.11 Comparison to Regulatory Criteria

The Phase I and Phase II sediment chemical results for individual PAH, total LPAH, total HPAH, PCP, dibenzofuran, and metals were compared to Ecology's Sediment Management Standards (Chapter 173-204 WAC). The Sediment Management Standards include two sets of standards: a lower Sediment Quality Standard (SQS) (WAC 173-204), which provides for "no adverse effects" to marine organisms [meaning below all apparent effects threshold (AET) values for a given set of biological indicators]; and an upper cleanup screening level (CSL) which allows for "minor adverse effects" to marine organisms (meaning that any one AET value may be exceeded for a given set of biological indicators). There currently are Sediment Management Standards for PAH compounds, PCP, dibenzofuran, and metals, but no standards or AETs for chlorophenols other than PCP, nor are there any for dioxins or furans.

The results of the comparison of Site sediment chemistry data to the Sediment Management Standards are summarized in Table 8 and Figures 51 through 54, and are discussed in the following sections. It should be noted that the Sediment Management Standards apply to surface sediments which are defined as those sediments within the predominant biologically active zone (which is estimated to be between 0-25 cm at the Site) and those sediments exposed to the water column. Therefore, the following comparisons of sediment quality to the Sediment Management Standards for those samples obtained below 25 cm (the C, D, E, and deeper zones) are provided primarily to allow evaluation of the status of sediment should dredging or other remedial action expose these sediments permanently, such that they then constitute surface sediments.

PAH

The Sediment Management Standards for PAH include standards for 16 individual PAH, and for total LPAH and HPAH. In the upper 10 cm sediment samples, one sample (from Station C1) contained several individual PAH exceeding the CSL (Table 8 and Figure 51). Three samples of the upper 10 cm contained one individual PAH above the CSL (a duplicate from Station C2 and one from Station G3 contained acenaphthene above the CSL and a sample from Station D3 contained 2-methylnaphthalene above the CSL). Several other samples in the upper 10 cm contained one or more individual PAH compounds above the SQS, but below the CSL. A sample in the upper 10 cm from Station C1 contained total LPAH above the CSL, and one from Station D3 contained total LPAH above the SQS, but below the CSL. No sample in the upper 10 cm contained total HPAH above the SQS.

Below 10 cm, the concentrations of several individual PAH compounds, and total LPAH and HPAH in intertidal sediment samples from 13 sampling stations were well above the SQS and/or CSL values (these exceedances are noted in Table 8 and shown by depth on Figures 52 through 54).

There are three station with exceedances of the SQS below 100 cm (A2D, G3E, and H9F). Two of these three stations (A2D and G3E) also show exceedances of the CSL for acenaphthene.

Dibenzofuran

In the upper 10 cm, two samples (from Stations C1 and D3) exceeded the CSL for dibenzofuran; four samples (from Stations G3, G7, H7 and a duplicate from Station C2) contained dibenzofuran above the SQS, but below the CSL (Table 8).

Concentrations of dibenzofuran detected in 15 intertidal sediment samples from below depths of 10 cm (from Stations B2, B3, C1, C2, D1, D3, F1, and G3) were well above the CSL for dibenzofuran. Five intertidal sediment samples and one subtidal sediment sample from below the 55 cm depth (from Stations A2, B3, D1, E2, and G3) exceeded the SQS for dibenzofuran, but were below the CSL (Table 8).

PCP

All PCP concentrations in Site sediments were reported at levels below the CSL and the SQS.

Metals

Only one sediment sample, H2D, contained metals exceeding the CSL, for cadmium, chromium, and copper. Zinc in Sample H2D exceeded the SQS. One other sample, a duplicate sample at a depth below 10 cm from Station C2, exceeded the SQS for mercury (Table 8). All other metal concentrations in sediments collected during Phases I and II were below the SQS and the CSL for metals.

4.2 MARINE WATER

As noted previously, three water column samples and five ponded water samples were collected from the Sediments Operable Unit during the RI (Figure 9). In addition, four water column samples were obtained from three background stations in Budd Inlet for comparison purposes. The chemical data are presented in Table C-4 in Appendix C, with dioxin and furan concentrations converted to TEQ.

4.2.1 Concentrations of PAH

None of the water column samples, nor the background water column samples, contained detectable PAH (in the detection limit range of 0.01-0.05 μg/L). In the ponded water samples, the highest concentrations of PAH were found at Station H12. The LPAH and HPAH concentrations in this sample were reported to be 20 and 18 μg/kg, respectively. Station H12 was collected from a natural drainage channel located between the B and C Zones. Sediment samples in this area contained high concentrations of LPAH and HPAH. The only other ponded water sample that contained PAH was at Station C2, which is also in an area of high sediment PAH concentration, but which was collected from a depression left by the earlier use of a vanVeen grab sampler. This sample contained low concentrations of phenanthrene, fluoranthene, and pyrene.

4.2.2 Concentrations of Chlorophenols

No chlorophenols were detected in any of the onsite or background water column or ponded water samples collected during the RI. The detection limits for chlorophenols are approximately: 0.05 µg/L for PCP; 0.2 µg/L for both 2,4,6-trichlorophenol and tetrachlorophenol; 0.4 µg/L for 2,4,5-trichlorophenol; 1 µg/L for 2,4-dichlorophenol; and 50 µg/L for 2-chlorophenol.

4.2.3 Concentrations of Dioxins and Furans

The dioxin and furan concentrations, expressed as TEQs, are shown in Table C-4 for water column, ponded water, and background water samples. The total TEQ were lowest in the background (mean=1.0E-5 µg/kg) water samples, were slightly higher in the water column samples (mean=3.9E-5 µg/kg), and were slightly higher still in the ponded water samples (mean=1.0E-4 µg/kg). The difference between the Site ponded water and water column data may reflect the influence of sediments on the ponded water samples and the greater dilution in water column samples. The highest TEQ occurred in the ponded water sample from Station H12 (0.000076 µg/L).

4.2.4 Comparison of Water to Water Quality Criteria

Phase II surface water chemical results for PAH and chlorophenols were compared to Ecology's water quality standards (WAC 173-201A-040) and EPA's marine acute, marine chronic, and fish consumption (associated with 10^{-6} cancer risk) water quality criteria (EPA 1992b.

4.2.4.1 PAH

All PAH concentrations detected in Site surface water during Phase II were below EPA's water quality criteria, with the exception of several PAHs in the ponded water sample from Station H12. At Station H12, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene and indeno(1,2,3-cd)pyrene exceeded the criteria for fish consumption (Table 9), and the detection limit for dibenz(a,h)anthracene in the sample from Station H12 exceeded the criteria.

4.2.4.2 Chlorophenols

All samples were reported to have undetected levels of chlorophenols and the detection limits for the chlorophenols were below the criteria for fish consumption. Therefore, none of the Site or background samples contained chlorophenols above surface water quality standards.

4.2.4.3 Dioxins and Furans

All Site and Budd Inlet background water samples contained dioxin and furan concentrations that exceed the EPA water quality criteria based upon consumption of fish.

4.3 BIOLOGICAL SAMPLES

4.3.1 Clam Tissue

Bentnose clams were collected from two areas in the Sediments Operable Unit, one sample from an area known to contain elevated sediment PAH concentrations (H2) and one sample from an area representative of lower sediment concentrations (F5) (Figure 10). An additional bentnose clam sample, CP2-C-EI, was collected from Eld Inlet for use as a reference sample. Between 40 and 60 individual clams were collected for each sample. The homogenized tissue samples were analyzed for PAH, chlorinated phenols, dioxins and furans, metals, and percent lipids. The results are tabulated in Table C-5 in Appendix C.

No PAH were detected above the detection limit of 96 µg/kg in clams from the onsite Station F5 nor in the background sample at a detection limit of 24 µg/kg. Concentrations of LPAH and HPAH (970 and 3,900 µg/kg, respectively) were reported in the clam sample from Station H2, which is located between the B and C transects where high concentrations of PAH were found in sediment samples.

The only chlorophenol detected in any of the clam samples was PCP, which was reported at a level near the detection limit (1 µg/kg), in the sample from Station H2. The detection limits for the chlorophenols are: 1,000 µg/kg for 2-chlorophenol, 20 µg/kg for 2,4-dichlorophenol, and 5 µg/kg for the trichlorophenols.

Dioxins and furans were detected in all clam samples, including the reference sample from Eld Inlet. The two samples from the Sediments Operable Unit contained higher concentrations of dioxins and furans, expressed as TEQ, than did the reference sample. After normalizing the results to lipid contents, the samples from the Site contained from 3.6 to 36 times the reference sample concentration. As with PAH, the clam sample with the highest concentration was from Station H2, from an area identified during Phase I as exhibiting elevated concentrations of organic chemicals in sediments.

In addition to reporting the requested analytes, the laboratory also reported tentatively identified compounds (TICs) in tissue samples. TICs are compounds that the laboratory identifies through comparisons to a library of mass spectra, but for which standards were not run. Therefore, the identifications are tentative, and the reported concentrations are only estimates. Of the seven reported TICs for the tissue samples, six were water-soluble carboxylic acids and the seventh was decanoyl chloride. Reported concentrations were generally in the low mg/kg (ppm) range. Individual compounds are tabulated and discussed in terms of their toxicity in the Sediments Risk Assessment (Landau Associates, 1992). TIC data were not validated and may in part represent laboratory contamination.

Trace concentrations of arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc were detected in all clam samples; the two samples from the Site exceeded twice the concentrations of the reference sample for copper, lead, mercury, silver, and zinc.

4.3.2 Bioassays

Two sediment samples were collected onsite during the RI (and one from an offsite reference location) for bioassays. The onsite station locations chosen for the bioassays (C3 and D3) were from areas identified from Phase I results as lying outside areas of the highest contamination, but still having sediment concentrations that exceeded the SQS and/or the CSL for at least one constituent of concern (a third station, B6, was planned, but was dropped after the field identification of NAPL contamination at that location). The bioassays provide a second mechanism by which to evaluate the effect that contaminants will have on biological resources. The sampled sediments underwent two acute (amphipod and echinoderm larvae) bioassays in which the organisms were introduced into the sediments, and survival (or mortality) rates were recorded over the test period. In addition, the sampled sediments underwent one chronic (microtox) bioassay in which the reduced luminescence of a luminescent bacterium was measured. All bioassays were performed per PSEP protocols.

The results of the bioassays and a brief explanation of the Sediment Management Standards biological criteria for SQS and CSL concentrations is provided in Table 10.

Amphipod bioassays performed on sediment from Stations C3 and D3 indicated a significant difference in mean mortality compared to the reference sediment ($p \leq 0.05$), but because the mean mortality in the test results from these two stations also did not exceed 25 percent on an absolute basis, the samples from Stations C3 and D3 passed the amphipod bioassay.

Echinoderm larvae bioassays performed on sediment from Stations C3 and D3 indicated a significant difference in mean mortality compared to the reference sediment ($p \leq 0.05$). The mean normal survivorship at Stations C3 and D3 were 56 percent and 78 percent of the reference sample, respectively. Therefore, the sediment samples from Stations C3 and D3 failed the SQS criteria for the echinoderm larvae bioassay. The sample from Station C3 also failed the CSL criteria due to high mean mortality. Microtox bioassays performed on sediment from Stations C3 and D3 passed both the SQS and CSL criteria. In summary, the results of the bioassays indicate that the sediment from Station D3 exceeds the Sediment Management Standard SQS biological criteria, but is below the CSL biological criteria. The results indicate that the sediment from Station C3 exceeds both the SQS and the CSL biological criteria. The bioassay results are therefore the reverse of the conclusions regarding these sediments that are obtained from a review of sediment chemistry of the upper 10 cm. The bioassay results for Station D3 are, however, consistent with the results of sediment chemistry at that station for the 10-55 cm depth interval. Ecology's Sediment Management Standards state that a sediment sample that fails any one of the biological tests shall be designated as failing the applicable Sediment Management Standards notwithstanding the sediment's designation on the basis of sediment chemistry. Given this, the apparent contradictions observed in the comparison of chemical concentration or bioassay-based passes or failures of SQS and CSL for Stations C3 and D3 may indicate the need for reconfirmation of the results during remedial design sampling. However, a possible explanation for the discrepancy between the results of the limited bioassay survey and the chemical criteria based survey is that the sediment used in the bioassays was collected separately (approximately 8 months after) from the sampling for the chemical survey. The difficulty in resampling the same station and the heterogeneity both vertically and laterally in the intertidal sediments at the Site may have contributed to the discrepancy in the results. Another potential reason includes noncontaminant related sensitivities of the bioassays.

4.3.3 Benthic Abundance and Diversity

Sediments from two onsite stations (C2 and E4) and one reference station (EI1) were evaluated for the abundance and diversity of benthic infauna. The results of these analyses are as follows (presented in full in Appendix G):

- Reference Station: The +4 ft (MLLW) Eld Inlet reference station, EI1, had a relatively diverse and rich community strongly dominated by crustaceans, particularly the tube-building amphipod *corophium salmonis*. The small, usually commensal crabs, *pimotheridae* were also abundant, followed by the cumacean *leucon subnasica*. Molluscs were well represented and were strongly dominated by the bentnose clam *macoma nasuta*, a species tolerant of fine-grained, sulfide-rich sediments. The softshelled clam, *mya arenaria*, was also common and the hardshelled clam, *protothaca staminea*, was present in one sample. This latter species is typically found in areas with substantially coarser material. Species composition (lack of dominance by a few pollution tolerant species) and presence of sensitive species (crustaceans) suggests that this site meets the criteria set forth for a reference site in WAC 173-204-315.

  The only data found from unimpacted mudflats in central or southern Puget Sound are from a transect sampled in the eastern side of the Nisqually Delta by Wisseman et al. (1977). The +3-ft elevation sampled there is suitable for direct comparison with the Eld Inlet site, although the Nisqually site has a much higher exposure to fresh water and sampling was accomplished during low tide. The total benthic density at Eld Inlet was only slightly less (2,630 organisms/m^2) than at the Nisqually station (about 2,800/m^2 in April 1977). The total number of taxa at the Eld site (28) was also similar to that at the Nisqually site (25). The most abundant taxon at the Nisqually site was identified as *corophium brevis*, followed by *macoma balthica*; *m. nasuta* was also common. Polychaetes were more abundant at the Nisqually site with several taxa (capitellidae, spionidae, *eteone longa*, *eulala quadrioculata*) present at more than 100/m^2.

  Total organism density at Eld Inlet (EI1) was somewhat lower than that at the Carr Inlet subtidal control site sampled in the Commencement Bay Remedial Investigation (Tetra Tech 1985). Densities of crustaceans were lower in the Carr Inlet subtidal than in the Eld Inlet intertidal, but densities of polychaetes and molluscs were far greater in the Carr Inlet samples as were mean number of taxa per grab in all three groups. This may reflect the more marine condition in Carr Inlet in addition to the typically richer subtidal infauna. The total benthic density at the Eld Inlet intertidal site was greater than at shallow (-2.5 m MLLW) stations sampled by the Corps of Engineers in the West Bay of Inner Budd Inlet (Pentec 1991).

- Station E4: The benthic assemblage at Station E4, on the northern portion of the Site at about +4 ft, was noticeably different from that at the Eld Inlet reference site, although some similarities were also seen. Total organism density was similar (2,302/m^2) to that at Eld Inlet but organisms were more evenly distributed among the three major taxa reported: crustaceans were much less abundant at E4 while polychaetes and bivalves were much more abundant than at EI1. Reduced numbers of crustaceans is not unexpected because this group is highly sensitive to a variety of organic pollutants. Polychaetes and, to a lesser extent, bivalves, are somewhat more tolerant of these pollutants.

Apart from the very high abundance of *corophium salmonis* at EI1 (a taxon not common at E4), the composition and abundances of crustaceans did not differ all that much between EI1 and E4. Dominants at E4 were pinnotherids (several taxa) and the cumacean *l. subnasica*. Dominant polychaetes at E4 were the spionid, *spiophanes berkeleyorum*, (also a dominant in the shallow subtidal stations in the Corps West Bay sampling; Pentec 1991), and the goniadid, *glycinde picta*. The extremely high density (838/m^2) of the bentnose clam, *m. nasuta*, at Station E4 is not seen in any other Puget Sound database examined. The high degree of variability in this species in the five replicates (three grabs averaged 132 per grab while the other two had 12 each) suggests a patchy settlement of young clams in an area of moderate overall abundance of larger animals. *Mya arenaria* and the very small *mysella tumida* were also common bivalves at Station E4.

- Station C2: In contrast to the relatively consistent total density and relative evenness of taxonomic distribution of benthic invertebrates at Stations EI1 and E4, Station C2 displayed several characteristics of a highly stressed community. Mean numbers of taxa in all three groups reported were markedly lower at Station C2. Numbers of taxa of crustaceans, polychaetes, and molluscs were 5, 7, and 2, respectively, compared to 10, 12, and 5 at Station E4. Density of organisms within individual taxa was even more obviously affected. Total density of crustaceans was only 20/m^2 at Station C2 compared with 438/m^2 at Station E4 and 2,100/m^2 at the reference site (EI1). Molluscs were also poorly represented at Station C2 (48/m^2) relative to Station E4 (1,380/m^2) and Station EI1 (396/m^2) than at other sites and were strongly dominated by a few taxa that are known to be pollution tolerant the Family Spionidae, especially *polydora ligni*, and *capitella capitata*. These two species were present in low numbers at the unpolluted intertidal site on the Nisqually Delta (Wisseman et al. 1977).

In summary, the abundance and diversity of infauna measured at Station E4 appear to exhibit slight differences from those recorded in the reference sample; the difference may be related to site-specific chemicals or may, to some degree, reflect the differences between an urban embayment and the more pristine environment of a reference area.In contrast, the results for Station C2 suggest a significant difference in abundance and diversity from that found in the reference sample, and are indicative of the effects of organic contaminants. The benthic abundance and diversity results are consistent with the RI sediment chemistry results.

5.0 CONTAMINANT FATE AND TRANSPORT

The primary contaminants identified during the RI in various media in the Sediments Operable Unit (as determined from comparisons of chemical concentrations in the Sediments Operable Unit to regulatory criteria and data available for background and reference areas in Puget Sound (see Section 4.1) are PAH compounds (both LPAH and HPAH); PCP; dibenzofuran; metals (primarily cadmium, chromium, copper, lead, and zinc); and dioxins and furans. PCP and metals are included in this section although there were relatively few exceedances of either regulatory criteria or measured levels in the three Budd Inlet background samples for these compounds. Dioxins and furans in sediments have no regulatory criteria for comparison.

5.1 SOURCES

5.1.1 Potential Sources

Potential sources of wood-treating related chemicals in the sediments at the Site include the following:

- Direct releases of PCP-, PAH-, and/or dioxin/furan-containing materials such as creosote, petroleum, and wood-treating carrier oils, wastes, or wastewater from former wood-treating operations into the Sediments Operable Unit
- Migration of either NAPL or dissolved constituents of creosote, PCP, or other chemicals associated with historical wood-treating operations from onshore soil through subsurface migration or through shoreline seepage.

The metals in the sediment at the Site also may be, in part, from the reported historical onshore wood-treatment activities at the Site [the actual composition of the inorganic wood preservative that historically was used at the Site is unclear; ESE (1992a) reports that copper was the inorganic preservative used historically at the Site].

Other potential sources of the observed contaminants in the Site sediment include storm drains, marinas, boat operation and maintenance activities, municipal sewage treatment plant effluent, combined sewer outfalls (CSO), pilings and other treated wood products used in marine construction, dredging operations, fuel or other chemical spills, past and present industrial activities, surface runoff from other properties, and atmospheric deposition of combustion products of fossil fuels, agricultural burning, and forest fires.

5.1.2 Source Evaluation

To gain a better understanding of the potential origin of contaminants in sediments at the Site, a chemical profiling method that compares HPAH ratios between potential sources and sediments was employed. Normalized concentrations of four- and five-ring PAH [fluoranthene, pyrene, benzo-(a)anthracene, chrysene, the sum of benzo(b and k)fluoranthenes, and benzo(a)pyrene] in sediment samples were graphically organized and compared to similar graphs from a range of potential sources. Previous studies have used this approach and have shown that creosote and sediments strongly affected by creosote exhibit a characteristic pattern (Cubbage 1989 and Ecology 1988). Variations of this method have been used by others to identify the source of HPAH in sediments (Lake et al. 1979 and Sporstol et al. 1983).

This chemical profiling method was chosen because the four- and five-ring HPAH are relatively stable (allowing comparison between samples) and are frequently detected in sediment samples; whereas 6-ring and higher molecular weight HPAH are often undetected in sediment samples, and LPAH are more affected by weathering processes (potentially altering the characteristic ratio of the source material).

PAH have been detected in pristine and contaminated sediments worldwide (LaFlamme and Hites 1978). PAH are known products of pyrolysis and combustion, with combustion being one of the most common sources of PAH in nature. Natural sources include forest fires and volcanoes. Anthropogenic sources of PAH in sediments include combustion of fossil fuels, urban runoff, and petroleum and creosote spills. As previously noted, potential sources of PAH in sediments at the Site include creosote, storm drains, marinas, boats, municipal sewage treatment plant effluent, combined sewer outflows, pilings, dredging operations, fuel spills, past and present industrial activities in the area, and surface runoff.

Figures 55 through 58 depict HPAH ratio profiles of various potential source materials, HPAH-contaminated sediments referenced in literature, and two of the three Budd Inlet background sediment samples (the third background sample was not amenable to profiling due to the fact that several HPAH used in the profiling were reported as undetected in that sample). The HPAH ratios for these and all other data discussed in this section, normalized to fluoranthene, are presented in Table 11. Figure 55 depicts the typical HPAH profile for DNAPL and LNAPL found in Site wells and for creosote collected from the Site. This profile is similar to those presented by Ecology (1988) for the Site, and Cubbage (1989) for the Wyckoff West Seattle site.

Figure 56 presents HPAH ratio profiles for several refined petroleum products. Analyses for benzo(b and k)fluoranthenes were not performed for these samples; therefore, these ratios are based on the remaining five HPAH. Additional petroleum HPAH profiles are presented on Figure 57 for oil from an oil spill, fuel oil, and petroleum-contaminated sediments near an offshore drilling platform. Crude petroleum products, and most refined petroleum products, contain low levels of HPAH (Gelboin and Ts'o 1978, Renzi and Phirong 1991). PAH are generally concentrated in the higher boiling point distillates and solid residues. Lighter products such as gasoline should be HPAH free; however, HPAH are formed in gasoline during upgrading steps in processing. Heavier petroleum products, such as Bunker C, are expected to contain a larger percentage of HPAH. The HPAH ratios in any petroleum product are quite variable, as evident on Figure 56. This is mostly due to the inherent variability of HPAH in crude oils and the different refining processes used to produce a given product.

HPAH ratio profiles in the two background samples from Budd Inlet (plus one duplicate) are presented on Figure 58. HPAH profiles in sediments from other nonspecific HPAH sources are plotted on Figure 59 for comparison to Site sediment data.

HPAH ratios for sediment samples from the Sediments Operable Unit with all six 4- and 5-ring HPAH reported at detectable concentrations were calculated (Table 12) and were classified into three profile types, based on the criteria noted below (the HPAH ratios were averaged within each data set and are presented graphically on Figure 60).

- Type 1 profiles correspond to the HPAH ratios observed for creosote and NAPL from Site wells. There are 10 Site sediment samples that fit this profile type; the locations of these are shown on Figure 61. Most of these samples were from the B or deeper zone, and are generally clustered directly northeast of the former wood treatment plant, relatively close to shore.
- Type 2 profiles are similar to Type 1; however, these Site samples were separated from Type 1 because the ratios indicate chrysene and benzo(b and k)fluoranthenes at higher concentrations than benzo(a)anthracene. There are 23 Site samples that fit the Type 2 profile; their locations are depicted on Figure 62. Type 2 samples are generally located in the same geographic area of the Site as Type 1 samples, but within the upper 10 cm (the A Zone). Type 2 samples are also observed further offshore in a northerly direction from the former wood treatment plant than are Type 1 samples.
- All Site sediment samples that deviated significantly from Type 1 and Type 2 samples are categorized as Type 3. There is a wider range of variability within the Type 3 group, but in general sediment samples exhibiting a Type 3 profile have a pyrene ratio higher than 1 (relative to fluoranthene) and frequently a benzo(b and k)-fluoranthene ratio higher than 1. There are 39

Site samples that exhibit this chemical profile. They are located throughout the intertidal area, as shown on Figure 63.

When compared to potential source materials or other HPAH-containing sediments, HPAH ratios for Type 1 Site sediment samples match well with the creosote and NAPL samples from the Site. Type 1 samples also generally exhibit the highest HPAH concentrations in Site samples, and include most Site samples containing evidence of NAPL (Figure 49). Type 2 HPAH ratios are most similar to creosote, and do not resemble any other of the potential source materials. The Type 2 profile may represent a slightly weathered Type 1 pattern. The characteristic pattern of the Type 2 profile is a relatively higher concentration of chrysene and benzo(b and k)fluoranthenes than in the Type 1 profile , indicating that the lighter HPAH are lower in relative concentration. Weathering processes would tend to change the HPAH ratio in this direction. Type 2 samples are generally located in the same area as Type 1, but at shallower depths, supporting the hypothesis that they may, at least in part, reflect weathered creosote. Type 2 samples also reflect generally lower overall HPAH concentrations than Type 1 samples.

The Type 3 profile does not exactly match any specific source material although some Type 3 samples resemble the CSO and coastal Washington sediment samples. Type 3 samples exhibit concentrations below Sediment Management Standards, and generally exhibit the lowest HPAH concentrations. These samples may reflect a combination of HPAH inputs into Budd Inlet, including weathered creosote.

Of the two background samples collected in Phase II, HPAH ratios from Samples BI1 and its duplicate fall into the Type 2 group, and Sample BI2 appears to be borderline between Types 2 and 3.

5.2 CHEMICAL FATE PROCESSES

This section summarizes the physical properties and environmental behavior of the chemicals of concern at the Site. More detail regarding the physical properties and environmental behavior of the chemicals of concern at the Site is presented in Appendix H.

5.2.1 Creosote

Coal tar creosote, made from the high-temperature treatment of coal, is the most widely used wood preservative in the United States. Creosote is a complex mixture of many chemicals; about 300 chemicals have been identified in coal tar creosote, and there may be 10,000 other chemicals present, but not yet identified, in the mixture (Clement Associates 1989). Creosote is heavier than water and has a continuous boiling range beginning at about 200°C.

Creosote typically contains 85 percent PAH and 10 percent phenolics (Mueller et al. 1989), although the composition of the mixture may vary across manufacturing lots and manufacturers. The major PAH components of creosote reported in several sources are shown in Table 13 (these sources do not provide information regarding the supplier of the creosote). Other constituents include coal tar acids such as phenols, cresols, and cresylic acids; and coal tar bases such as pyridines, quinolines, and acridines.

The major source of creosote released to the environment is the release of creosote and creosote-containing wastewater effluents from wood-treatment facilities (Clement Associates 1989). Some creosote components may also be released to the atmosphere by fugitive emissions from these facilities; however, atmospheric releases are considered to be relatively minimal (Clement Associates 1989). Creosote components also may be slowly released from the surface of treated wood products by oil exudation, leaching by rainwater, or volatilization. Losses of creosote from impregnated wood are dependent on the kind of coal used to produce the coal tar, the kind of coke oven used to make the coal tar, and the conditions under which the treated wood is used (Leach and Weinert 1976).

Creosote constituents released to surface waters will differentially partition between water and soil or sediment depending on their water solubility and sorptive properties. PAH, the major constituents of creosote, generally tend to sorb strongly to soil and sediment particulates and have low aqueous solubilities and mobility (Hickock et al. 1982). Nitrogenous bases present in creosote wastewater (e.g., aniline, toluidines, and xylidines) are relatively soluble, mobile, and persistent in groundwater (Pereira et al. 1983). However, behavior at a given site is also dependent on site-specific characteristics (e.g., TOC).

In an investigation of the release of creosote from treated wood into freshwater and seawater, naphthalene, phenanthrene, acenaphthene, dibenzofuran, fluorene, and 2-methylnaphthalene were the major components that migrated into water (Ingram et al. 1982). In another investigation, creosote mixed with seawater was observed to form an LNAPL, a DNAPL, and a dissolved phase (Merrill and Wade 1985). Creosote as NAPL may act as a wetting agent in sediment; measurements of the wetting angle of coal tar against quartz, in a slightly mineralized water at 135°C indicated a coal tar wetting system under hydrodynamic displacement conditions (Villaume 1985). In a modeling study of creosote migration near the Bow River in Calgary, Alberta, creosote was determined to be a nonwetting fluid (Trudell 1992).

5.2.2 PAH

PAH are strongly hydrophobic, and therefore exhibit a tendency to sorb to soil or sediment from water. The extent of the sorption will be limited by the sorption capacity of the soil, and if separate phases of organic liquids are present (NAPL), the PAH may preferentially accumulate in these. Sorption of PAH to soil and sediment increases with increasing organic carbon content, and is generally inversely proportional to particle size (due to increasing surface area with decreasing particle size). Lower molecular weight PAH may volatilize from sediments, whereas this process is not significant for the higher molecular weight compounds (Southworth 1979).

The degree of sorption varies with the individual PAH. The organic carbon partition coefficient, Koc, indicates the potential of a chemical to bind to organic carbon in soil and sediment. The low molecular weight PAH have Koc values in the range of 10^3 to 10^4, which indicates a moderate potential to be adsorbed to organic carbon in soil and sediment. The medium molecular weight compounds have Koc values around 10^4. High molecular weight PAH have Koc values in the range of 10^5 to 10^6, which indicates stronger tendencies to adsorb to organic carbon.

Microbial metabolism is the major process for degradation of PAH in soil. Photolysis, hydrolysis, and oxidation are not considered important processes for the degradation of PAH in soil.

Because of their low solubilities, PAH in aquatic systems are primarily found sorbed to particles that either have settled to the bottom or are suspended in the water column. Sorption and deposition is probably the major removal mechanism of HPAH from water, whereas volatilization and microbial degradation may be the major removal processes for LPAH.

5.2.3 PCP

PCP was at one time one of the most widely used biocides in the United States. Before restrictions were placed on its use, PCP was widely used as a wood preservative for poles used for power lines, cross arms, and fence posts, with small use in cooling towers, and pulp and paper mills. It was registered for use by the EPA as an insecticide, fungicide, herbicide, molluscicide, algicide, disinfectant, and as an ingredient in antifouling paint. The wide spectrum of uses can be partially attributed to the solubility of the nonpolar form (PCP) in organic solvents and of the sodium salt (pentachlorophenate) in water. PCP is now a restricted-use pesticide and is still used throughout the United States for wood treatment.

Pure PCP exists as colorless crystals and has a very sharp, characteristic smell when hot, but very little odor at room temperature (Merck 1989). Technical-grade PCP is dark gray to brown in the form of dust, beads, or flakes. Technical-grade PCP also contains impurities, including chlorodiphenylethers, dioxins, furans, and hydroxychloro-diphenylethers. Commercial PCP contains significant quantities of tetrachlorophenols; the ratio of PCP to tetrachlorophenol in Dowicide G-ST, a commercial PCP formulation, was 2.5±0.1, or 29 percent (Verschueren 1983). Properties of PCP relevant to environmental behavior are shown in Table 14. Unlike strictly nonpolar organics, PCP changes its properties with pH. Under acid conditions, PCP is nonpolar; it is soluble in organics and has very low solubility in water (sorption and consequent retardation tendencies are seen on Table 14 in the log of the partitioning coefficient: log Kow). Under neutral to alkaline conditions (e.g., sea water which has a pH of approximately 8), PCP is transformed into the anionic form, pentachlorophenate. As an anion, it has a lower solubility in organics, a higher water solubility, less sorption, and higher mobility in aqueous environments.

PCP releases to soil and sediment occur through numerous nonpoint and point sources, including the leaching of treated wood, seepage from impoundments, and spillage from transfer operations. Arsenault (1976) reported that PCP migrated from the surface of utility poles to the adjacent soil, which had an average PCP concentration of 654 mg/kg; however, the mobility away from the pole was limited.

Once in soil, PCP is susceptible to microbial biodegradation, sorption, and transport in aqueous and NAPL phases. Photo-oxidation may occur in the surface layer. Hydrolysis, oxidation, and volatilization are probably not important pathways in soil.

Biodegradation is considered to be the major transformation mechanism for PCP in soil; the rate of biodegradation in soil has been observed to be increased in soil with high organic content, higher moisture content, and at optimum temperatures for microbial growth.

Sorption reactions of PCP in soil are pH dependent. Under acid conditions in which organic matter is present, sorption can be described by Koc; an average Koc value of 32,900 was measured by Schellenberg et al. (1984) for lake sediment, river sediment, and aquifer materials.

Under neutral to alkaline conditions, PCP transforms to pentachlorophenate, an anion, and mobility is greatly increased. Choi and Aomine (1974) observed maximum sorption at pH of 4.6-5.1 with no sorption observed above pH 6.8.

Photolysis and biodegradation are believed to be the dominant transformation processes for PCP in aquatic systems.

5.2.4 Metals

This section discusses the environmental behavior of the metals observed in the Sediments Operable Unit above background estimates: cadmium, chromium, copper, lead, and zinc:

- Cadmium. In natural waters and sediments, cadmium occurs in the +2 state. It may occur in the uncomplexed Cd^{2+}, as a soluble complex with inorganic or organic ligands, adsorbed onto particulate surfaces, or precipitated into mineral structures. It is relatively more mobile in the environment than other divalent heavy metals. The pH of sediment or waters is perhaps the single most important variable controlling the speciation and mobility of cadmium; cadmium tends to be more mobile under acidic conditions.

- Chromium. Chromium exists in two oxidation states in natural systems: Cr(III) and Cr(VI). The hexavalent form is quite soluble, existing in solution as a complex anion, and is not sorbed to any significant degree by clays or hydrous metal oxides. However, the trivalent form, which occurs as a cation, may be strongly sorbed to particulate surfaces, may be precipitated as the insoluble chromium hydroxide, $Cr(OH)_3$, or may be complexed with a variety of organic materials. The two oxidation states of chromium are readily interconvertible under natural conditions. If aquatic conditions favor Cr(VI), then chromium will accumulate as soluble forms in waters; if, however, Cr(III) is favored, then the accumulation will occur in the sediments.

- Copper. Copper occurs in natural environments predominantly in the +2 oxidation state, although it may be occur in the +1 state under certain reducing conditions. Environmental behavior of copper is highly dependent on such variables as pH, redox, concentrations of organic material and mineral adsorbents, biological activity, and competition with other heavy metals.

  Copper has a pronounced affinity for organic materials. Several studies have reported that the majority of copper in river waters studied was associated with organic matter either as suspended particulates or as dissolved organic complexes (Stiff 1971, Ramamoorthy and Kushner 1975). The adsorption or complexation of copper with organic matter may result in increased mobility of copper if the products formed are soluble.

- Lead. Although lead may exist in the 0, +2, or +4 oxidation states, throughout most natural systems Pb^{2+} is the stable ionic species. If the sulfur activity is very low, metallic lead can be a stable phase in alkaline or neutral reducing conditions. Sorption processes appear to exert a dominant effect on the distribution of lead in the environment. Under most natural conditions, adsorption to clay and other mineral surfaces, coprecipitation/sorption by hydrous iron oxides, and incorporation into cationic lattice sites in crystalline sediments are the important sorption processes. The sorption of lead, like that of most metals, is highly pH dependent, with increased sorption with increased pH.
- Zinc. Zinc occurs in natural systems with an oxidation state of +2. The main factor controlling zinc solubility in sediments and waters is adsorption and complexation. Precipitation, mainly with sulfides, is more important under very reducing conditions. The degree of adsorption is dependent on environmental conditions. Adsorption of zinc increases with increases in pH; other factors affecting zinc sorption include the presence of complexing ligands, especially Cl^-, OH^-, and SO_4^{2-}, and salinity[zinc has been observed to desorb from sediments as salinity increases (Helz et al. 1975)].

5.3 POTENTIAL CONTAMINANT TRANSPORT MECHANISMS

Potential historical and/or current contaminant transport processes from known or suspected source areas to and within the Sediments Operable Unit include dissolved phase transport, NAPL transport, particle transport (in or associated with groundwater), surface water runoff, former NPDES wastewater discharge, direct discharge from former waste disposal practices, offshore spills, and airborne transport. These processes are discussed further in the following sections.

5.3.1 Dissolved Phase

Transport of dissolved constituents in groundwater to sediments would occur through groundwater seepage along the shoreline during low tides, and potentially offshore. The seep fluid would be expected to contain lower concentrations than those observed in groundwater farther inland, due to tidal mixing in the aquifer; seepage concentrations would also vary throughout the tidal cycle, although "tidal fluctuation hastens the rate of plume migration near the bank of the estuary because of the relatively high advective and dispersive fluxes induced by tides" (Yim and Mohsen 1992).

Dissolved phase transport from onshore to the Sediments Operable Unit also could occur as surface water runoff. Dissolved phase transport in groundwater and/or via surface water runoff appears to be the primary explanation of elevated chemicals at Station F1, north/northwest of the former wood treatment plant.

Dissolution of NAPL or desorption of adsorbed chemicals within sediment pore water or at the sediment/water interface will create a concentration gradient, resulting in dissolved phase transport of chemicals out of the sediment. The degree to which this process will occur depends, in part, on the relative concentrations of the chemicals in the sediment. Once in the water column, the dissolved components would be diluted significantly. Dissolved phase transport would continue, with the chemicals transported with the water parcel into which they diffused. Most of the chemicals would be expected to reattach to particles in the water column, although a fraction of the dissolved chemicals have the potential to be transported by tidal currents to other areas of Budd Inlet. Contaminants that are transported from the Site due to contaminated sediment resuspension will generally have the fate of any sediment resuspended and transported from the Site. Because the predominant sediment transport mechanism is eastward longshore drift, the majority of resuspended contaminated sediments will move toward the East Bay Marina basin, where the docks and deeper water associated with the marina may slow currents and thus enhance particle settling. Some amount of resuspended contaminated sediment will settle out onsite, and some will settle out in other areas of Budd Inlet, but the concentrations of contaminants in any of the settled material also will be diluted considerably by other sediment from sources other than the Site.

5.3.2 NAPL

NAPL movement in the subsurface is driven by gravity and pressure forces. NAPL migration is influenced by the volume and time duration of the release, the area of infiltration, the properties of both the NAPL and the media through which it is migrating, and subsurface flow conditions (Mercer and Cohen 1990).

After release to the environment, NAPL will travel downward through the unsaturated zone (if present). At the top of the capillary fringe, the NAPL will either spread laterally or it will displace the soil porewater and will continue downward migration. NAPL with a density less than that of water will spread laterally (light NAPL, or LNAPL); while NAPL with a density greater than that of water will continue downward into the saturated zone (dense NAPL, or DNAPL).

NAPL movement in the subsurface is affected by soil heterogeneities, such that NAPL migration may be temporarily slowed, completely halted, or redirected, depending on the nature of the heterogeneity. Soil heterogeneities that offer resistance to continued downward migration can cause NAPL to spread laterally (to the extent that capillary resistance to lateral flow is less than that for continued vertical flow) (Mercer and Cohen 1990).

As it migrates through the soil pores, a portion of the NAPL will be trapped within the soil pores due to surface tension. The trapped NAPL, referred to as residual NAPL, will remain essentially immobile in the soil pores. Downward NAPL migration will continue until the NAPL is depleted, or until it encounters a barrier layer. Given sufficient volume, the NAPL may continue to migrate downslope atop the barrier under pressure and gravity forces. NAPL also will tend to accumulate in topographic lows atop barrier layers. According to Mercer and Cohen (1990), a NAPL that acts as a wetting fluid may exhibit a greater residual saturation, preferentially occupy the smaller pore spaces, require a lower displacement entry pressure, and exhibit a continuous phase at residual saturation. Creosote DNAPL may act as a wetting fluid in sediments. Migration of creosote DNAPL would most likely be enhanced if it were a wetting fluid.

DNAPL migration generally is not affected by groundwater flow, except in those cases in which hydraulic gradients are high enough to overcome the gravity and pressure forces that otherwise dominate in DNAPL migration. Several case studies and modeling studies have demonstrated conditions that have altered gravity-driven DNAPL migration. Reitman et al. (1992) showed by a modeling study that upward migration of creosote into a river was partially due to hydraulic gradients (changes in groundwater and river levels) and "in part to the fact that the creosote is only marginally denser than water." Parker (1989) demonstrated with a model that migration of a low viscous DNAPL was affected by the groundwater flow regime. Faust et al. (1989) showed with a model, and confirmed with subsequent field studies, that significant amounts of DNAPL would move with the groundwater flow, in a direction opposite to the bedrock dip. Hunt et al. (1988) state that trapped ganglia can be distorted and released by groundwater flow.

LNAPL transport from the Site on the water surface will be affected most by winds and water currents. With time, the LNAPL will be broken down, mixed into the water column, and scavenged by particles. Chemical degradation will also occur to an enhanced degree relative to that onshore or within the sediments because of the exposure to sunlight and the greater concentration of oxygen.

A potential exists for bulk flow of DNAPL that reaches nearshore sediments to continue to areas further offshore. If a continuous phase of DNAPL exists, and if sufficient head of

DNAPL or hydraulic pressure gradient exists, DNAPL could potentially migrate downdip through a more permeable sand or shell lens. Both the head of any DNAPL and the hydraulic pressure gradient would decrease with distance from the shoreline; therefore, bulk DNAPL flow becomes increasingly less likely with increasing distance offshore. A potential also exists for DNAPL to migrate downward into fractures, worm holes, or other more permeable zones. If DNAPL exists in a residual saturation state, migration of residual DNAPL would be expected to occur only if one or more of the forces controlling DNAPL migration changed substantially.

Simple analytical equations for calculating DNAPL entry pressure relationships are presented in Mercer and Cohen (1990). Two of these equations are potentially applicable to estimating the potential for bulk DNAPL flow in the sediments at the Site:

$$Z_n = \frac{2\sigma \cos \phi}{g\,(\rho_n - \rho_w)} \left(\frac{1}{r'_t} - \frac{1}{r_p} \right) \qquad (1)$$

$$grad\ p = \left[\frac{2\sigma \cos\phi}{l_n} \left(\frac{1}{r_t} - \frac{1}{r_p} \right) \right] - g(\sin\theta)(\rho_n - \rho_w)] \qquad (2)$$

Where:

Z_n = critical NAPL height for downward DNAPL penetration from a coarser grained medium into a finer grained water-saturated medium

grad p = hydraulic pressure gradient required for lateral downdip movement of NAPL

σ = interfacial tension between water and the NAPL

ϕ = contact angle

r_t = pore throat radius within coarser grained medium

r'_t = pore throat radius within finer-grained medium

r_p = pore radius within coarser grained medium

θ = dip of aquitard in degrees

ρ_n = NAPL density

ρ_w = water density

l_n = Length of the NAPL ganglion or NAPL pool

g = gravitational acceleration constant

Equation (1) is useful for predicting the potential for downward migration of DNAPL from coarse grained sediments into silt or clay sediments. Equation (2) can be used to estimate the required hydraulic pressure gradient for movement of a continuous pool or lense of DNAPL downdip along the aquitard. Using reasonable estimates for the variables in both these equations (from the literature and Site-specific data where available), the estimated height of DNAPL for penetration into a silt is 29 ft or more (Table 15). A DNAPL head of this magnitude has not been observed at the Site, especially offshore in the sediments.

Results of Equation (2) indicate that a high hydraulic gradient is required to move a 5-ft long DNAPL lense, while only a low gradient is necessary to move a 400-ft long continuous lense. A high gradient would exist near the shoreline at low tide, when the water table onshore is well above MLLW and the water elevation in the sediments approaches 0 ft MLLW. A low gradient exists farther out in the sediments. Based on this theoretical equation, bulk DNAPL migration could occur in the offshore sediments, if a long continuous DNAPL lense exists in a downward dipping sand layer.

Migrating and residual NAPL is subject to volatilization (in the unsaturated zone) and to dissolution (in both the unsaturated and saturated zones). The relative degree to which these processes occur is in part a function of the chemical(s) that comprise the NAPL.

5.3.3 Other Transport Processes

Surface water runoff may have transported contaminants to the Sediments Operable Unit from contaminated surface soils, drip pads, or other surface features in which wood-treatment chemicals may have accumulated at the Site. Contaminants may have been transported as a dissolved phase, as NAPL mixed in water, or adsorbed to the suspended load of the runoff.

Direct discharge of wood treatment wastewater from the former NPDES discharge and any other direct offshore spill or disposal that may have occurred historically at the Site would provide potential pathways for contaminants to the sediments. Historical dredging of contaminated sediments within or near the former log pond or other areas may have released contaminants to surface sediments either as part of the dredge operations themselves, or through dredge spoil disposal. Airborne transport of PAH from natural and anthropogenic sources may also contribute to current sediment contamination, although this is not considered to be a major source of the chemicals in the sediments.

5.4 CONCEPTUAL MODEL OF TRANSPORT TO AND WITHIN THE SEDIMENTS OPERABLE UNIT

A conceptual model of contaminant transport pathways from upland source areas to the Sediments Operable Unit is presented on Figure 64. This model was originally presented in the

Sediments Scoping Document (Landau Associates 1990c). All of the pathways represented in this conceptual model have probably played a role in transporting contaminants to and within Site sediments, either presently or historically.

As evidenced by contaminant contour distributions, aqueous solubility exceedances, field observations and chemical interpretations of NAPL, and HPAH ratio evaluation , Site sediment directly offshore in an east-northeast direction from the former wood treatment plant are contaminated with NAPL that exhibits chemistry similar to creosote and/or sorbed chemicals associated with wood treating activities at the Site, and nearshore sediment to the north/northwest of the former wood treatment plant are contaminated with sorbed chemicals associated with PCP wood treating activities at the Site. The NAPL is distributed in Site sediment in a pattern that is generally, but not directly, downslope from the former wood treatment plant. NAPL has been observed in fine-grained sediments (silts) as well as in sands and wood debris buried in the sediments. Both the observed NAPL, and the chemical concentrations in the sediments, decrease significantly below the surface of the clay aquitard.

The distribution of wood-treating chemicals and NAPL in the Sediments Operable Unit suggests that the primary historical transport processes from the uplands portion of the Site to the sediments was seepage and direct discharge (either from the log pond or other site activities/processes such as the oil water separator). Prior to the 1980 East Bay development, the zone of tidal mixing within the aquifer would have been directly beneath the wood treatment plant, allowing for significant tidal mixing in the Fill Aquifer and the subsequent release of dissolved contaminants through seepage. NAPL in the soil would have been subject to outward migration into the intertidal area, through daily seepage. NAPL released in this way would preferentially bind to resettling sediments, and to both surficial sediments near the shoreline and to those in the drainage channels through which the water flowed at low tide. The NAPL would have been retained in the sediments by capillary forces, and, over time, NAPL would accumulate in these sediments. NAPL released through direct discharge, and dissolved contaminants in the seeps or direct groundwater discharges would also preferentially partition to the organic carbon in the sediments, as it discharged across the sediment surface and along surface drainage channels (see Figure 13). The pre-1980 topography of the sediments, over which seepage would have flowed, was similar to that which exists today: sloping downward to the east, with dredged or natural east/southeastward-oriented channels.

With the creation of more land east of the former wood treatment plant during the East Bay Marina project in 1980, an impedance to NAPL transport was created. A rise, or "lip" in the aquitard surface just east of the historical log pond (Figure 22) appears to contribute to the significant volume of DNAPL that was recorded onshore at the Site in Well EW3 during late 1991. The surface of DNAPL has been recorded at Elevation 5.39 MLLW in Well EW3, and the highest detected elevation of the aquitard in this vicinity is approximately 2.1 MLLW at Boring C1 (Figure 15). Based on the elevation of the surface of the DNAPL pool relative to the highest recorded elevation of the aquitard (at C1), a driving force appears to have existed at that time for DNAPL to migrate into the sediments. The degree to which such migration occurred (the height of DNAPL at Well EW3 has been decreased by pumping during 1991) is dependent on the local heterogeneities in the fill and sediments. Because it is possible that this perturbation was formed during the 1980 East Bay fill project, DNAPL may have been freer to migrate along the aquitard surface prior to the 1980s. However, due to physical limitations to such flow in the sediments environment, bulk DNAPL transport within the sediments may be relatively limited in scale (physical limitations of bulk DNAPL flow in the sediments include the following: predominantly small pore size of the silt and clay sediments, discontinuous sand lenses, insufficient head of DNAPL to act as a driving force, and probable small continuous DNAPL lense length). If the sediment surface was ever lower than that shown on Figure 13 for 1979, bulk flow also potentially could have occurred on the sediment surface from the log pond.

It should be noted that the PCP concentrations reported for the NAPL-containing sediment samples obtained from Station C1 are significantly lower than those reported for soil samples obtained during drilling at EW3 (maximum of 140 ppb at C1 versus a maximum of 3,000 ppb at EW3). Because of the increased solubility (and mobility) of PCP in the higher pH environment of sea water (see Section 5.2.3), PCP that entered the intertidal marine environment would be much more rapidly dispersed into the ambient waters. The presence of dioxins (which are associated with the PCP) in intertidal sediments at significantly greater levels than would be predicted by the PCP concentration found in the sediments, indicates that PCP-related contamination did migrate or was emplaced in the intertidal sediments. The subsequent mobilization of the PCP from the sediment due to the chemical effects discussed above would have left behind a residue of the less mobile dioxins.

Other transport processes that may also have contributed to the observed chemical and NAPL distributions in the Sediments Operable Unit include surface water runoff from the uplands portion of the Site, spills directly into the sediments from bulk shipments and transfer of wood-treating chemicals, and dredging (and dredge disposal) associated with the historical dock and log pond. With perhaps the exception of the latter, these transport processes are believed to be more localized phenomenon, secondary to the daily discharge of contaminants through seeps. For example, the observed elevated PCP concentrations in sediments nearshore to the northern shoreline of the Site could have resulted from shoreline seepage and/or surface water runoff from the post-treatment log storage areas. It is also possible that seepage of LNAPL with PCP has contributed to the contamination observed in this area. Other contaminant concentrations in sediments north of the former wood treatment plant suggest predominantly dissolved phase transport and partitioning.

Current contaminant releases to the Sediments Operable Unit from the uplands portion of the Site are likely to be lower than those that occurred historically. This would be due in part to the placement of fill east of the former wood treatment plant, in part to ceased operations at the plant, and in the future, to the recent installation of a sheet pile wall at the shoreline as part of the DNAPL Expedited Action under the Consent Decree.

Contaminant transport within the sediments appears to be limited vertically by the fine-grained sediments of the aquitard. Therefore, dissolved phase transport, and any continued NAPL transport, generally would be expected to occur primarily within the recent deposits that lie above the aquitard or any coarse grained lenses within the aquitard.

6.0 SUMMARY AND RECOMMENDATIONS

6.1 SUMMARY OF RI FINDINGS

The data collected during the RI was evaluated to identify the soil types that occur in the sediments, the areal and vertical extent of contamination in the sediment, the potential for sediment resuspension and transport, and the depth of the biologically active zone.

The RI distinguished three geologic units in the Sediments Operable Unit: 1) recent deposits consisting of fill and recent intertidal sediments, 2) marine sediments that comprise the upper aquitard, and 3) alluvial sands that comprise the Lower Aquifer. The recent deposits in the Sediments Operable Unit range in thickness from greater than 13 ft in the west to approximately 0.3 ft in the east, and consist of varying amounts of sand; silty sand; sandy silt; silt; clayey silt; and silty clay with shells, shell fragments, and wood debris. The upper layer of the recent deposits typically consists of black to olive-black organic silt and clayey silt up to 2.3 ft thick. This upper layer of intertidal sediments is thickest in the eastern nearshore area and thins to the west and north, which is consistent with Site oceanographic characteristics.

Underlying the recent deposits are tidal and subtidal marine deposits that comprise the upper aquitard. The upper aquitard encountered in the RI is typically olive-gray to dark olive-gray in color, consisting of stiff clay and silty clay. This unit has occasional silty and sandy zones with frequent but variable shells, shell fragments, and wood fragments. The upper aquitard was encountered throughout the Sediments Operable Unit, and generally ranged in thickness from 16.1 to 17.4 ft (490 to 530 cm) [at Boring A2, the thickness of the aquitard was found to be significantly less (8.2 ft), due to dredging for the East Bay Marina]. Beneath the upper aquitard lie the silty sands and sands of the Lower Aquifer.

The topography of the Sediments Operable Unit at the Site was found to influence contaminant distribution. The surface of the sediments consists of gently sloping surfaces that begin at the base of the riprap along the shoreline, and extend out into the subtidal zone. East of the former wood treatment plant, the shoreline slopes downward to the east, and north of the former wood treatment plant, the surface of the intertidal sediments slopes downward to the north and northeast. Several erosional channels exist in the sediment surface.

The current topography of the Sediments Operable Unit is altered from its historical surface as a result of dredging and fill activities associated with the building and development of the Port peninsula. The most recent major alteration to the sediment surface occurred in the early 1980s when the area south and immediately east of the wood treatment plant was filled as part of the Port's East Bay development. Offshore dredging of a channel for marina access also occurred at that time.

Tides, winds, and vessel traffic all contribute to sediment erosion, deposition, and resuspension at the Site. The mean tidal range for lower Budd Inlet is 10.5 ft. Tides in Budd Inlet are mixed diurnal tides, with a significant diurnal inequality and a fortnightly cycle (a 2-week cycle in which tides of extreme highs and lows gradually change to shallow tidal variations). Winds at the Site are predominantly from the south and southwest; therefore, the Sediments Operable Unit is relatively protected from the prevailing winds. The western portion of the Sediments Operable Unit is most likely to be subject to the occasional storms with northerly winds and waves, and the predominance of coarser grained sediment in that area supports this model. Sediments resuspended by these storm waves would be expected to move easterly along the shore and to the offshore. To the southeast, near the breakwater, the sediments grade finer, suggesting a significantly more quiescent environment. Vessel traffic occurs in both the East and West bays of Budd Inlet; however, the contribution of this to sediment processes at the Site was determined to be insignificant.

Net sediment deposition (or loss) rates cannot be calculated precisely for the Site without long-term, controlled monitoring. The Sediments Operable Unit is a low-energy environment, and in general, the greatest sediment resuspension is expected to occur in areas with elevation generally greater than +5 ft mean lower low water (MLLW). Pb-210 data was collected during the RI to evaluate the depth of the surface mixed layer (which can be used as an indicator of the vertical extent of the predominant biologically active zone) and the rate of sediment accumulation. The data from the Site was found to be influenced by interferences that prevented precise definition of these parameters. However, in general, benthic activity in coastal marine sedimentary environments is highest in the upper few centimeters of the sediment column, although burrowing organisms can go as deep as 1 meter. Typically, the very deep burrowers are rarer, and given the types of fauna observed at the Site, the majority of biological activity is estimated to be within the upper 0-25 cm interval of the Site sediment. This estimate is not contradicted by the rough estimate of 25 cm for the mixing zone that was postulated from the data from Station H4 (the station with Pb-210 data least subject to interferences) and also is consistent with direct (though limited) observations at the Site. Very rough estimates of maximum sediment accumulation rates from the Pb-210 data range from 0.2 to 0.3 $gm/cm^2/yr$. These rates are comparable to those measured in other shallow bays in Puget Sound.

The field investigations, and chemical and biological data evaluations conducted as part of the Sediments RI result in the following findings:

- Sediment offshore of the former wood-treatment plant at the CPC Site contains contaminants associated with historical wood-treating activities at the Site.
- The highest levels of creosote-related contaminants are located just offshore, east of the former wood treatment plant, at the 10-55 cm depth interval. The highest levels of PCP-related contaminants are located nearshore, to the north/northwest of the former wood treatment plant, in the upper 10 cm.
- The lateral distribution of the contamination is primarily to the east of the former wood treatment plant, with some spreading to the north and northeast. This distribution is consistent with current, and reasonably postulated, past Site characteristics (e.g., the historical and current aquitard surface, historical and current shorelines, and offshore topography) and with contaminant migration mechanisms.
- The vertical distribution of contamination is such that the highest concentrations are found in the depth intervals 10-55 and 55-100 cm below the surface. The vertical extent of contamination generally is limited by the presence of the silts and clays of the original intertidal surface (the aquitard).
- The contamination exists in sediments primarily as sorbed chemicals, with some occurrences of NAPL (the NAPL appears to be limited to the area east of the former wood treatment plant).
- Current State Sediment Management Standards chemical criteria (both SQS and CSL) are exceeded for PAH, dibenzofuran (constituents of creosote), and to a lesser degree, several metals, in sediments north and east of the former wood treatment plant. The highest exceedances were at stations located nearshore, east of the former wood treatment plant. Bioassays from two locations indicate exceedance of the Sediment Management Standard SQS biological criteria at both locations, and the CSL biological criteria at one location (C3, east/northeast of the former wood treatment plant).
- Current State Sediment Management Standards chemical criteria for PCP were not exceeded in any of the sediment samples collected during the RI.
- There currently exist no State Sediment Management Standards for dioxins and furans; however, these chemicals were detected at levels that are considered elevated [dioxins and furans are evaluated with respect to human health in the Sediments Risk Assessment (Landau Associates 1992)].
- Surface water ponded on or flowing in channels in the surface of the sediments, and in the water column above the sediments, does not appear to be affected by contamination from the Site at levels that exceed the current Federal and State marine acute and chronic criteria for protection of the environment (and Federal criteria that address human consumption of fish from the marine environment). The only exceptions to this are 1) all Site and

Budd Inlet background water samples contained dioxin above the Federal criteria that addresses human consumption of fish from marine environment, and 2) one drainage channel just east of the former wood treatment plant in which flowing water in the channel contained chemical concentrations that slightly exceeded the health-based water quality criteria for six PAH.

- Clams obtained from an area of elevated sediment chemical concentrations contained levels of wood-treating chemicals significantly above concentrations in samples obtained from Eld Inlet. Clams obtained from an area at the Site with lower contaminant sediment concentrations contained contaminant levels above those reported for the reference sample, but significantly below those in the clams from the most contaminated sediments.
- Differences in benthic infaunal abundance and diversity were found between the two sediment samples obtained from the Site and between the Site samples and the reference sample obtained from Eld Inlet. The Site sample collected from the northwest portion of the Sediments Operable Unit exhibited minor differences from the reference sample; these differences may be related to site-specific chemicals or may, to some degree, reflect the differences between and urban embayment and the more pristine environment of the reference area. In contrast, the results for the station east of the former wood treatment plant indicate decreases in abundance and diversity that are indicative of sediment adversely affected by organic contamination.

The results of this RI and the companion Risk Assessment (Landau Associates 1992) indicate the need for remedial action in the sediments nearshore, generally east and northeast of the former wood treatment plant.

6.2 RECOMMENDATIONS

The sampling and data evaluations conducted during the Remedial Investigation provide data sufficient to conduct the Risk Assessment, and to evaluate both the need for remedy, and the remedial alternatives available for the contaminants in the Sediments Operable Unit. There remain a number of questions, raised by the data collected during the RI, that may warrant further investigation. However, the need to expend resources to answer the questions should be evaluated in relation to the value of the data in making future decisions regarding the need for remedy and/or the appropriate remedial alternatives for the Site. The primary questions that remain, and the value of the data in future Site decisions, are summarized below:

- Extent of NAPL. Many samples collected during the RI provide some information on the bounds of the extent of NAPL-containing sediment, but questions remain regarding the extent of the NAPL in several areas, the most notable of which is the area southeast of the B-transect. Sampling will be necessary to further define the extent of NAPL in all areas that require remedial action decisions on the basis of NAPL presence alone. Any area that will be remedied on the basis of other contaminant or engineering considerations would not necessarily require effort to delineate the extent of NAPL-containing sediment.

- Extent of Contamination in the Dredged Area of the East Bay Marina. The presence of contamination in subsurface samples adjacent to the East Bay Marina breakwater and the potential for that area to accumulate sediment resuspended by wave action across the Sediments Operable Unit suggest that further sampling in this area is warranted. Unless it is found during the Feasibility Study stage that the selection of the preferred remedial alternative will depend upon the extent of the contamination in this area, the sampling could be deferred until the predesign stage. In this way, the sampling could be coordinated with other predesign sampling.
- Bioassays. The results of the very limited number of bioassays conducted during the RI did not correspond to the results of the chemistry data collected at these locations. This discrepancy is of concern in that the majority of data from the site, and upon which decisions will be made regarding remedy, are chemical, not biological. Efforts to resample the site for bioassays may not be productive, especially in light of the questions regarding the reason for the discrepancy and the sensitivity of the bioassays to false positives. The value of further bioassays should be discussed between Ecology and the Parties prior to a decision regarding the need for further sampling.

Questions remain regarding several other issues (e.g., depth of the biologically active zone, channelized transport of contaminants); however, the need to more precisely define these areas would best be determined following completion of the FS and selection of the preferred remedial alternative for the Sediments Operable Unit.

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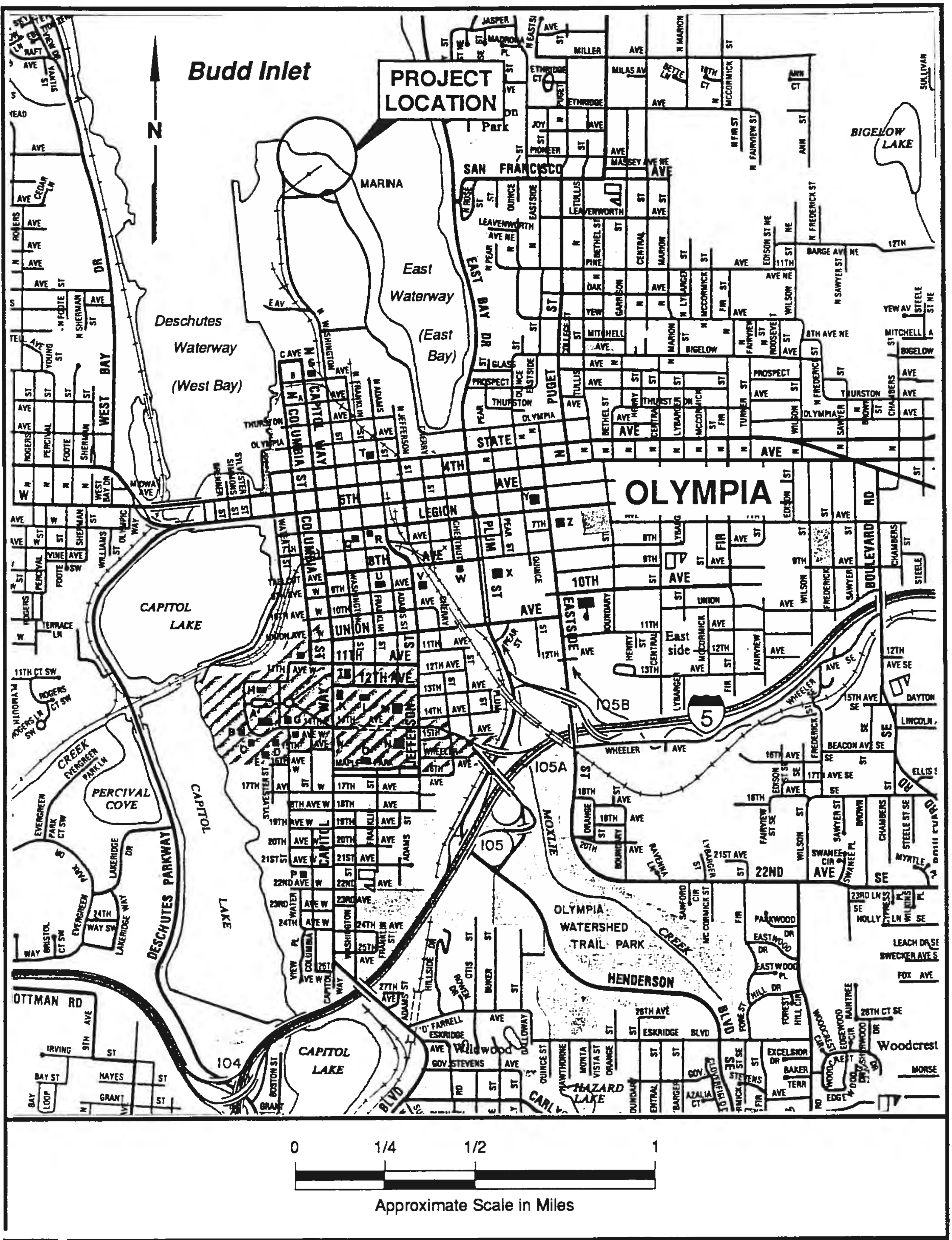
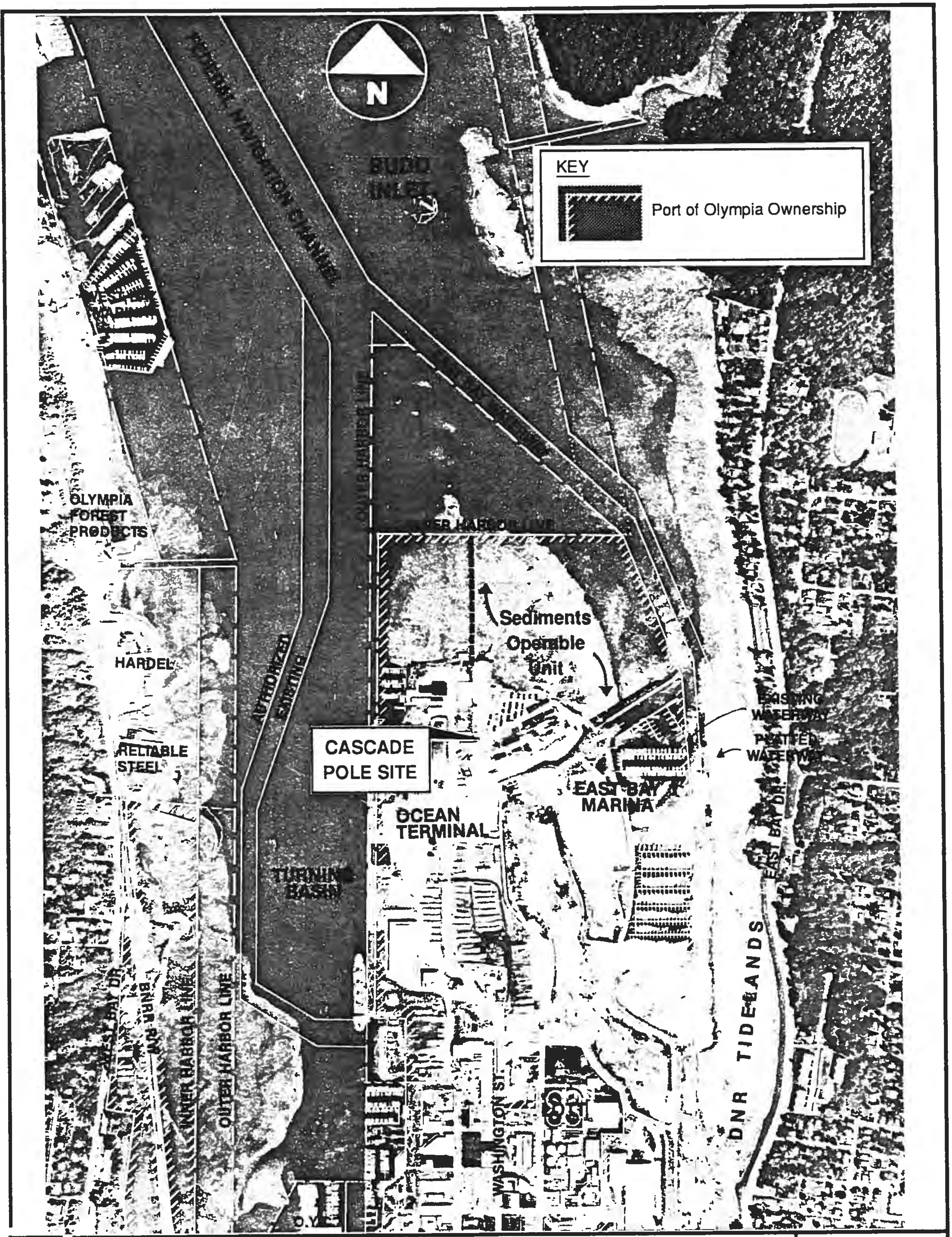
Text Figures



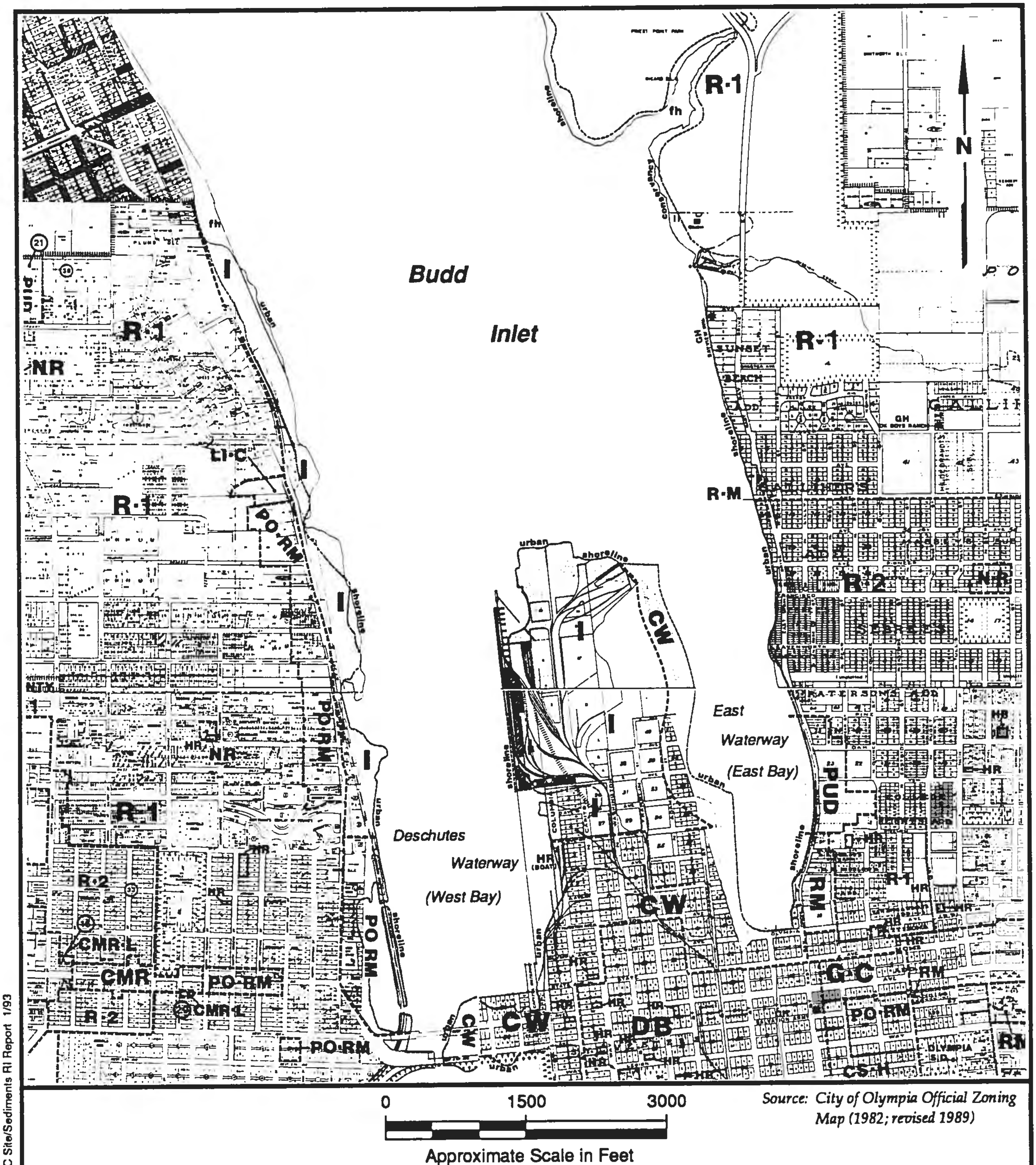
Vicinity Map

Figure 1



Sediments Operable Unit in Relation to Port of Olympia Ownership and Federal Harbor Lines

Figure 2



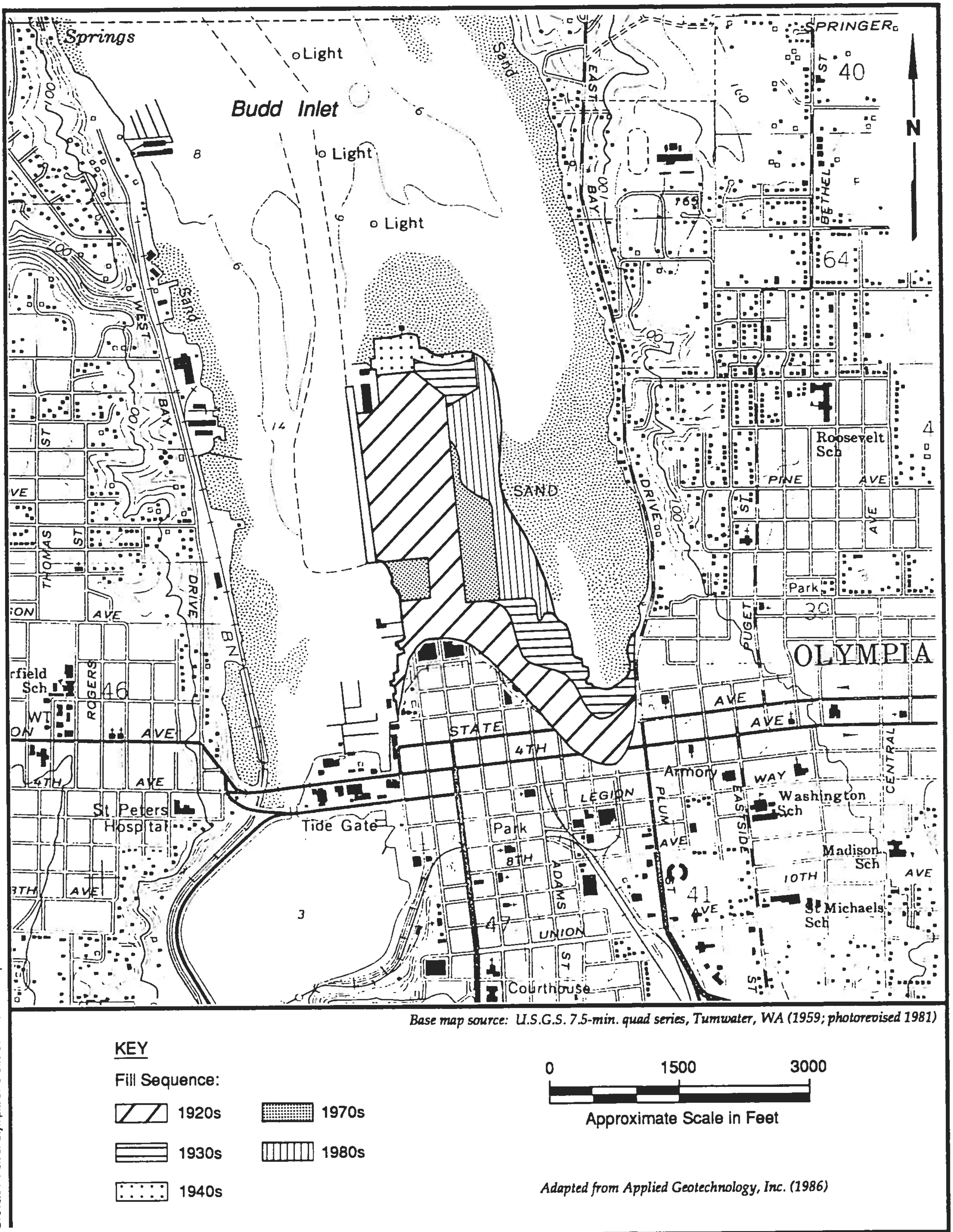
Source: City of Olympia Official Zoning Map (1982; revised 1989)

KEY

R-1	Single-Family Residential	CMR	Community Retail	LI-C	Light Industrial/Commercial
R-2	Two-Family Residential	CS-H	Community Services-High Density	I	Industrial
RM	Multifamily Residential	CW	Central Waterfront	PUD	Planned Unit Development
PO-RM	Professional Office/Residential	DB	Downtown Business	-----	Zoning District Boundary
NR	Neighborhood Retail	GC	General Commercial	▭	Shoreline

Zoning Map

Figure 3



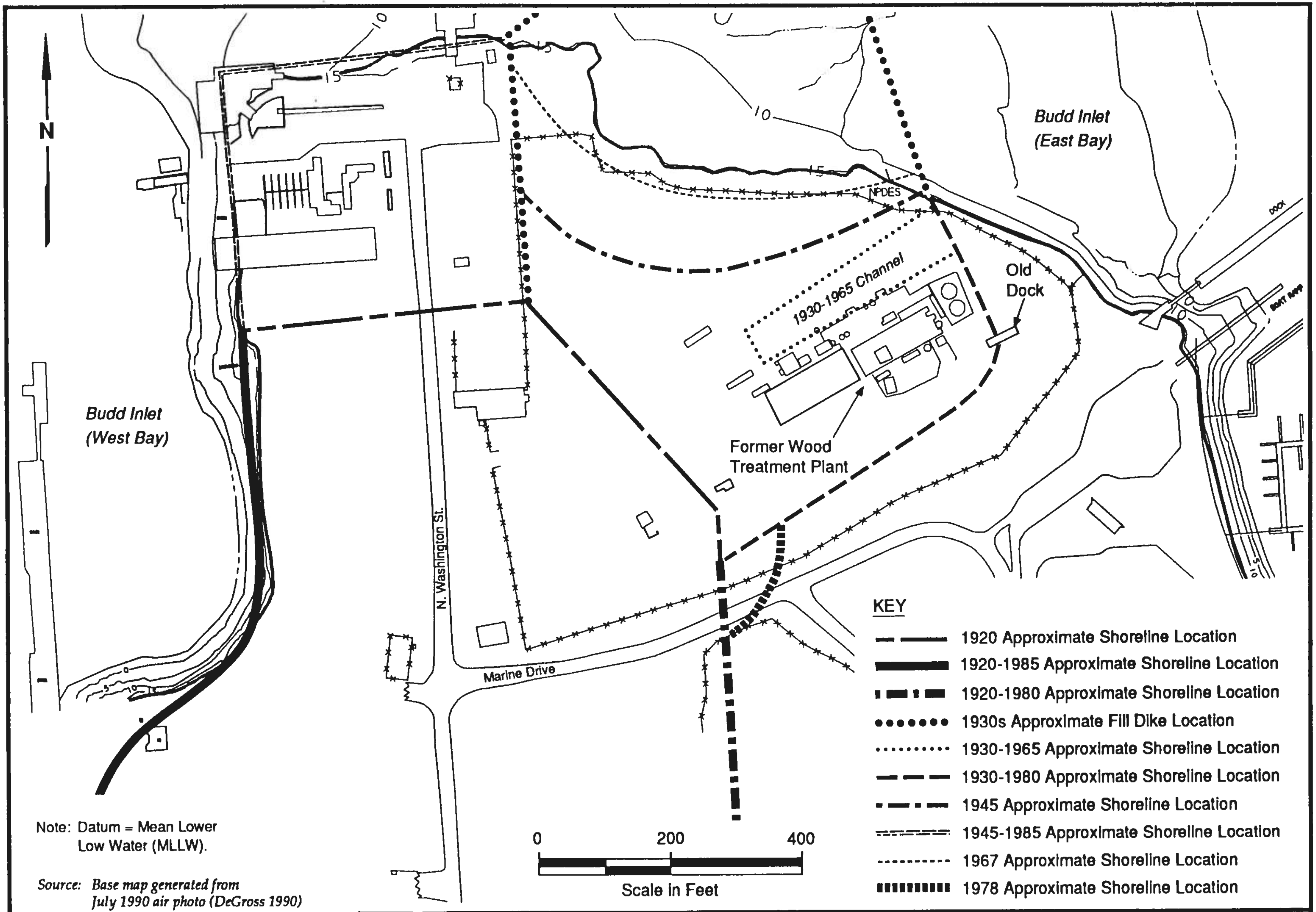
Base map source: U.S.G.S. 7.5-min. quad series, Tumwater, WA (1959; photorevised 1981)

Adapted from Applied Geotechnology, Inc. (1986)

21015.54 Port of Olympia/CPC Site/Sediments RI Report 1/93

Port Peninsula Fill History

Figure 4



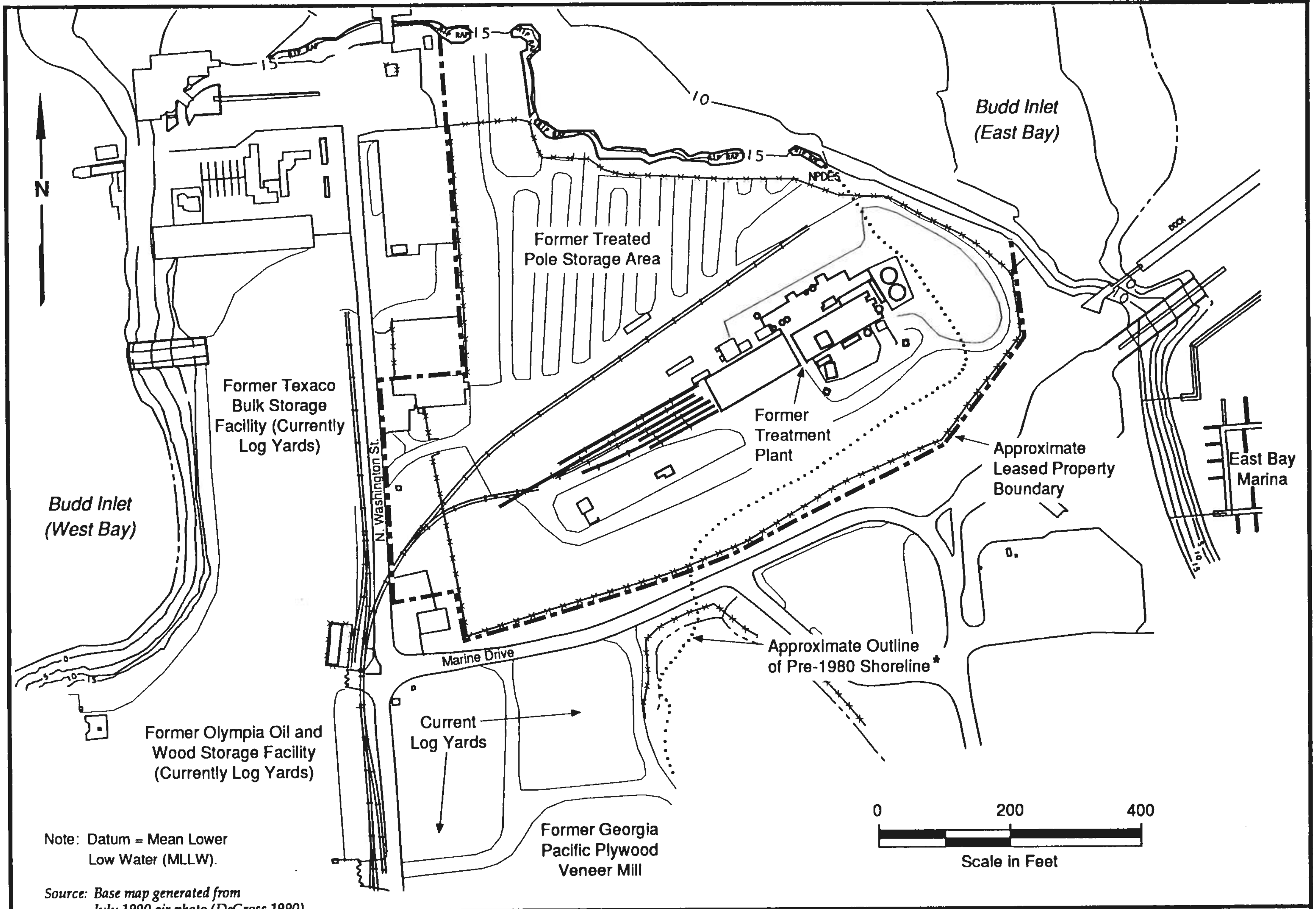
Note: Datum = Mean Lower
Low Water (MLLW).

*Source: Base map generated from
July 1990 air photo (DeGross 1990)*

Adapted from Applied Geotechnology, Inc. (1986)

Historical Shorelines

Figure 5



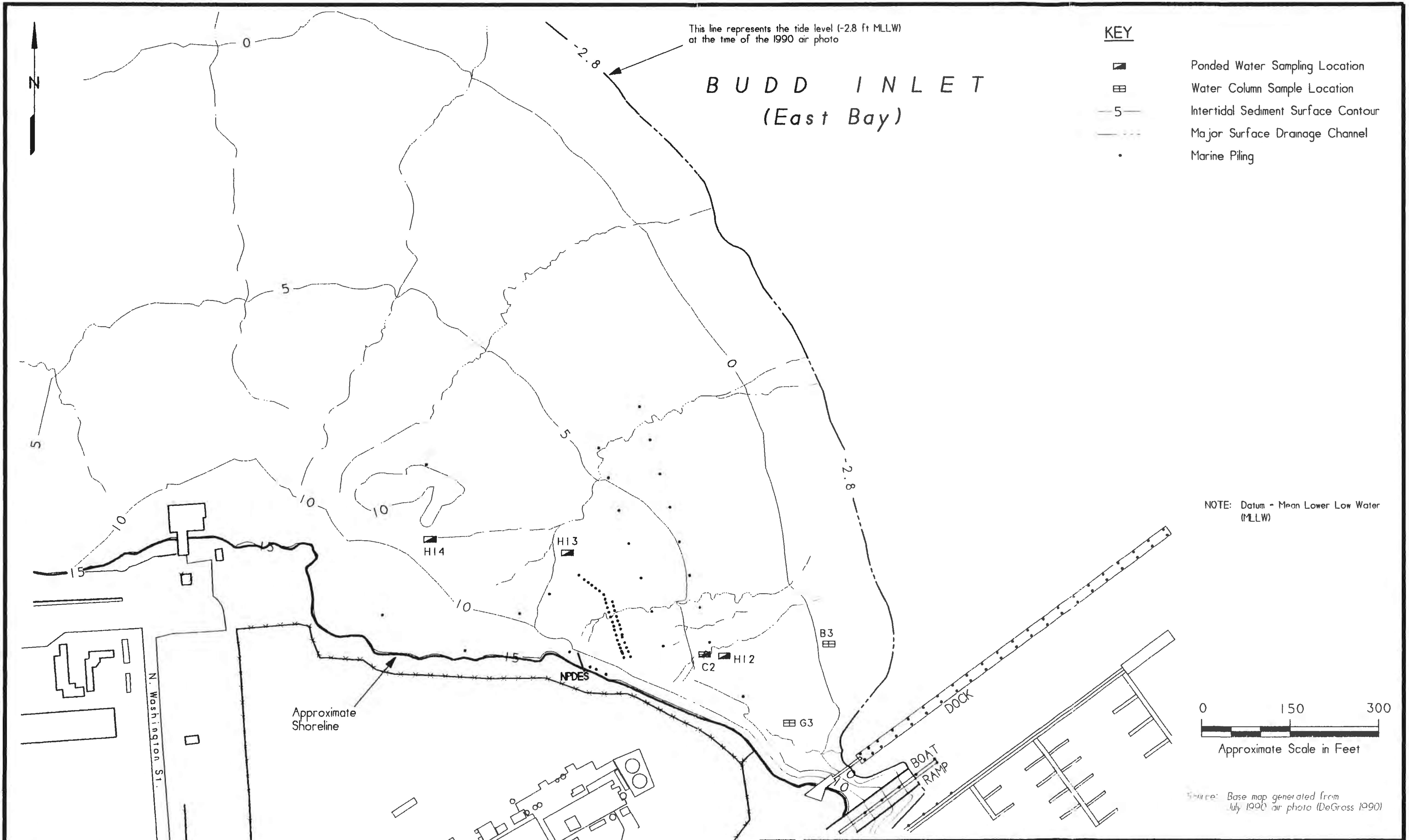
Note: Datum = Mean Lower
Low Water (MLLW).

Source: Base map generated from
July 1990 air photo (DeGross 1990)

**Shoreline alignment adapted from Corps (1980)*

Historical Use of Site and Surrounding Areas

Figure 6



NOTE: Datum - Mean Lower Low Water (MLLW)

Source: Base map generated from July 1990 air photo (DeGross 1990)

Remedial Investigation Surface Water Sampling Locations

Figure 9

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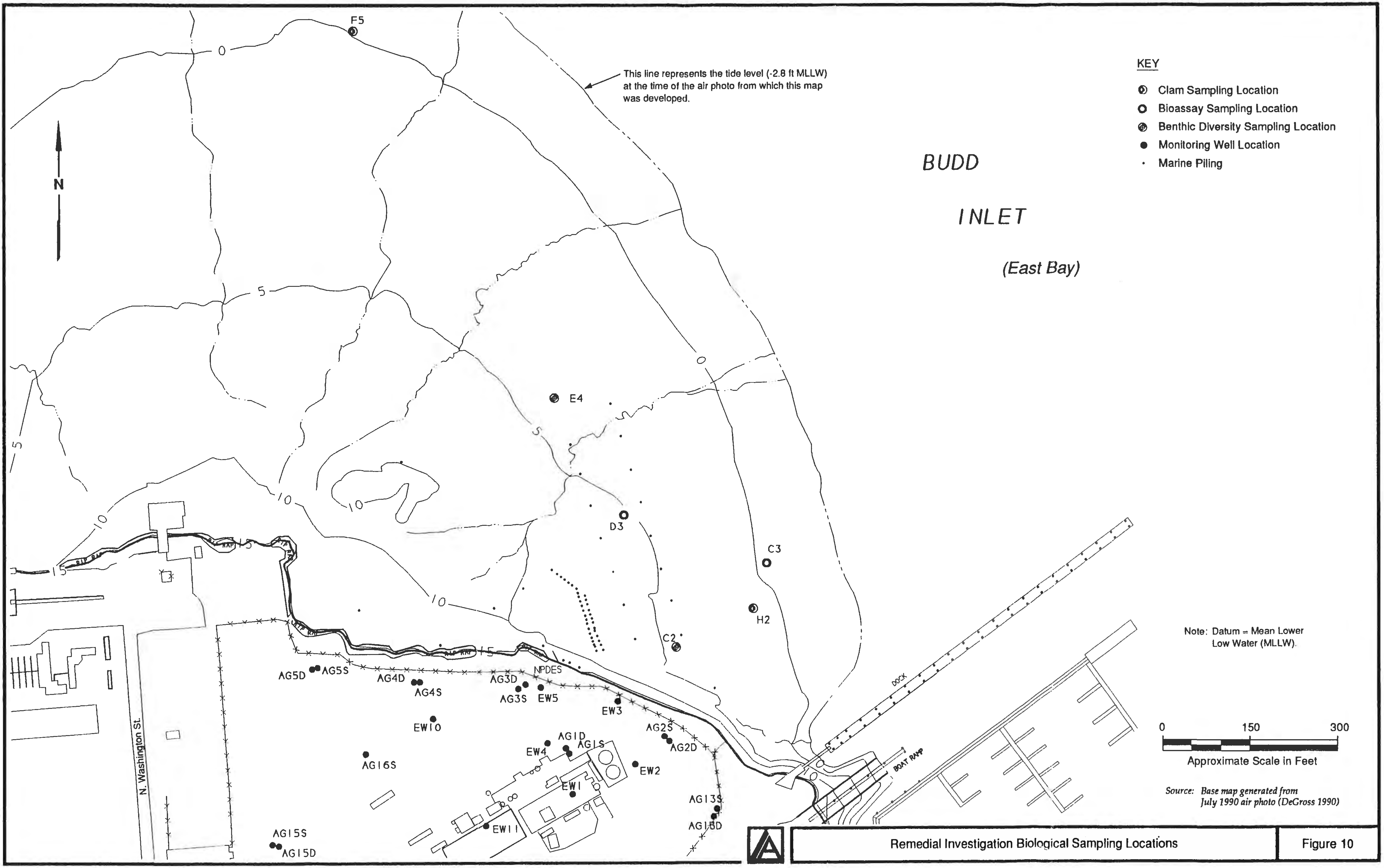
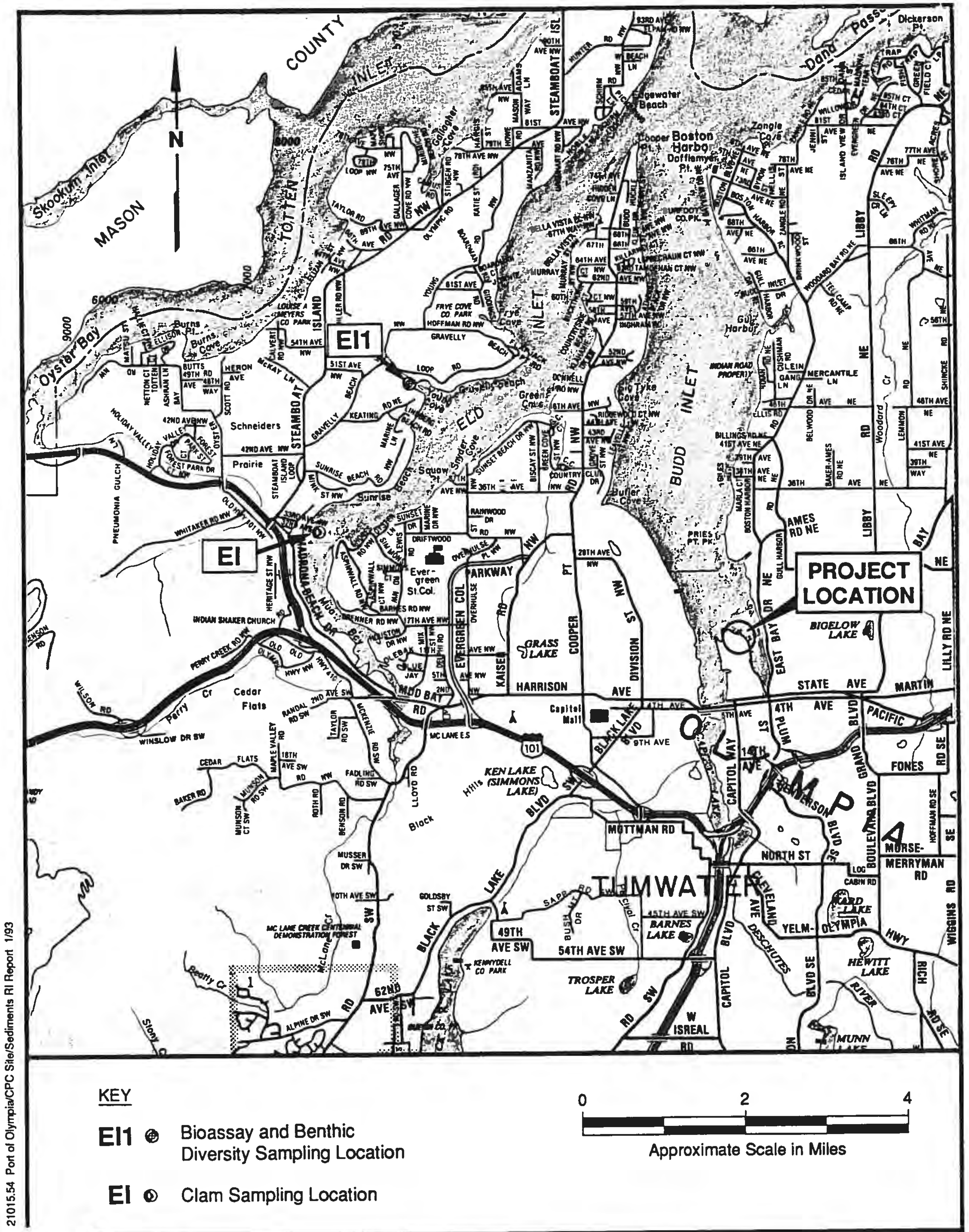


Note: Datum = Mean Lower Low Water (MLLW).

Source: Base map generated from July 1990 air photo (DeGross 1990)

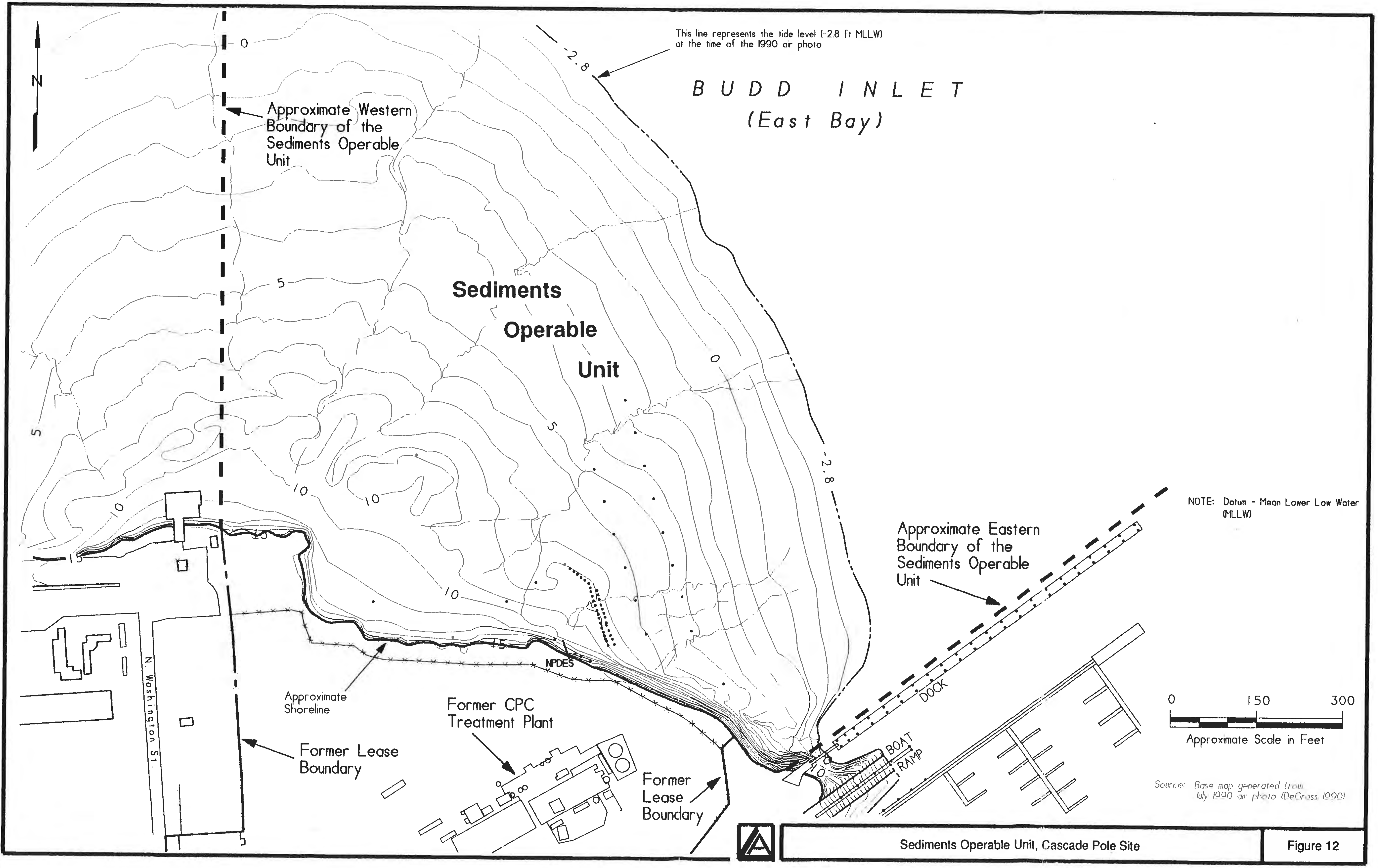
Remedial Investigation Biological Sampling Locations

Figure 10



Reference Station Locations for Biological Samples

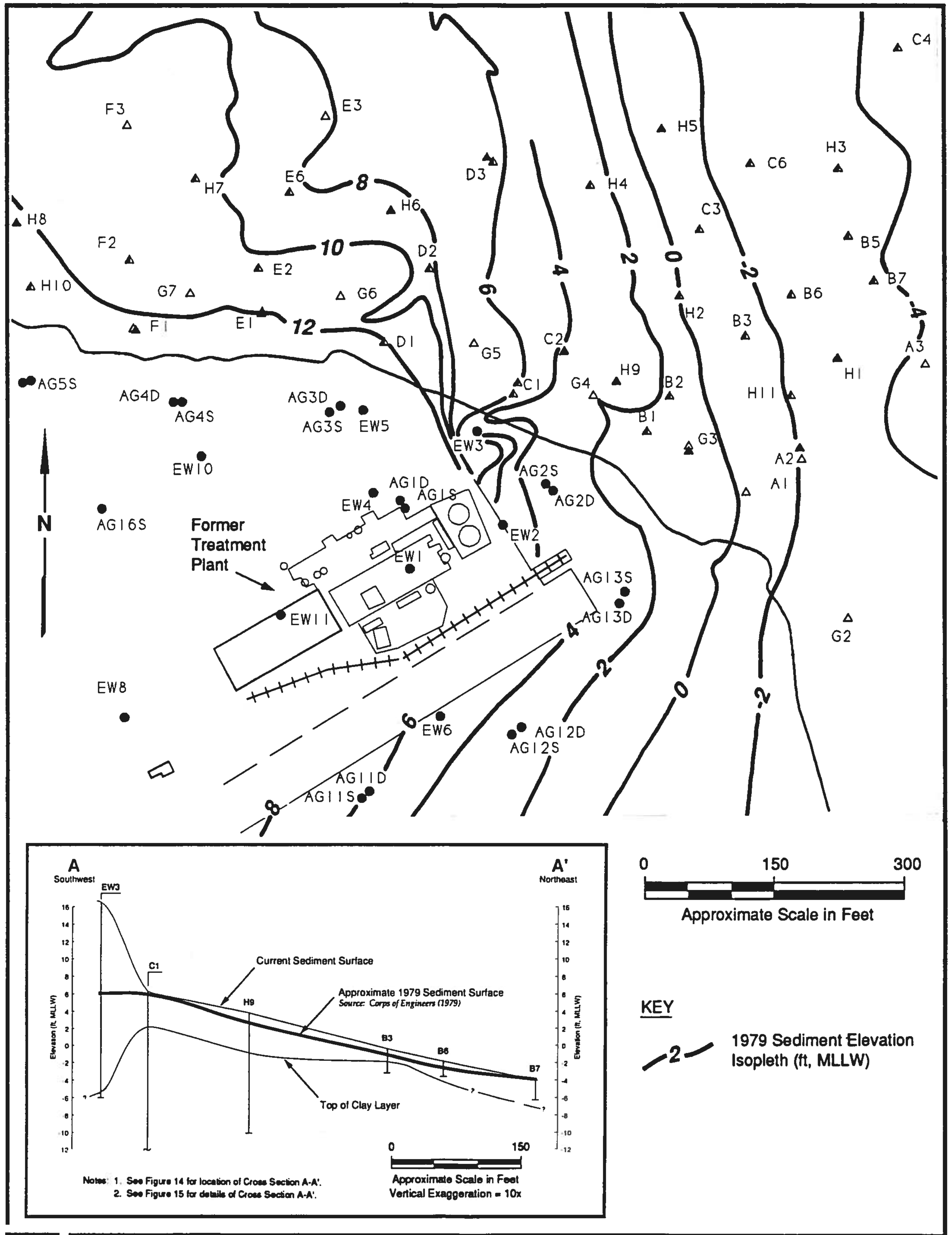
Figure 11



Source: Base map generated from July 1990 air photo (DeGross 1990)

Sediments Operable Unit, Cascade Pole Site

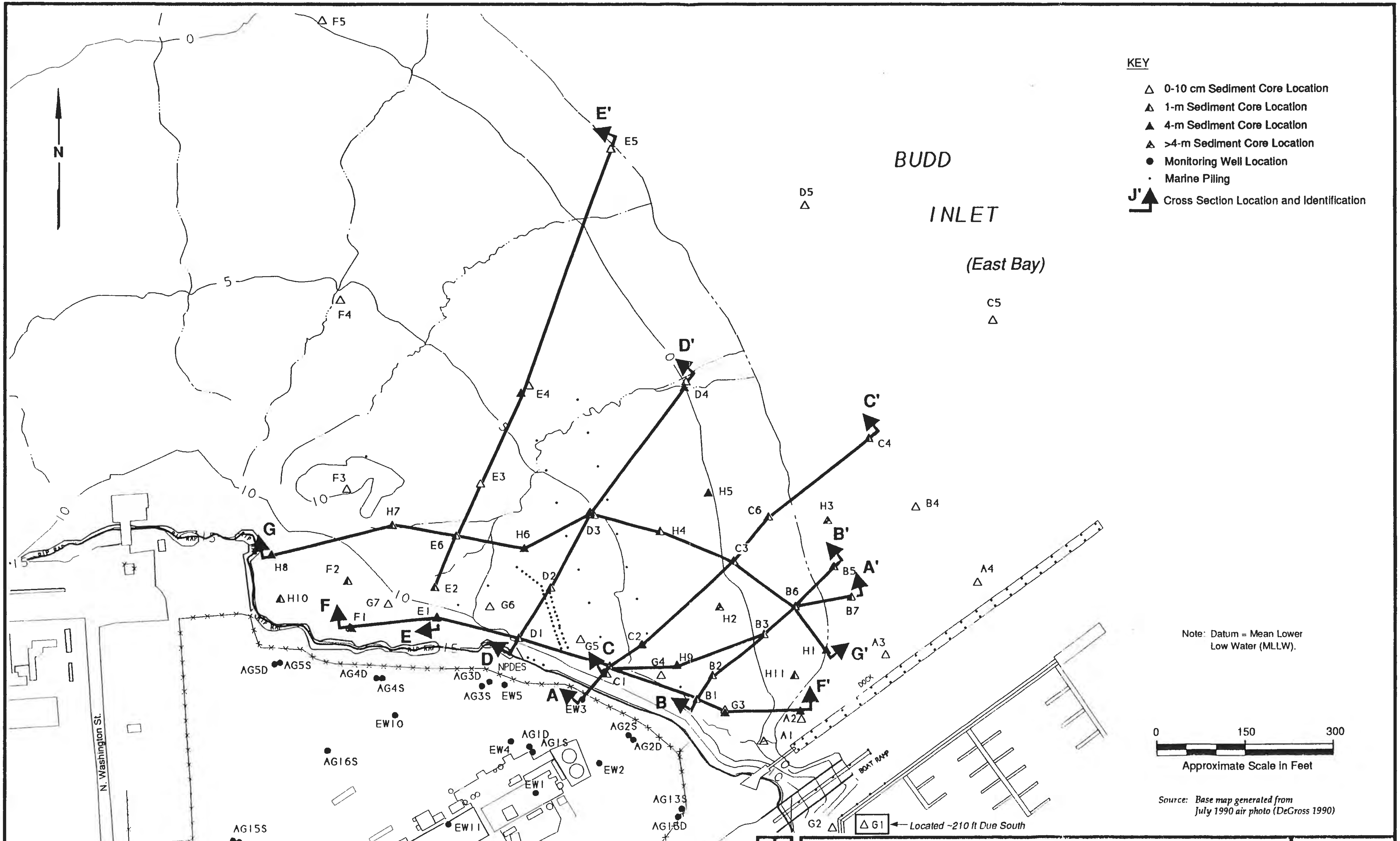
Figure 12



Notes: 1. See Figure 14 for location of Cross Section A-A'.
2. See Figure 15 for details of Cross Section A-A'.

Historical Sediment Topography

Figure 13



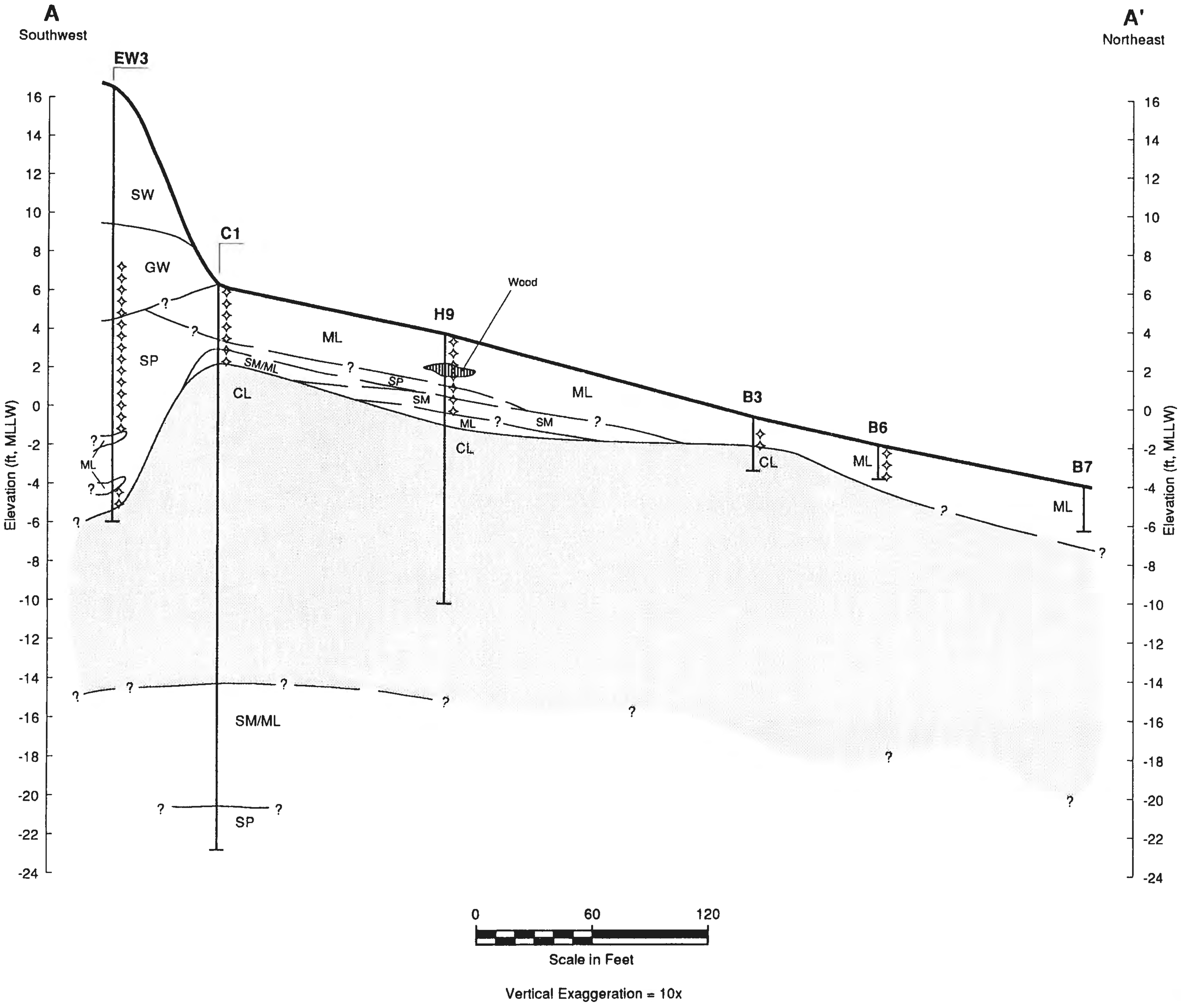
Note: Datum = Mean Lower Low Water (MLLW).

Source: Base map generated from July 1990 air photo (DeGross 1990)

Locations of Cross Sections

Figure 14

21015.54 Port of Olympia/CPC Site/Sediments RI Report 1/93



KEY

B3 ← Approximate Boring Location and Identification

Ground Surface

Approximate Geologic Contact (Queried Where Uncertain)

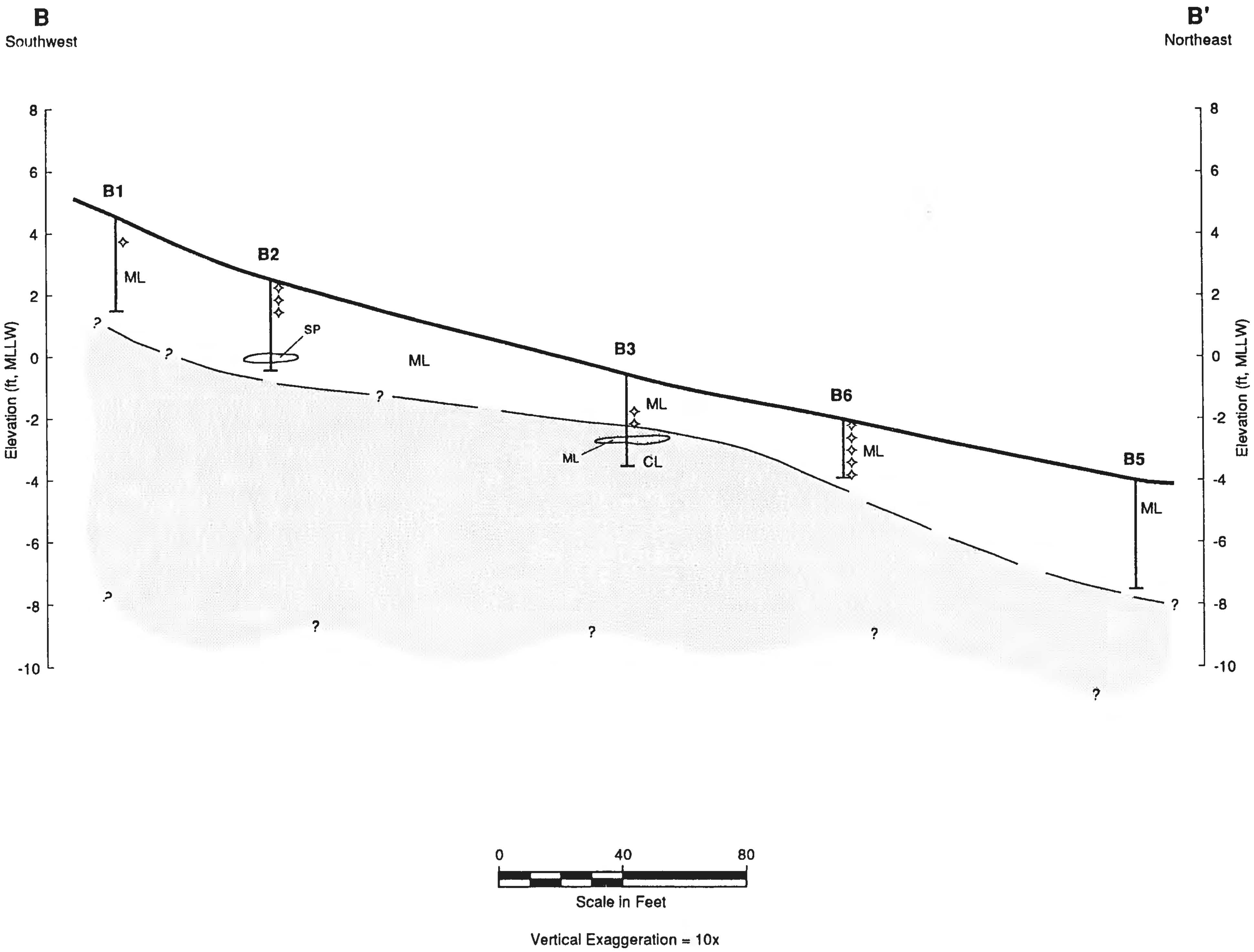
Bottom of Boring

CL	Clay or Silty Clay
GW	Sandy Gravel
ML	Silt or Clayey Silt
SM	Silty Sand
SP	Fine to Medium Sand
SW	Gravelly Sand
✧	Visible Sheen or Product
▢	Aquitard

Notes:
1. This cross section has been generalized from project field data. Variations between this cross section and actual subsurface conditions may be encountered. The project boring logs and written reports must be referenced for a proper understanding of the nature of subsurface materials.
2. Slash between units (e.g., SM/ML) indicates borderline soil classification.

Cross Section A-A'

Figure 15



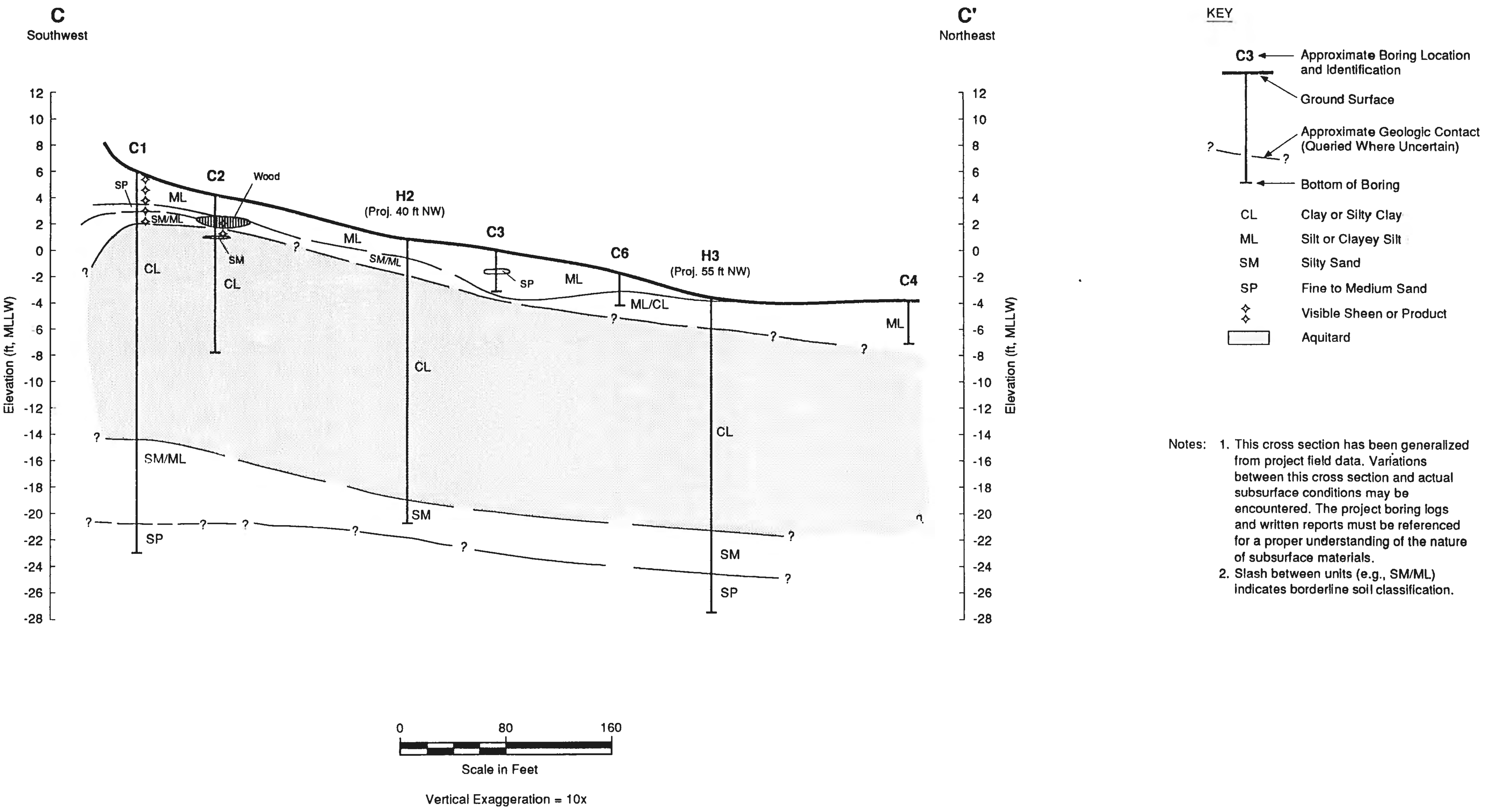
KEY

B3	Approximate Boring Location and Identification
	Ground Surface
? — — ?	Approximate Geologic Contact (Queried Where Uncertain)
⊥	Bottom of Boring
CL	Clay or Silty Clay
ML	Silt or Clayey Silt
SP	Fine to Medium Sand
✧	Visible Sheen or Product
▭	Aquitard

Notes: 1. This cross section has been generalized from project field data. Variations between this cross section and actual subsurface conditions may be encountered. The project boring logs and written reports must be referenced for a proper understanding of the nature of subsurface materials.

Cross Section B-B'

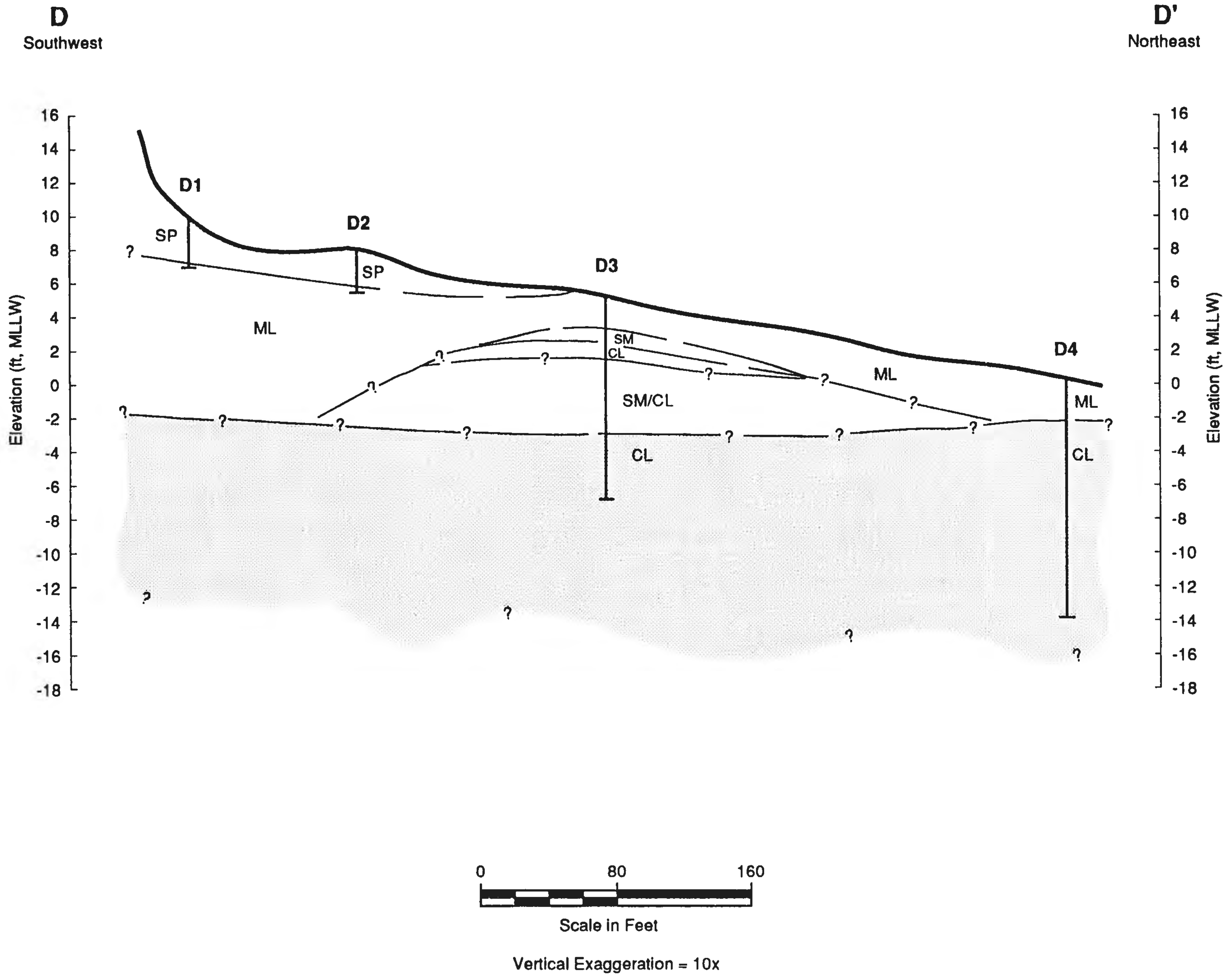
Figure 16



Notes:
1. This cross section has been generalized from project field data. Variations between this cross section and actual subsurface conditions may be encountered. The project boring logs and written reports must be referenced for a proper understanding of the nature of subsurface materials.
2. Slash between units (e.g., SM/ML) indicates borderline soil classification.

Cross Section C-C'

Figure 17



KEY

D3 ← Approximate Boring Location and Identification

Ground Surface

Approximate Geologic Contact (Queried Where Uncertain)

Bottom of Boring

CL	Clay or Silty Clay
ML	Silt or Clayey Silt
SM	Silty Sand
SP	Fine to Medium Sand
▢	Aquitard

Notes:
1. This cross section has been generalized from project field data. Variations between this cross section and actual subsurface conditions may be encountered. The project boring logs and written reports must be referenced for a proper understanding of the nature of subsurface materials.
2. Slash between units (e.g., SM/ML) indicates borderline soil classification.

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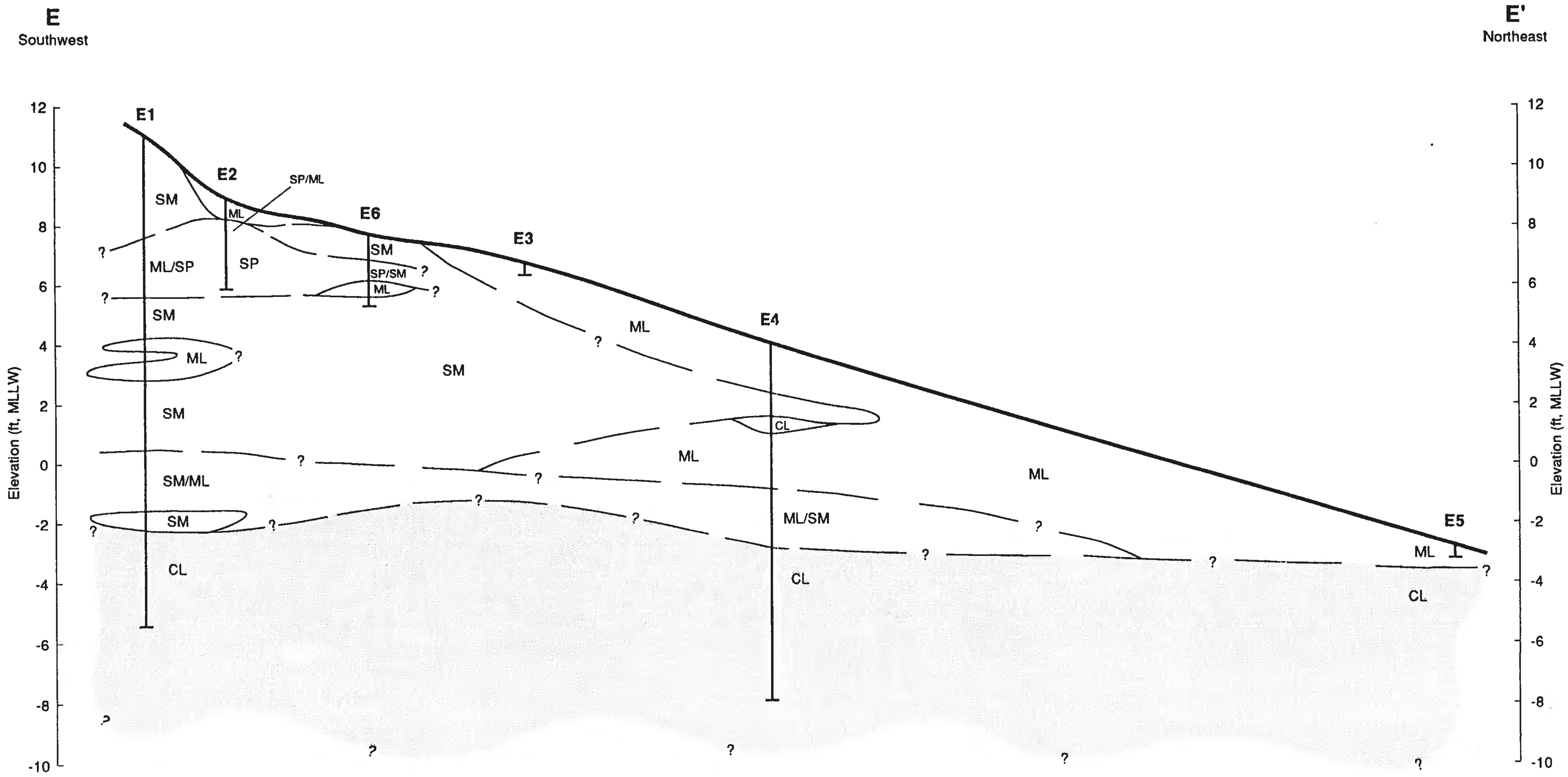
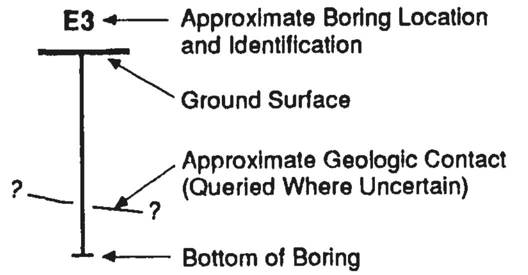
Cross Section D-D'

Figure 18

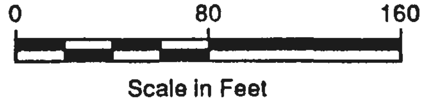


KEY



CL	Clay or Silty Clay
ML	Silt or Clayey Silt
SM	Silty Sand
SP	Fine to Medium Sand
▨	Aquitard

Notes:
1. This cross section has been generalized from project field data. Variations between this cross section and actual subsurface conditions may be encountered. The project boring logs and written reports must be referenced for a proper understanding of the nature of subsurface materials.
2. Slash between units (e.g., SM/ML) indicates borderline soil classification.

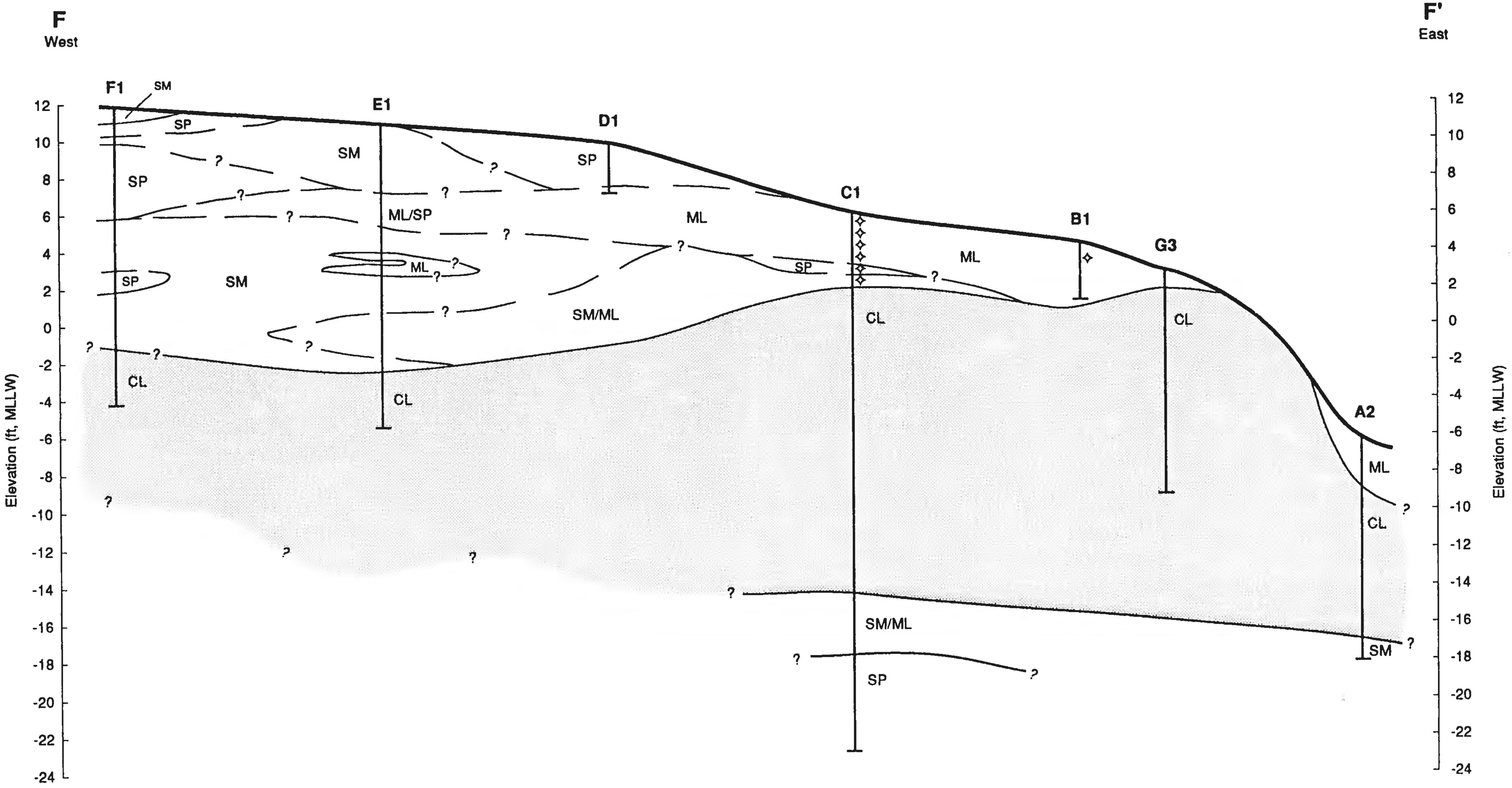


Vertical Exaggeration = 20x

Cross Section E-E'

Figure 19

21015.54 Port of Olympia/CPC Site/Sediments RI Report 1/93



KEY

F1 ← Approximate Boring Location and Identification

Ground Surface

? ? Approximate Geologic Contact (Queried Where Uncertain)

Bottom of Boring

CL	Clay or Silty Clay
ML	Silt or Clayey Silt
SM	Silty Sand
SP	Fine to Medium Sand
✧	Visible Sheen or Product
▭	Aquitard

Notes:
1. This cross section has been generalized from project field data. Variations between this cross section and actual subsurface conditions may be encountered. The project boring logs and written reports must be referenced for a proper understanding of the nature of subsurface materials.
2. Slash between units (e.g., SM/ML) indicates borderline soil classification.

0 80 160

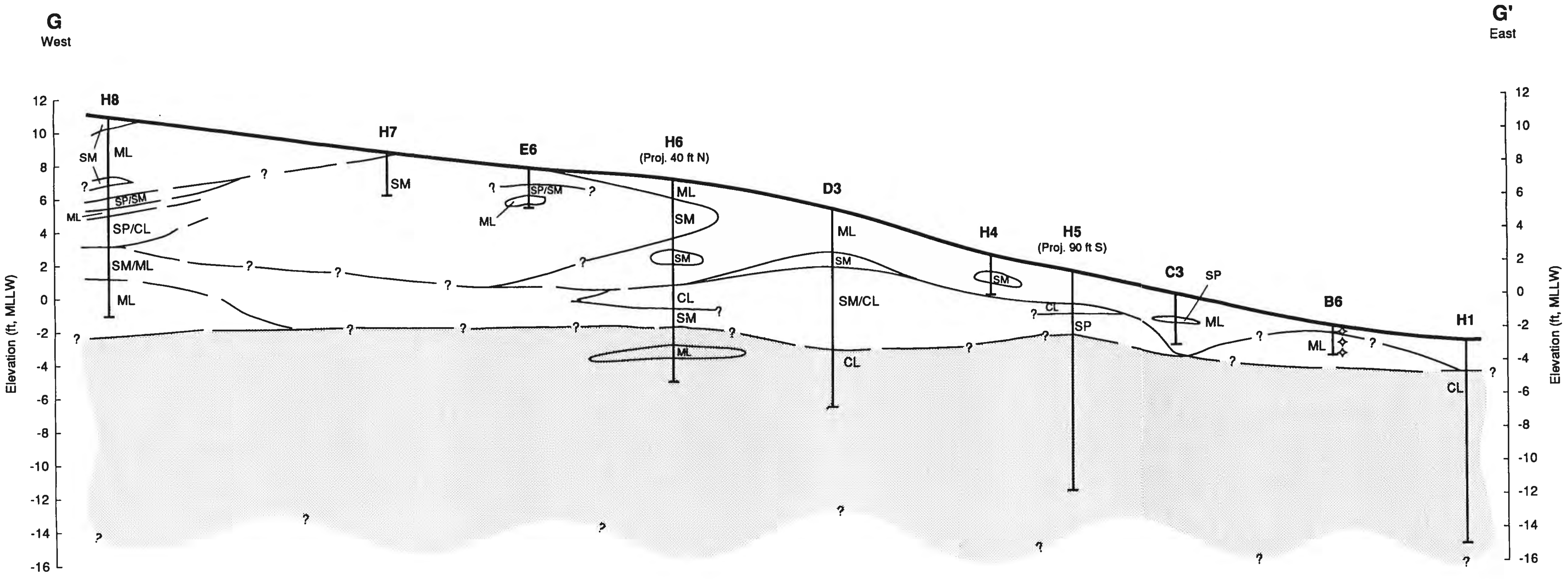
Scale in Feet

Vertical Exaggeration = 12.5x

Cross Section F-F'

Figure 20

21015.54 Port o mpia/CPC Site/Sediments RI Report 1/93



KEY

D3 ← Approximate Boring Location and Identification

Ground Surface

Approximate Geologic Contact (Queried Where Uncertain)

Bottom of Boring

CL	Clay or Silty Clay
ML	Silt or Clayey Silt
SM	Silty Sand
SP	Fine to Medium Sand
✧	Visible Sheen or Product
▭	Aquitard

Notes:
1. This cross section has been generalized from project field data. Variations between this cross section and actual subsurface conditions may be encountered. The project boring logs and written reports must be referenced for a proper understanding of the nature of subsurface materials.
2. Slash between units (e.g., SM/ML) indicates borderline soil classification.

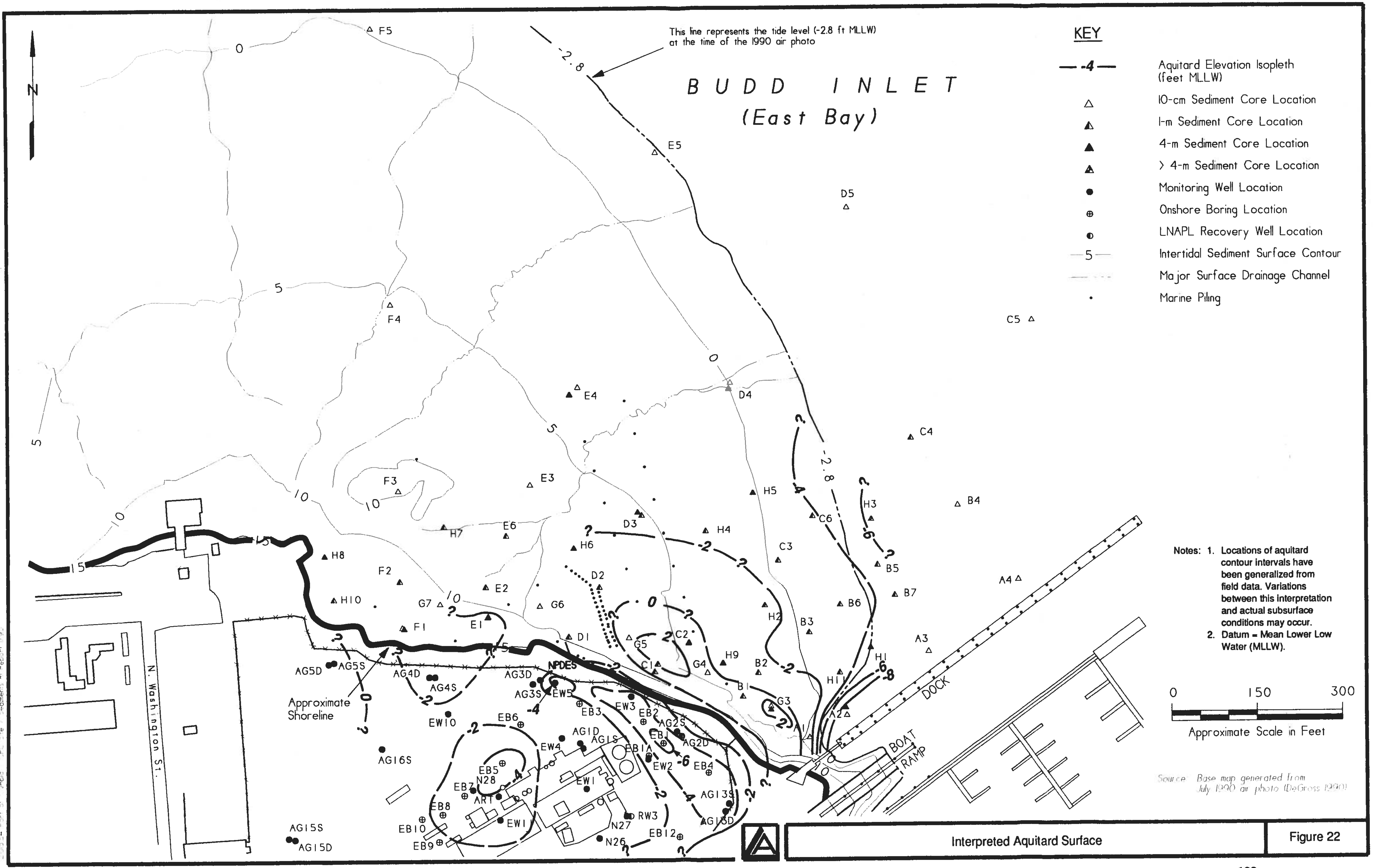
0 80 160

Scale in Feet

Vertical Exaggeration = 12.5x

Cross Section G-G'

Figure 21



Notes: 1. Locations of aquitard contour intervals have been generalized from field data. Variations between this interpretation and actual subsurface conditions may occur.

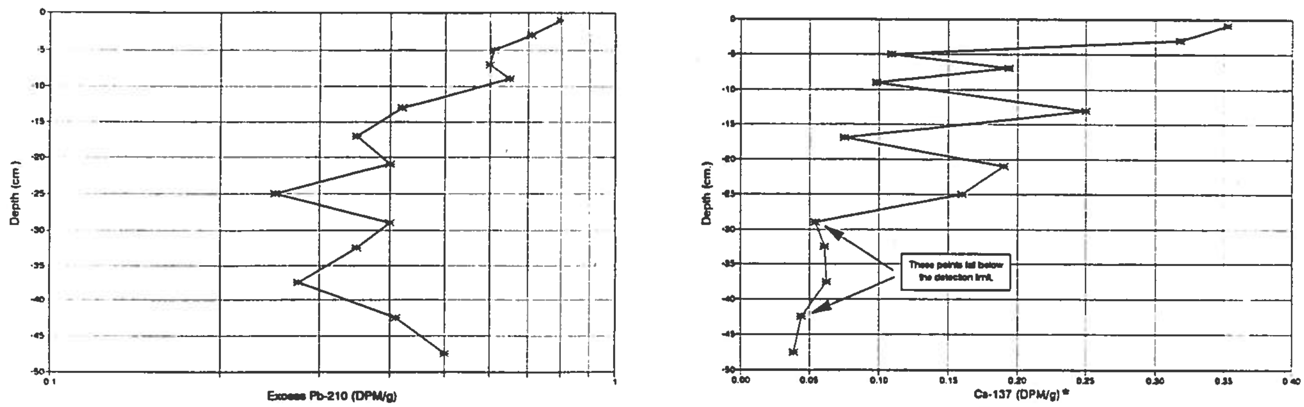
2. Datum = Mean Lower Low Water (MLLW).

Source: Base map generated from July 1990 air photo (DeGross 1990)

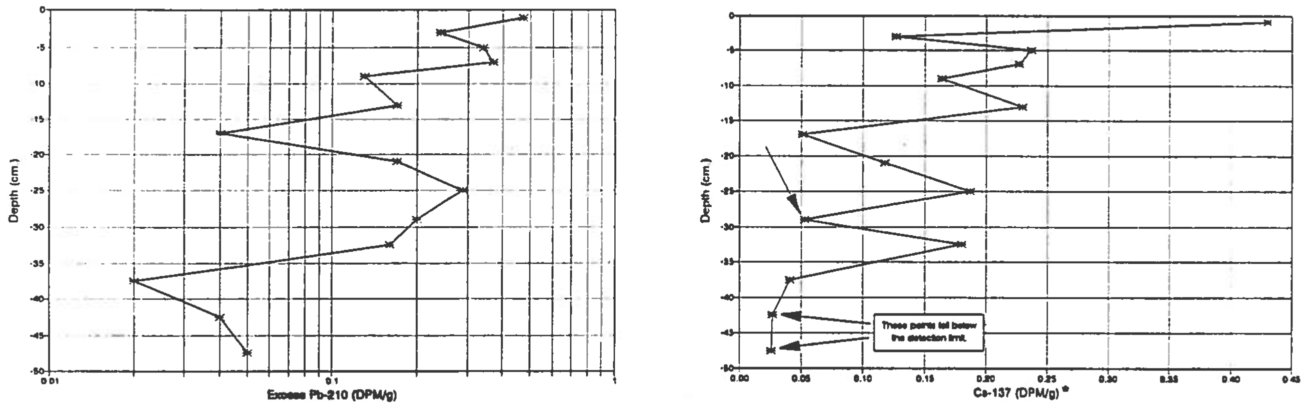
Interpreted Aquitard Surface

Figure 22

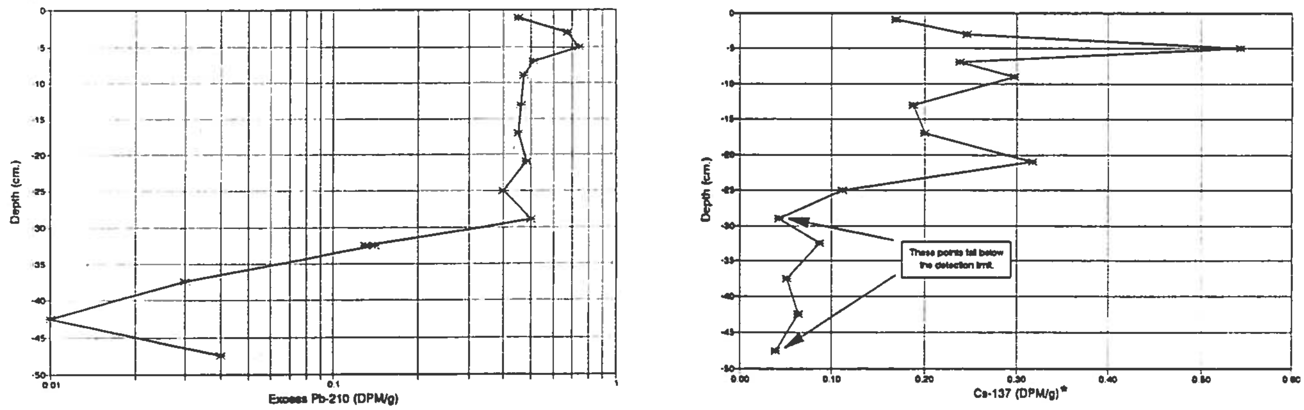
Sediment Core C6



Sediment Core E6



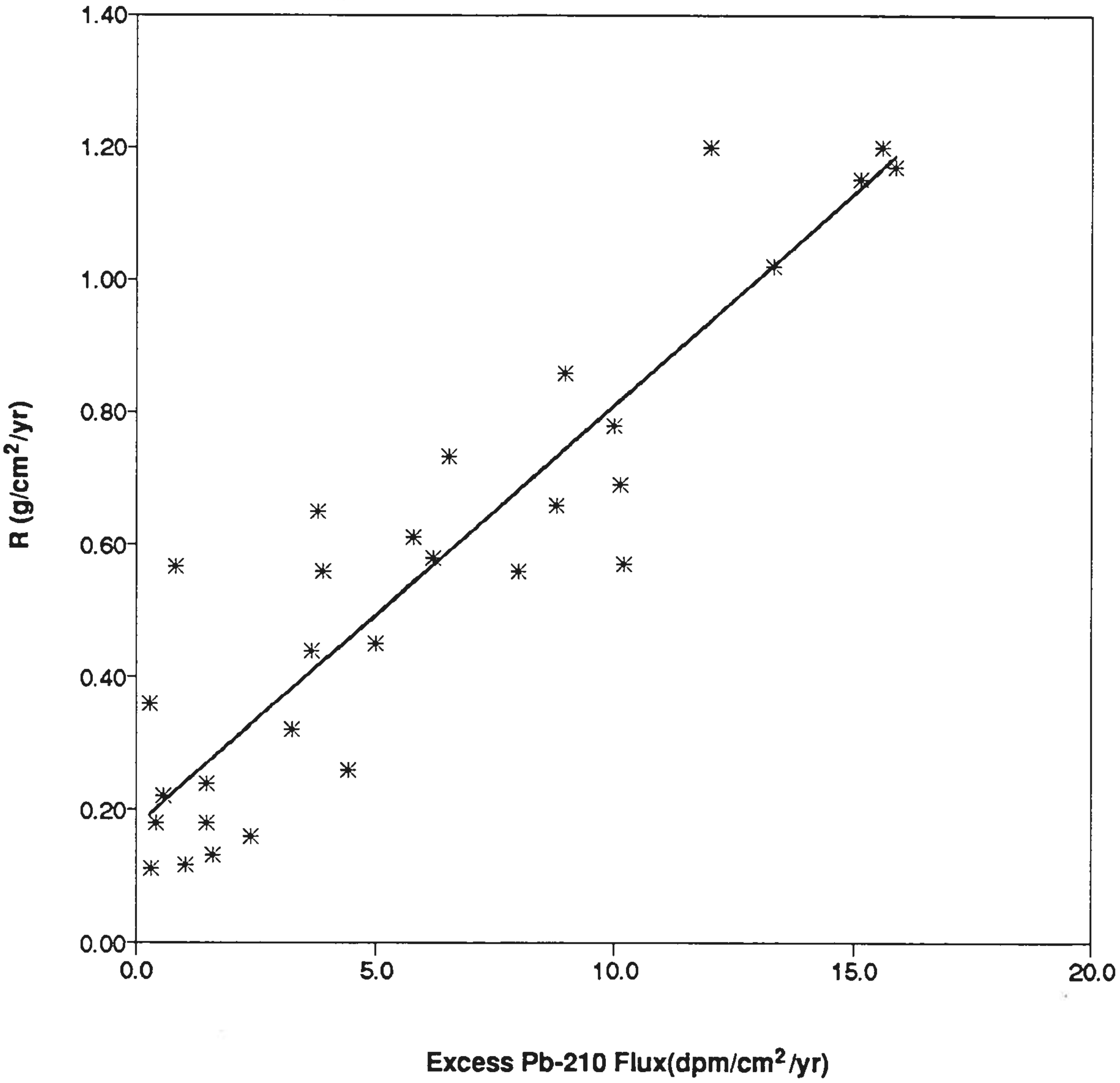
Sediment Core H4



* DPM/g = Disintegrations Per Minute/gram

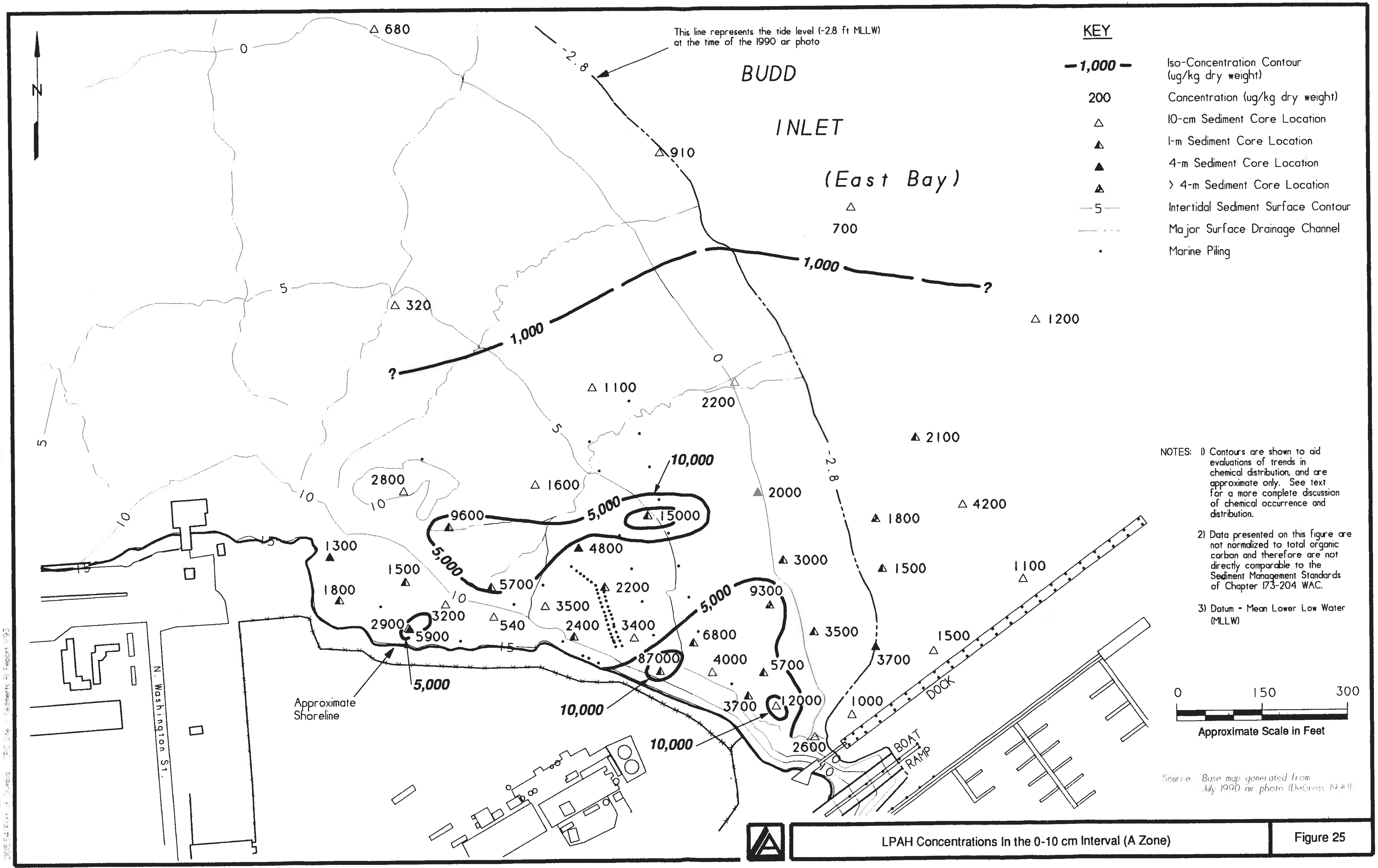
Sediment Pb-210 and Cs-137 Activity Profiles

Figure 23



Pb-210 Flux Estimated by Integration vs. Sediment Accumulation Rate
Predicted by Pb-210 Decay

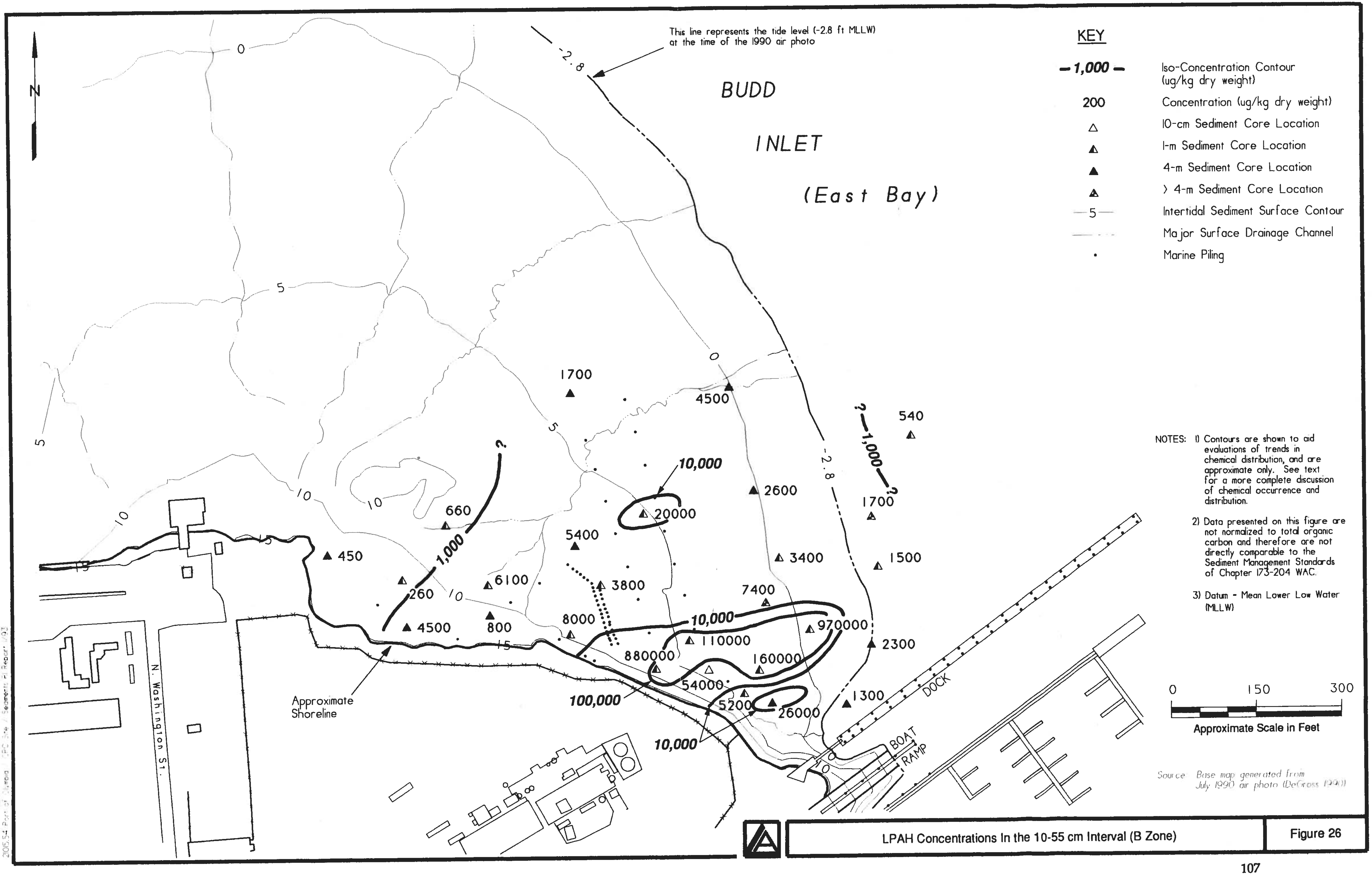
Figure 24



NOTES:
1) Contours are shown to aid evaluations of trends in chemical distribution, and are approximate only. See text for a more complete discussion of chemical occurrence and distribution.
2) Data presented on this figure are not normalized to total organic carbon and therefore are not directly comparable to the Sediment Management Standards of Chapter 173-204 WAC.
3) Datum - Mean Lower Low Water (MLLW)

LPAH Concentrations in the 0-10 cm Interval (A Zone)

Figure 25



KEY

—1,000—	Iso-Concentration Contour (ug/kg dry weight)
200	Concentration (ug/kg dry weight)
△	10-cm Sediment Core Location
▲	1-m Sediment Core Location
▲	4-m Sediment Core Location
▲	> 4-m Sediment Core Location
—5—	Intertidal Sediment Surface Contour
— · —	Major Surface Drainage Channel
•	Marine Piling

NOTES:

1) Contours are shown to aid evaluations of trends in chemical distribution, and are approximate only. See text for a more complete discussion of chemical occurrence and distribution.

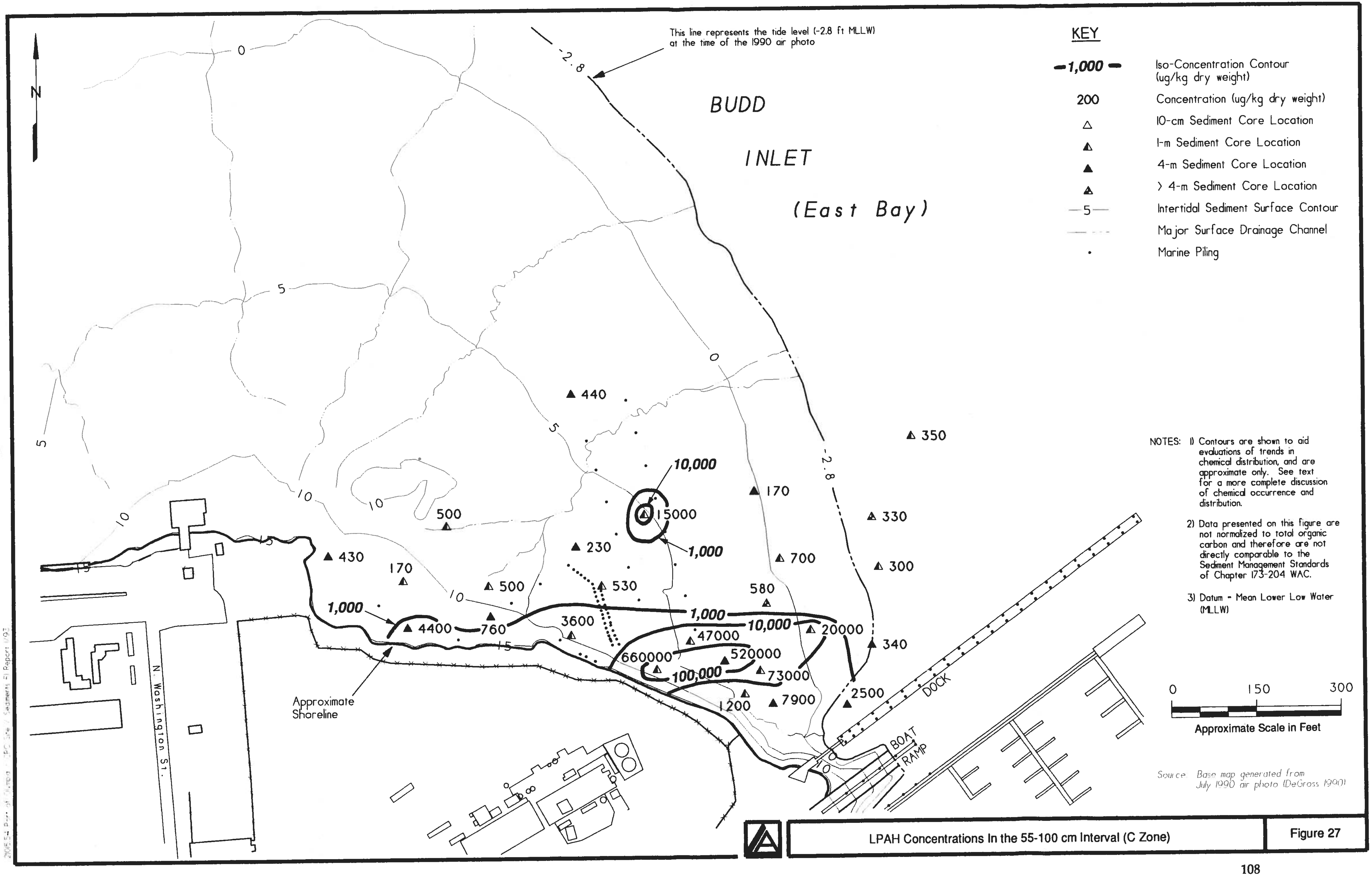
2) Data presented on this figure are not normalized to total organic carbon and therefore are not directly comparable to the Sediment Management Standards of Chapter 173-204 WAC.

3) Datum - Mean Lower Low Water (MLLW)

Source: Base map generated from July 1990 air photo (DeGross 1990)

LPAH Concentrations In the 10-55 cm Interval (B Zone)

Figure 26



NOTES: 1) Contours are shown to aid evaluations of trends in chemical distribution, and are approximate only. See text for a more complete discussion of chemical occurrence and distribution.

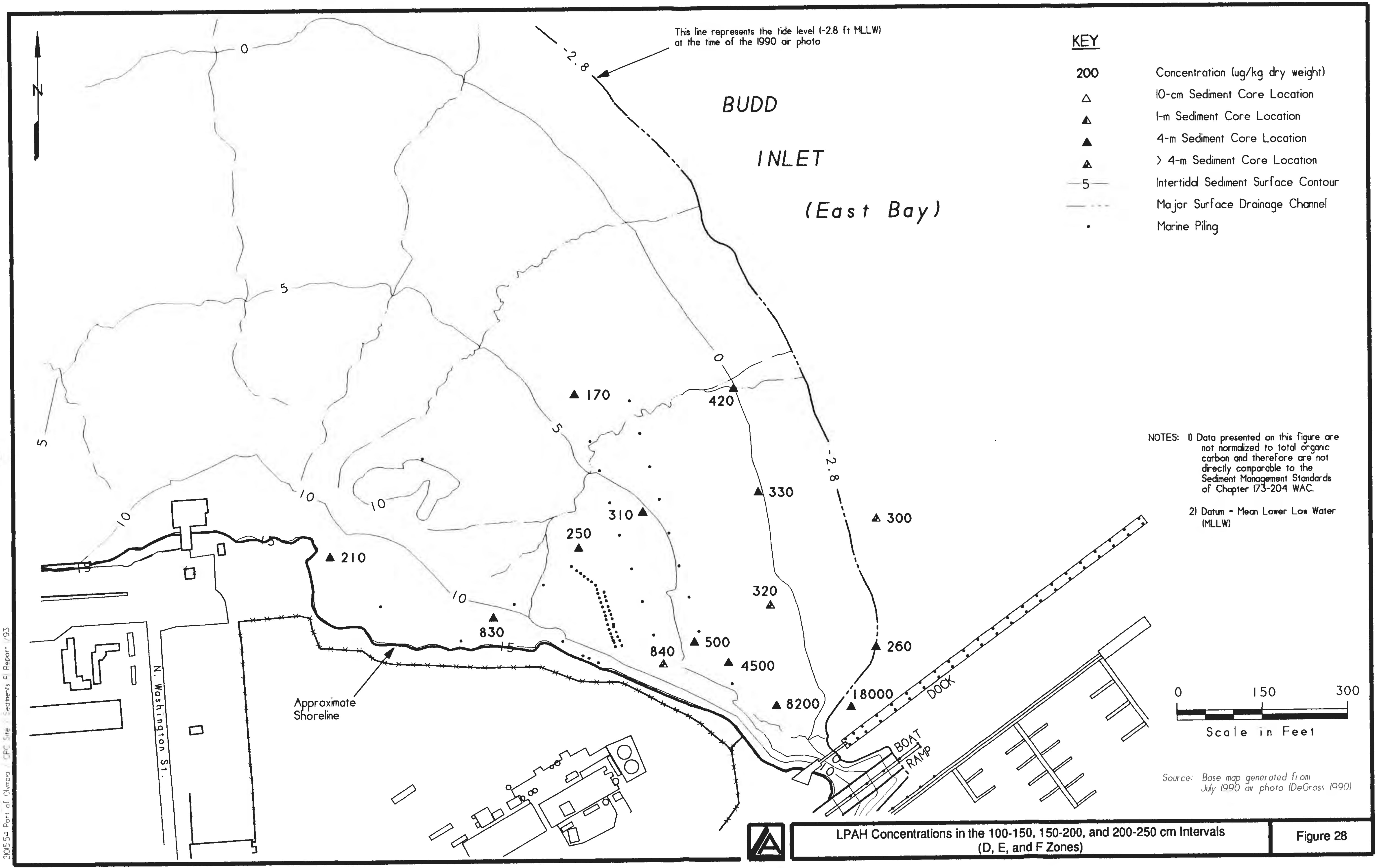
2) Data presented on this figure are not normalized to total organic carbon and therefore are not directly comparable to the Sediment Management Standards of Chapter 173-204 WAC.

3) Datum - Mean Lower Low Water (MLLW)

Source: Base map generated from July 1990 air photo (DeGross 1990)

LPAH Concentrations In the 55-100 cm Interval (C Zone)

Figure 27



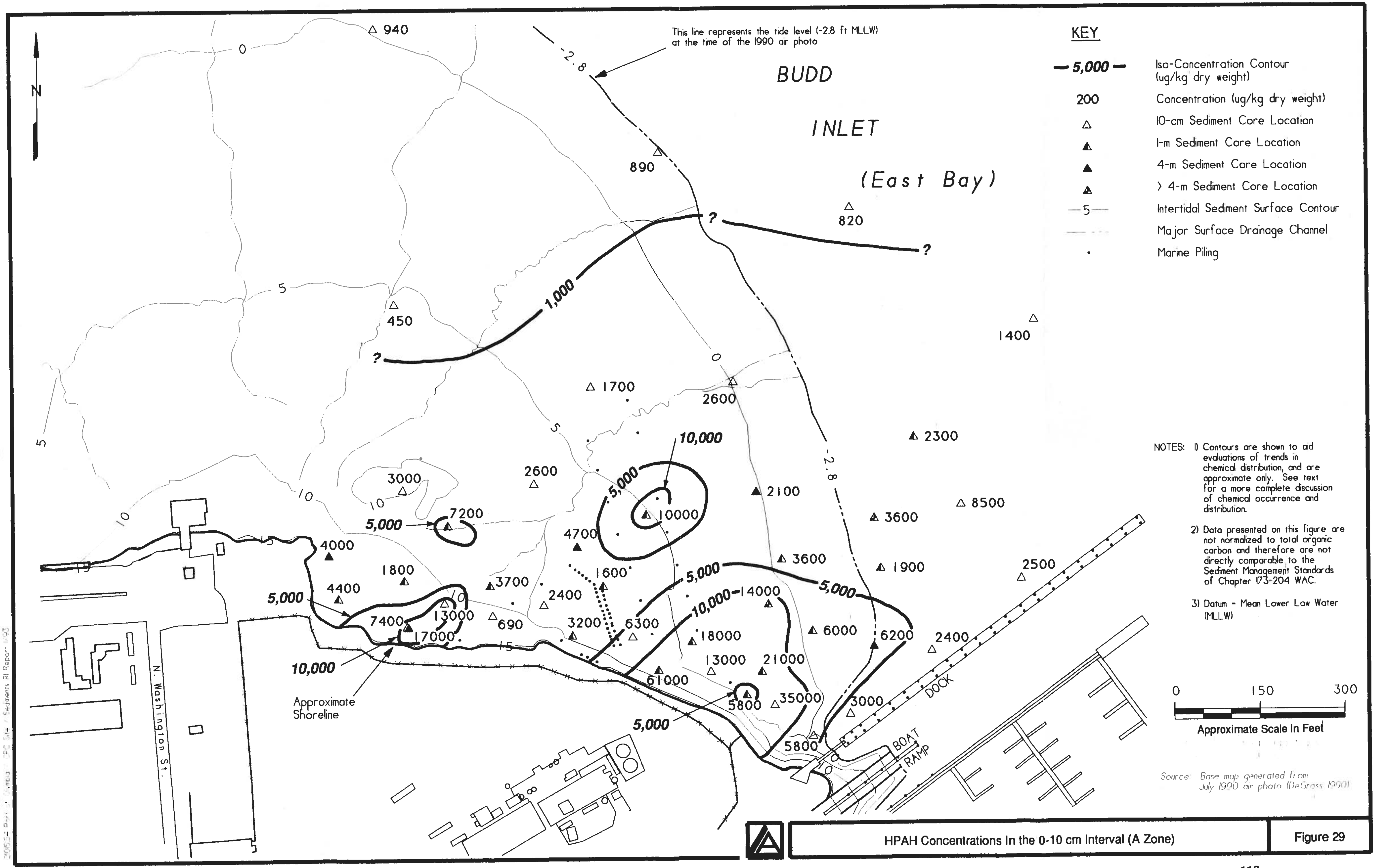
NOTES: 1) Data presented on this figure are not normalized to total organic carbon and therefore are not directly comparable to the Sediment Management Standards of Chapter 173-204 WAC.

2) Datum - Mean Lower Low Water (MLLW)

Source: Base map generated from July 1990 air photo (DeGross 1990)

LPAH Concentrations in the 100-150, 150-200, and 200-250 cm Intervals (D, E, and F Zones)

Figure 28

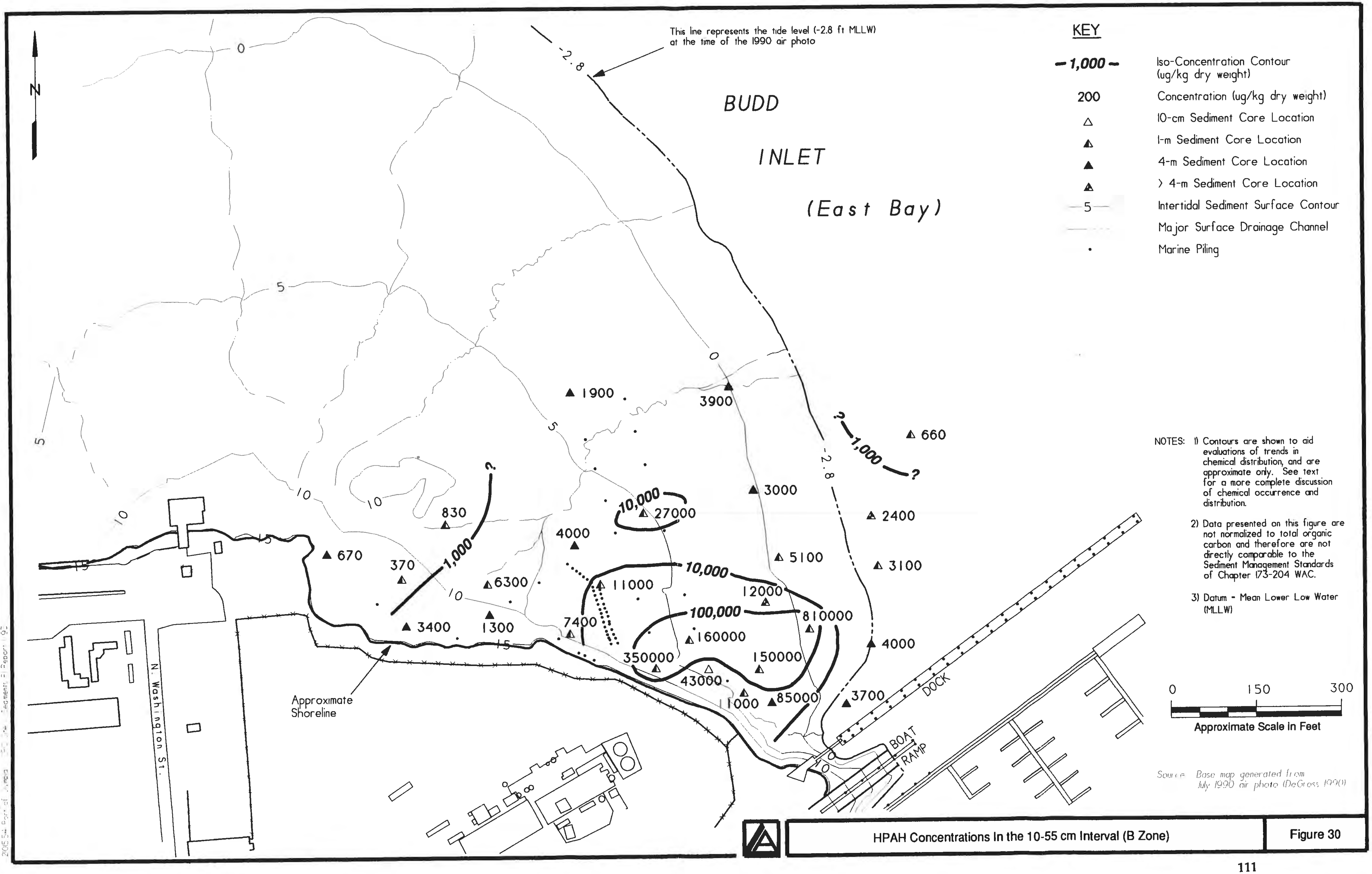


NOTES:
1) Contours are shown to aid evaluations of trends in chemical distribution, and are approximate only. See text for a more complete discussion of chemical occurrence and distribution.
2) Data presented on this figure are not normalized to total organic carbon and therefore are not directly comparable to the Sediment Management Standards of Chapter 173-204 WAC.
3) Datum - Mean Lower Low Water (MLLW)

Source: Base map generated from July 1990 air photo (DeGross 1990)

HPAH Concentrations In the 0-10 cm Interval (A Zone)

Figure 29

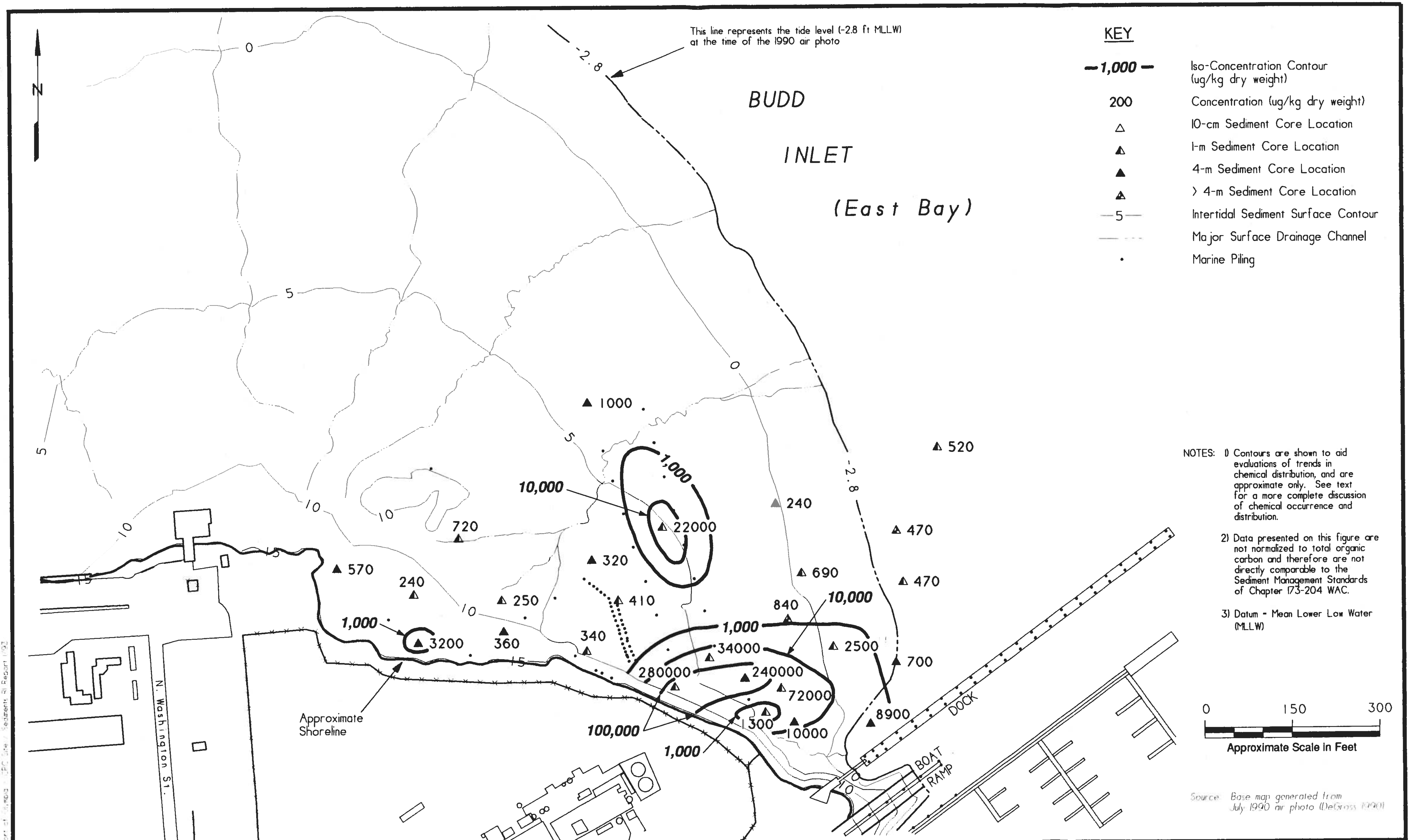


NOTES:
1) Contours are shown to aid evaluations of trends in chemical distribution, and are approximate only. See text for a more complete discussion of chemical occurrence and distribution.
2) Data presented on this figure are not normalized to total organic carbon and therefore are not directly comparable to the Sediment Management Standards of Chapter 173-204 WAC.
3) Datum - Mean Lower Low Water (MLLW)

Source: Base map generated from July 1990 air photo (DeGross 1990)

HPAH Concentrations In the 10-55 cm Interval (B Zone)

Figure 30

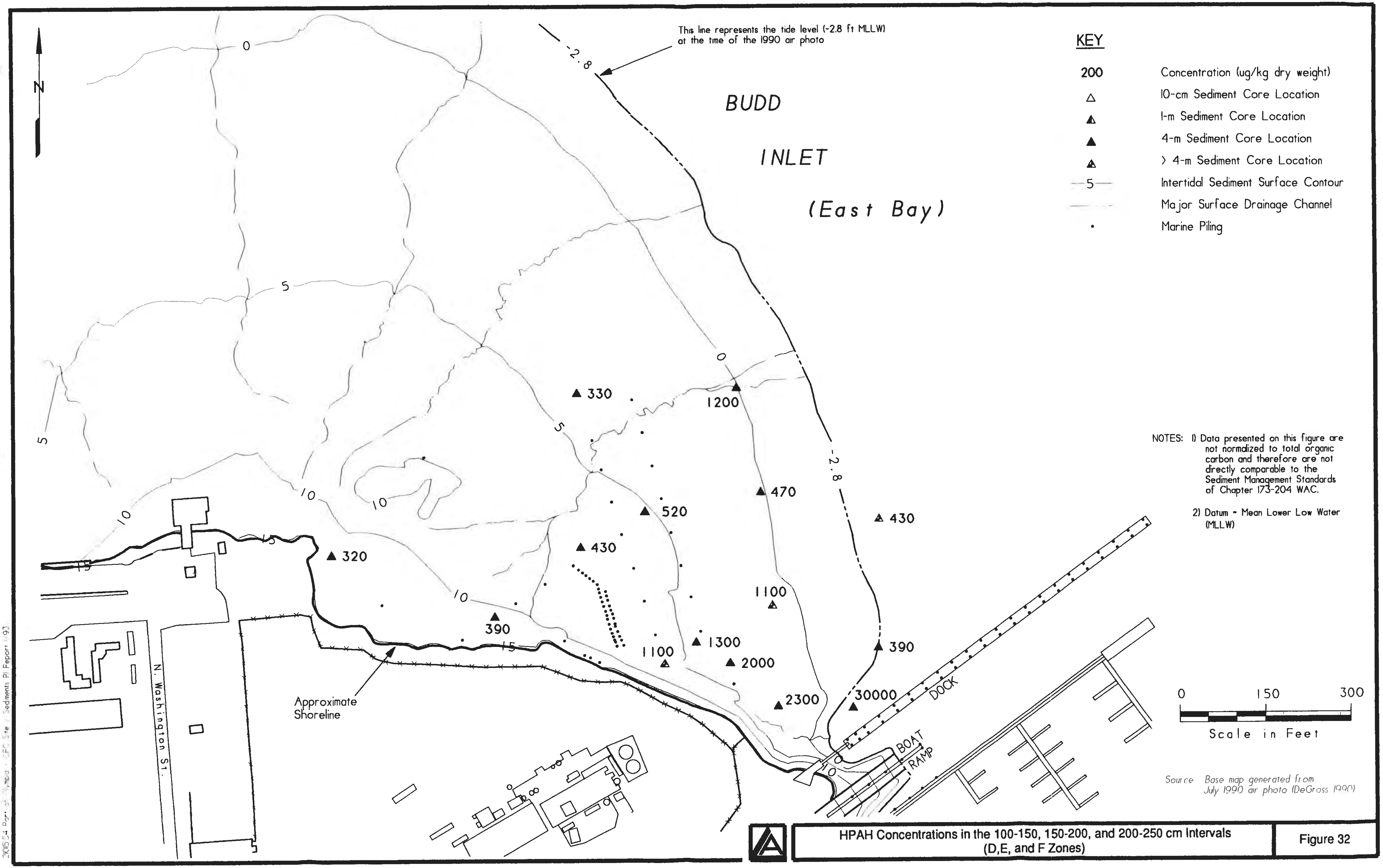


NOTES:
1) Contours are shown to aid evaluations of trends in chemical distribution, and are approximate only. See text for a more complete discussion of chemical occurrence and distribution.
2) Data presented on this figure are not normalized to total organic carbon and therefore are not directly comparable to the Sediment Management Standards of Chapter 173-204 WAC.
3) Datum - Mean Lower Low Water (MLLW)

Source: Base map generated from July 1990 air photo (DeGross 1990)

HPAH Concentrations In the 55-100 cm Interval (C Zone)

Figure 31



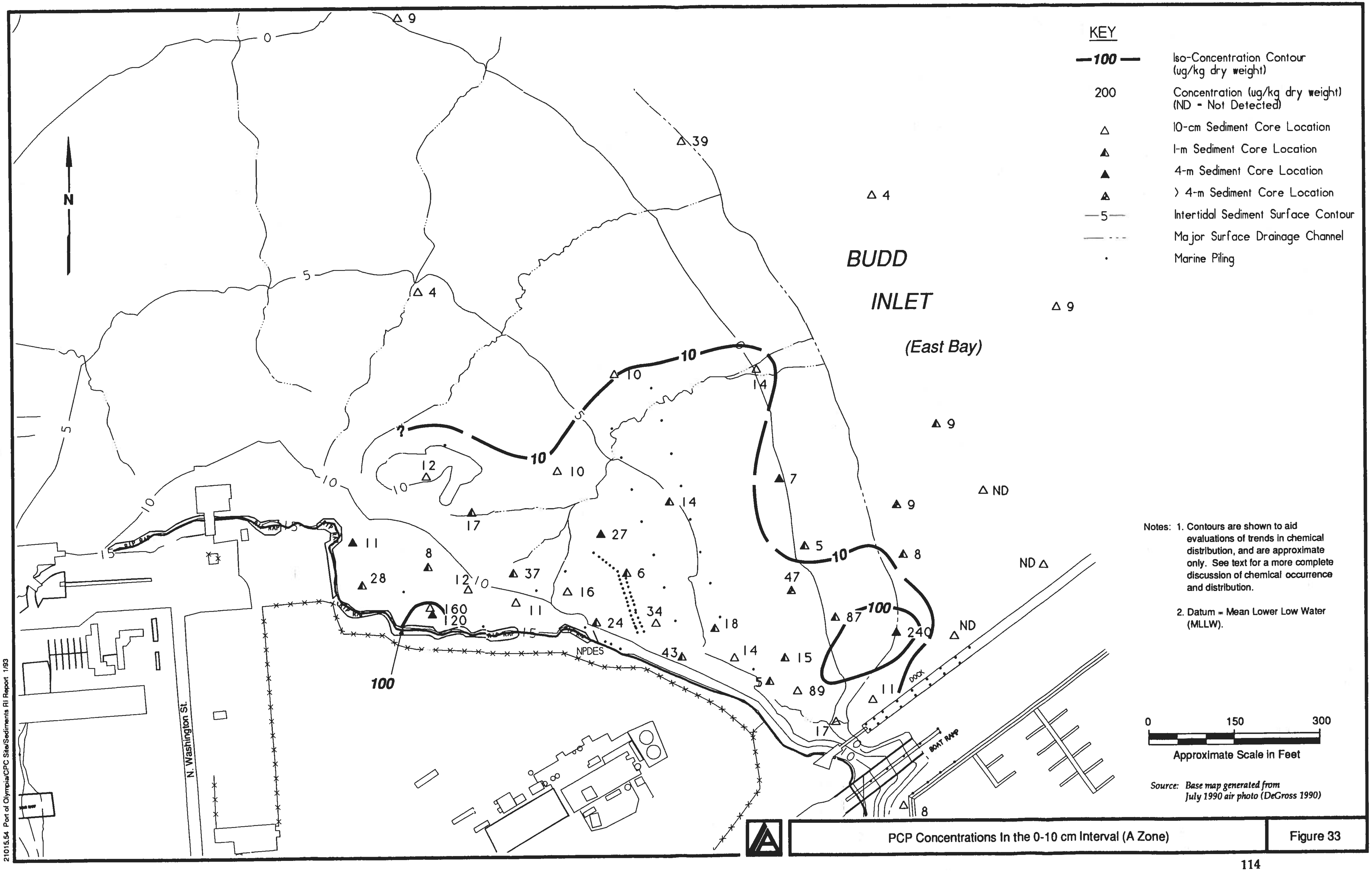
NOTES: 1) Data presented on this figure are not normalized to total organic carbon and therefore are not directly comparable to the Sediment Management Standards of Chapter 173-204 WAC.

2) Datum - Mean Lower Low Water (MLLW)

Source Base map generated from July 1990 air photo (DeGross 1990)

HPAH Concentrations in the 100-150, 150-200, and 200-250 cm Intervals (D,E, and F Zones)

Figure 32



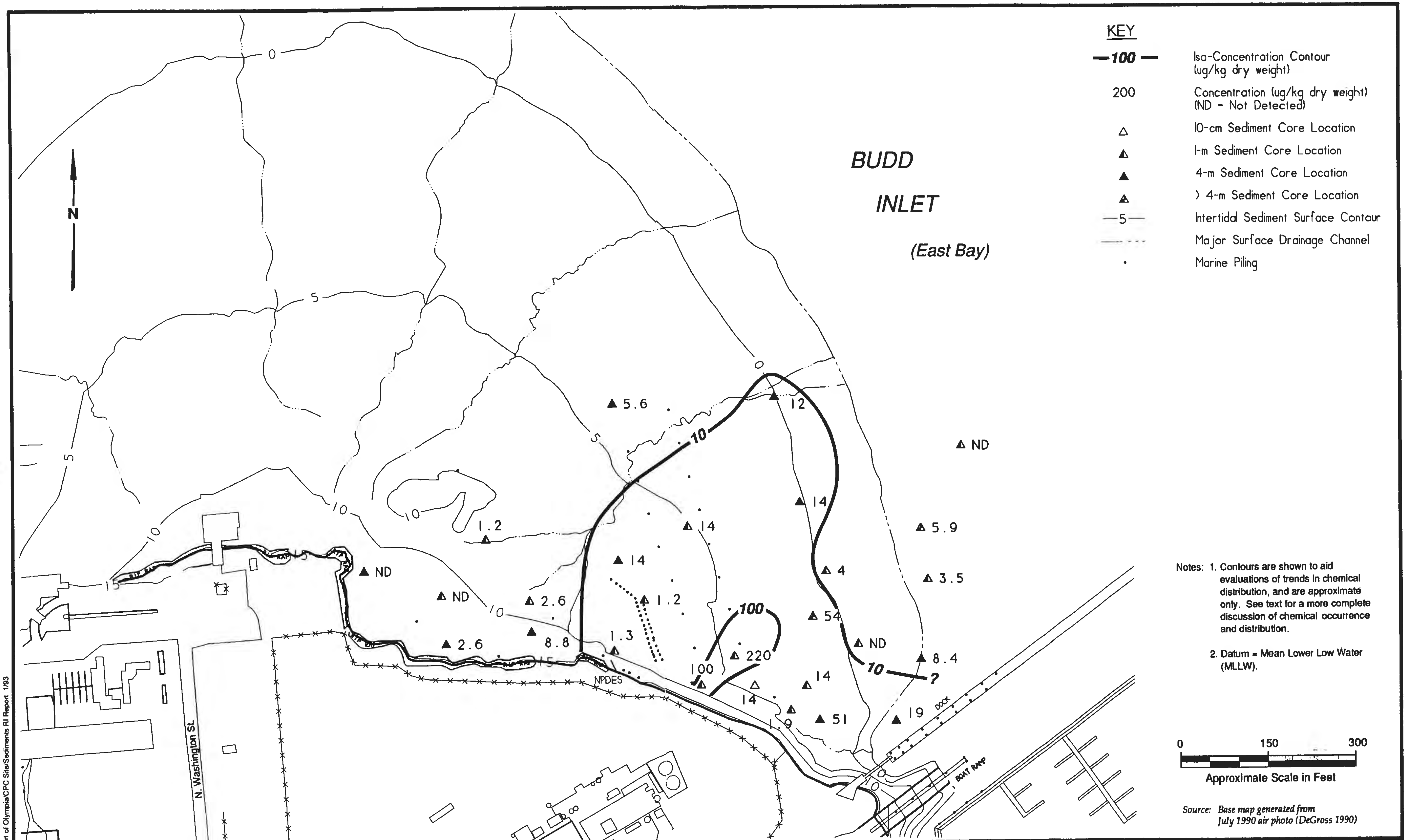
Notes: 1. Contours are shown to aid evaluations of trends in chemical distribution, and are approximate only. See text for a more complete discussion of chemical occurrence and distribution.

2. Datum = Mean Lower Low Water (MLLW).

Source: Base map generated from July 1990 air photo (DeGross 1990)

PCP Concentrations In the 0-10 cm Interval (A Zone)

Figure 33



Notes:
1. Contours are shown to aid evaluations of trends in chemical distribution, and are approximate only. See text for a more complete discussion of chemical occurrence and distribution.
2. Datum = Mean Lower Low Water (MLLW).

Source: Base map generated from July 1990 air photo (DeGross 1990)

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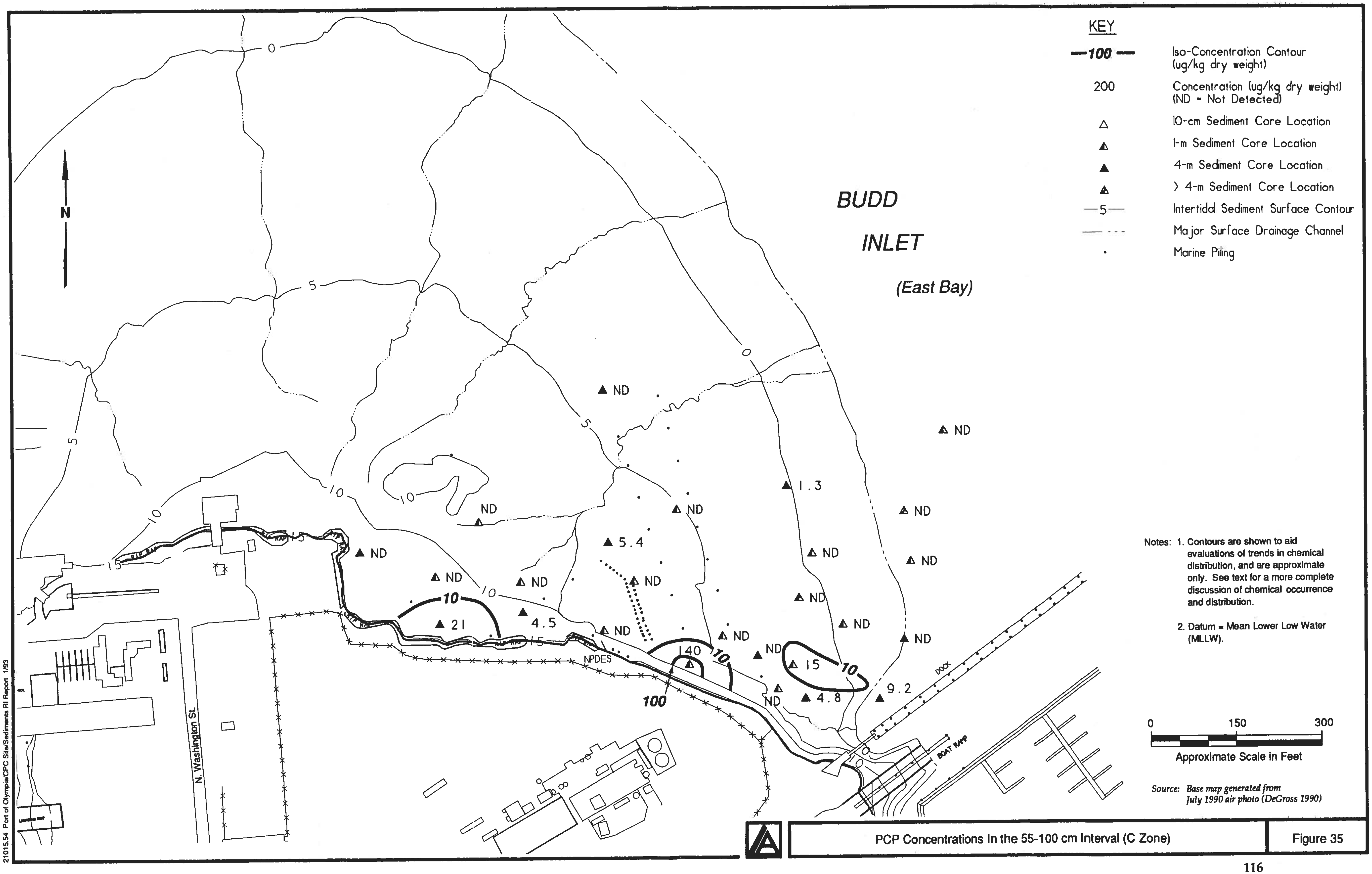
PCP Concentrations In the 10-55 cm Interval (B Zone)

Figure 34



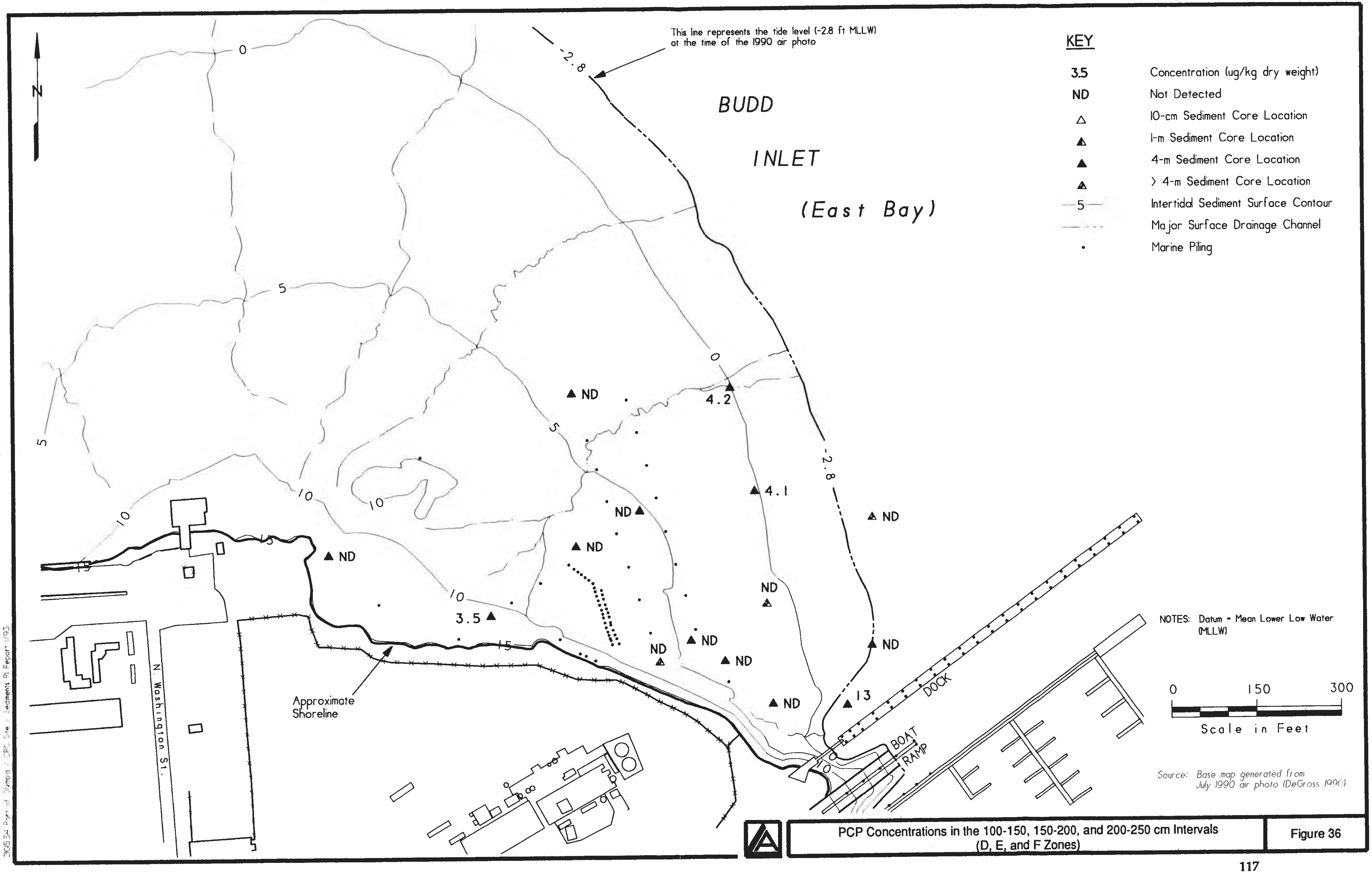
Notes: 1. Contours are shown to aid evaluations of trends in chemical distribution, and are approximate only. See text for a more complete discussion of chemical occurrence and distribution.

2. Datum = Mean Lower Low Water (MLLW).

Source: *Base map generated from July 1990 air photo (DeGross 1990)*

PCP Concentrations In the 55-100 cm Interval (C Zone)

Figure 35

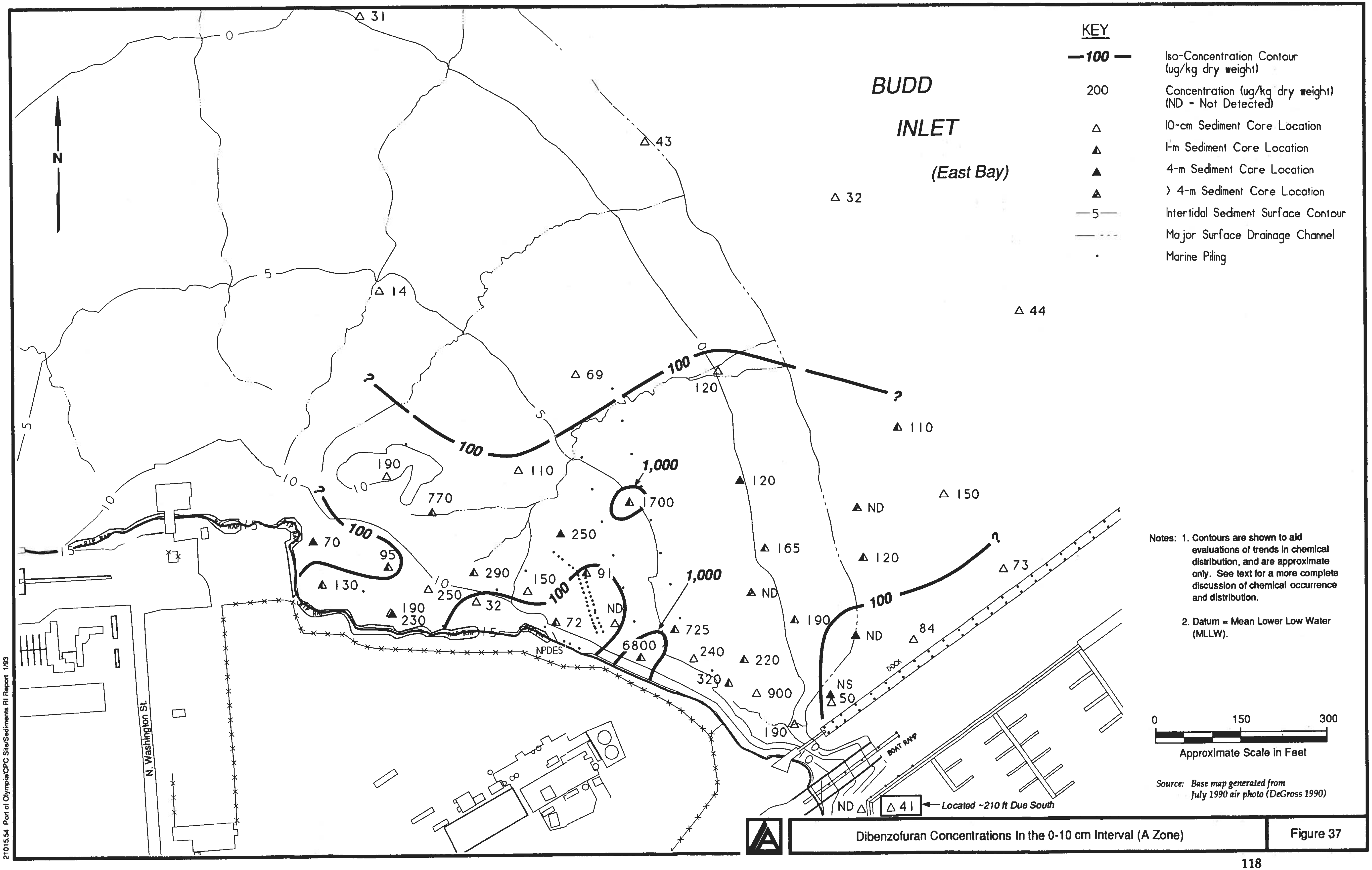


NOTES: Datum - Mean Lower Low Water (MLLW)

Source: Base map generated from July 1990 air photo (DeGross 1990)

PCP Concentrations in the 100-150, 150-200, and 200-250 cm Intervals (D, E, and F Zones)

Figure 36



KEY

—100—	Iso-Concentration Contour (ug/kg dry weight)
200	Concentration (ug/kg dry weight) (ND - Not Detected)
△	10-cm Sediment Core Location
▲	1-m Sediment Core Location
▲	4-m Sediment Core Location
▲	⟩ 4-m Sediment Core Location
—5—	Intertidal Sediment Surface Contour
— · · ·	Major Surface Drainage Channel
·	Marine Piling

Notes: 1. Contours are shown to aid evaluations of trends in chemical distribution, and are approximate only. See text for a more complete discussion of chemical occurrence and distribution.

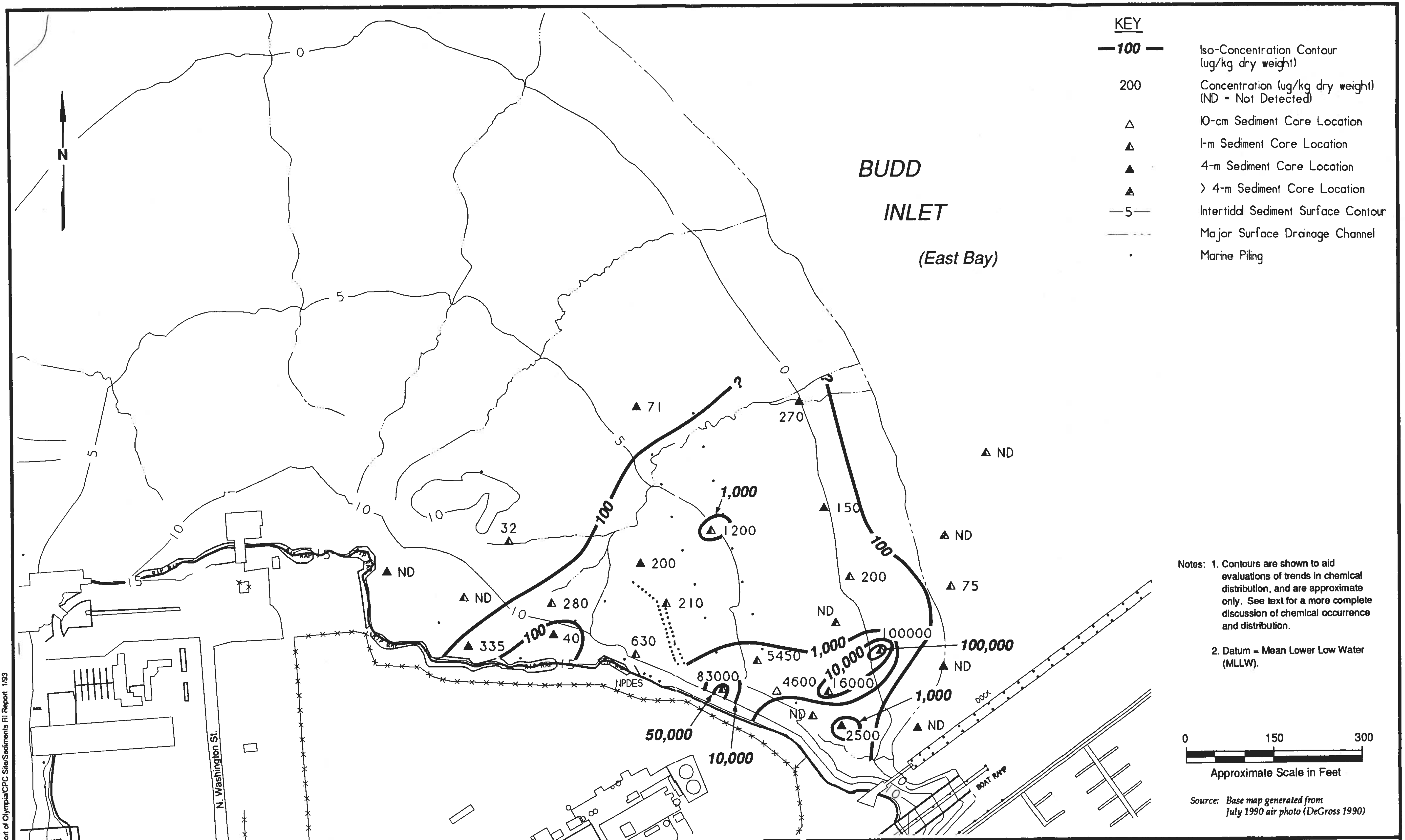
2. Datum = Mean Lower Low Water (MLLW).

Source: Base map generated from July 1990 air photo (DeGross 1990)

Dibenzofuran Concentrations in the 0-10 cm Interval (A Zone)

Figure 37

21015.54 Port of Olympia/CPC Site/Sediments RI Report 1/93



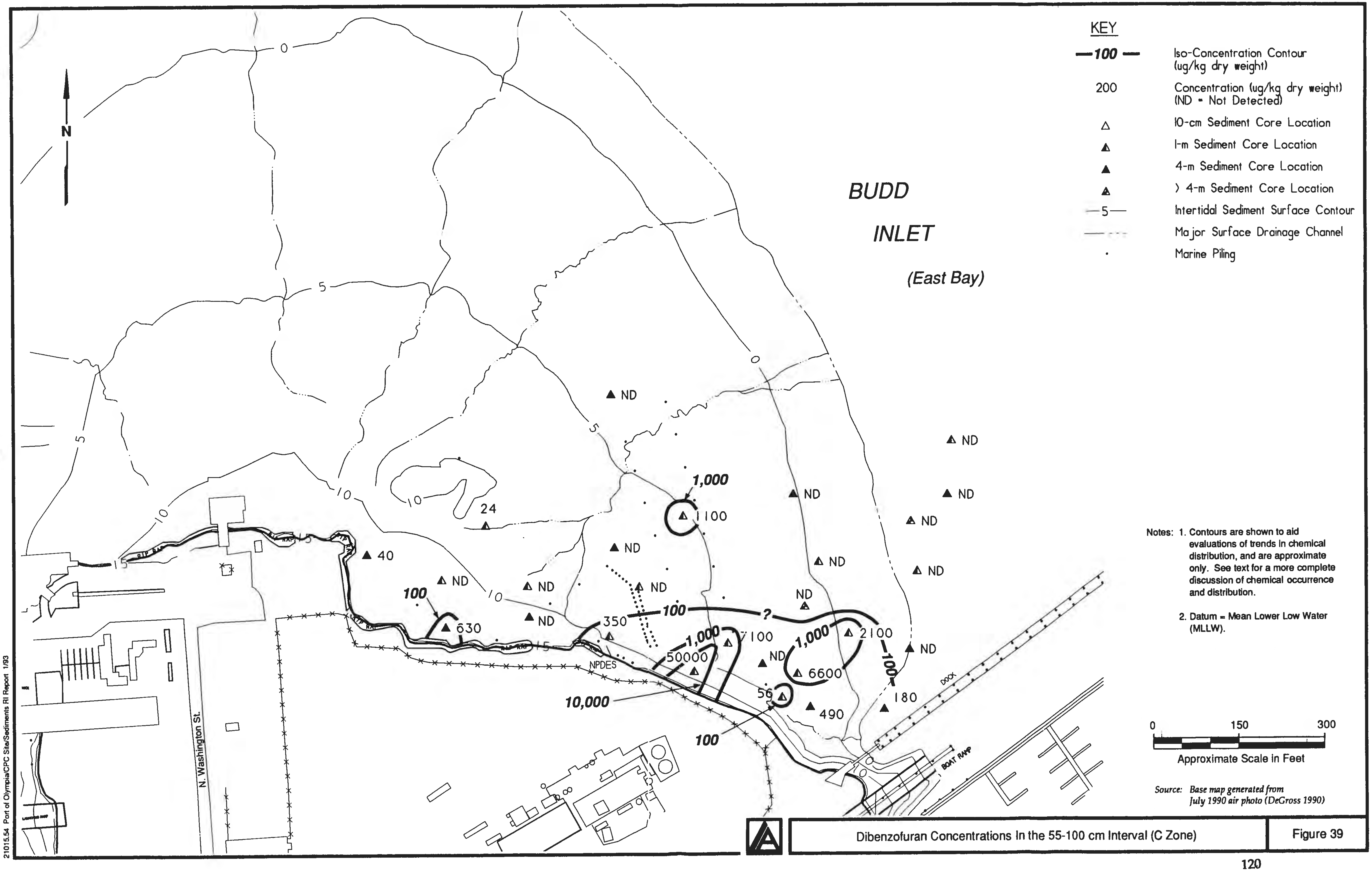
Notes: 1. Contours are shown to aid evaluations of trends in chemical distribution, and are approximate only. See text for a more complete discussion of chemical occurrence and distribution.

2. Datum = Mean Lower Low Water (MLLW).

Source: Base map generated from July 1990 air photo (DeGross 1990)

Dibenzofuran Concentrations In the 10-55 cm Interval (B Zone)

Figure 38



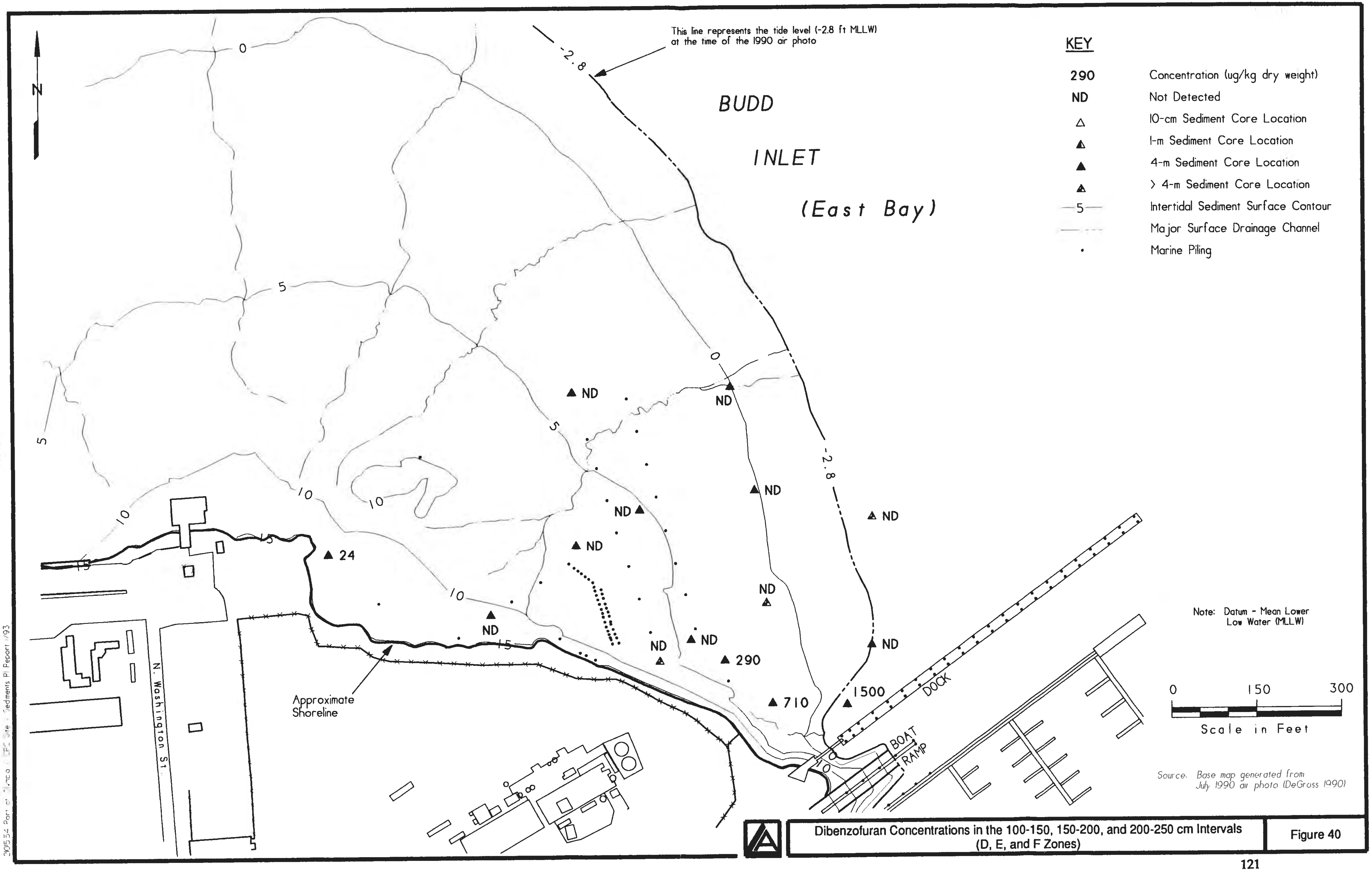
Notes: 1. Contours are shown to aid evaluations of trends in chemical distribution, and are approximate only. See text for a more complete discussion of chemical occurrence and distribution.

2. Datum = Mean Lower Low Water (MLLW).

Source: *Base map generated from July 1990 air photo (DeGross 1990)*

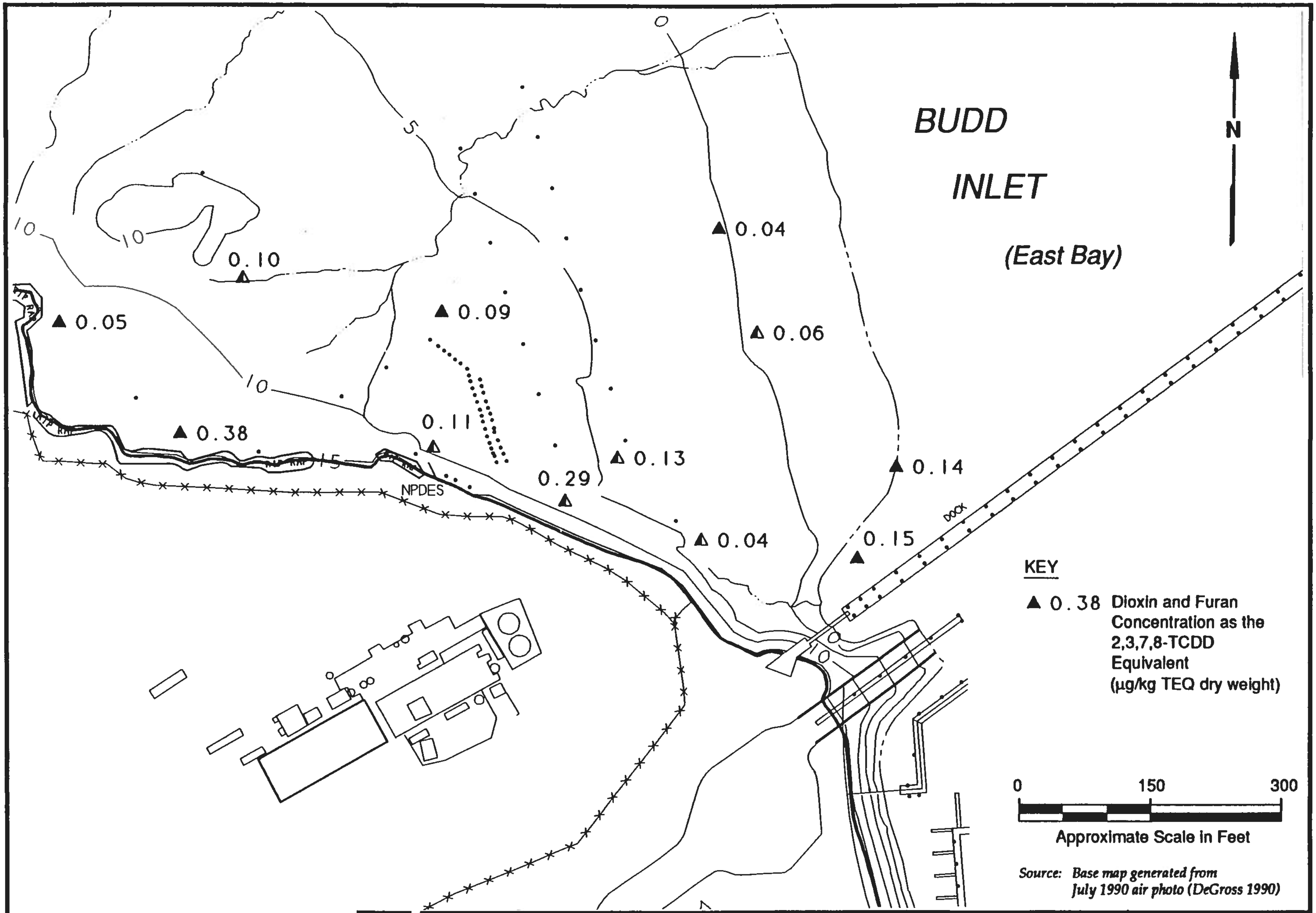
Dibenzofuran Concentrations In the 55-100 cm Interval (C Zone)

Figure 39



Dibenzofuran Concentrations in the 100-150, 150-200, and 200-250 cm Intervals (D, E, and F Zones)

Figure 40

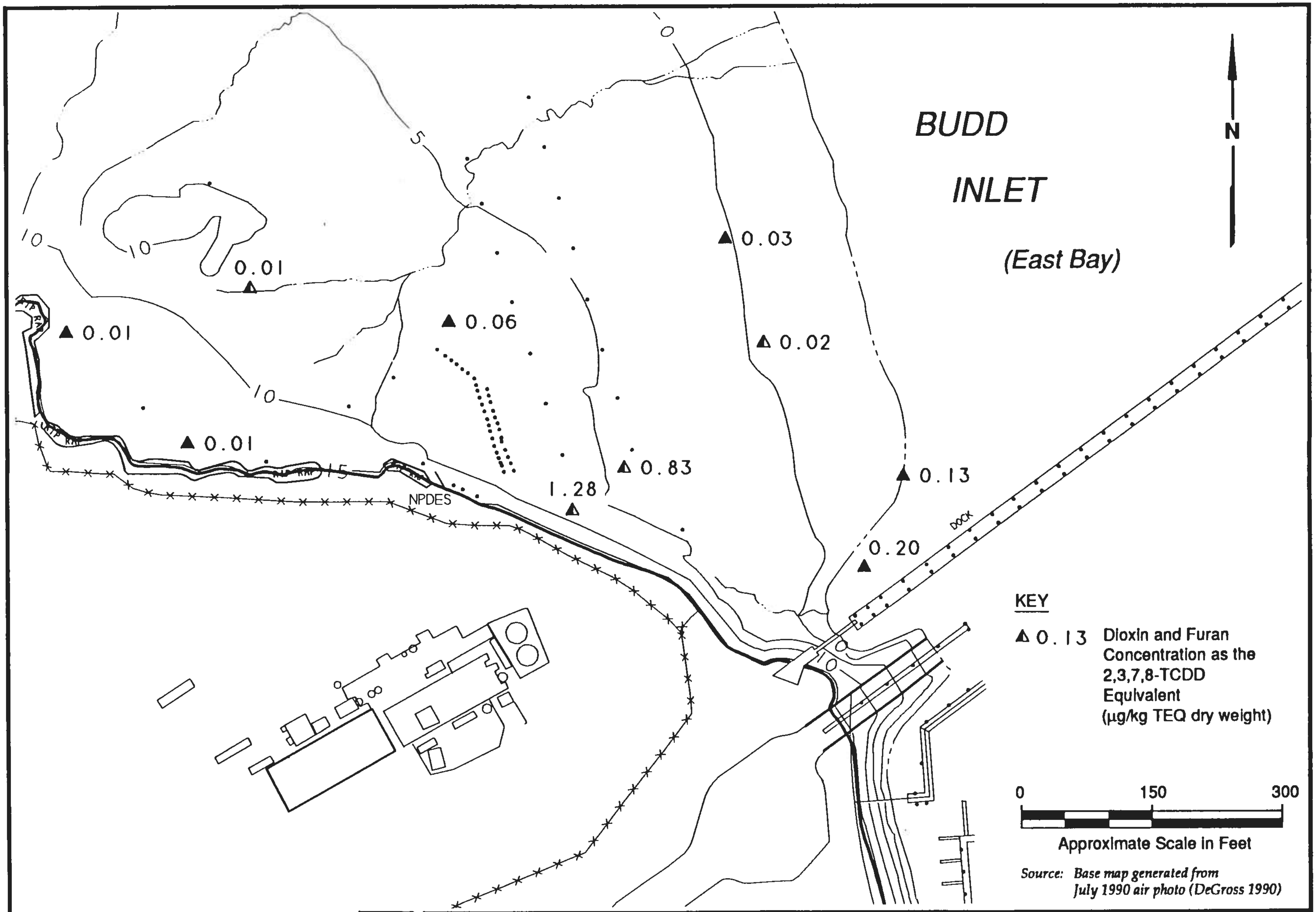


Source: Base map generated from July 1990 air photo (DeGross 1990)

Note: Datum = Mean Lower Low Water (MLLW).

Dioxins and Furans In the 0-10 cm Interval (A Zone)

Figure 41

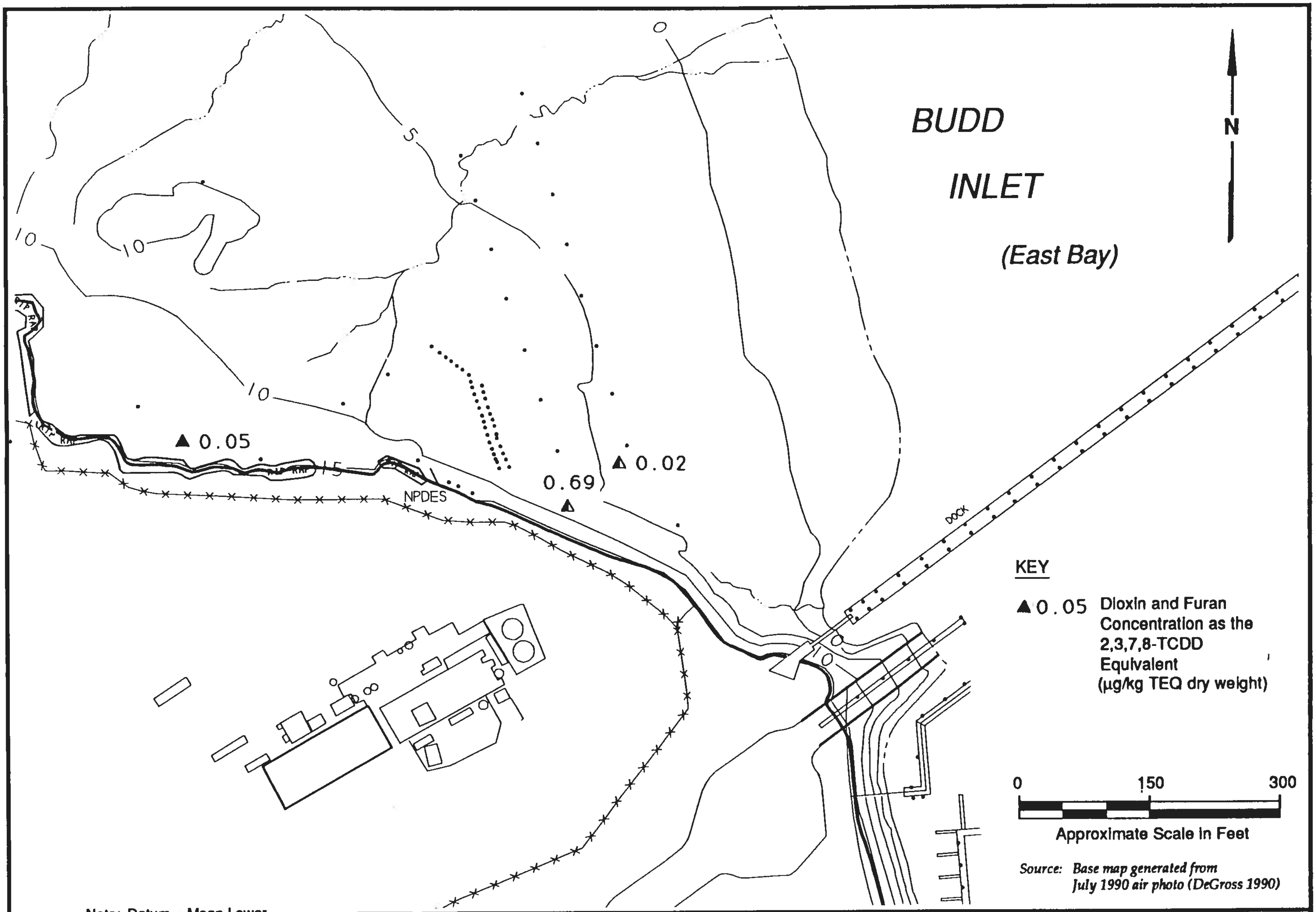


Source: Base map generated from July 1990 air photo (DeGross 1990)

Note: Datum = Mean Lower Low Water (MLLW).

Dioxins and Furans In the 10-55 cm Interval (B Zone)

Figure 42



KEY

▲ 0.05 Dioxin and Furan Concentration as the 2,3,7,8-TCDD Equivalent (µg/kg TEQ dry weight)

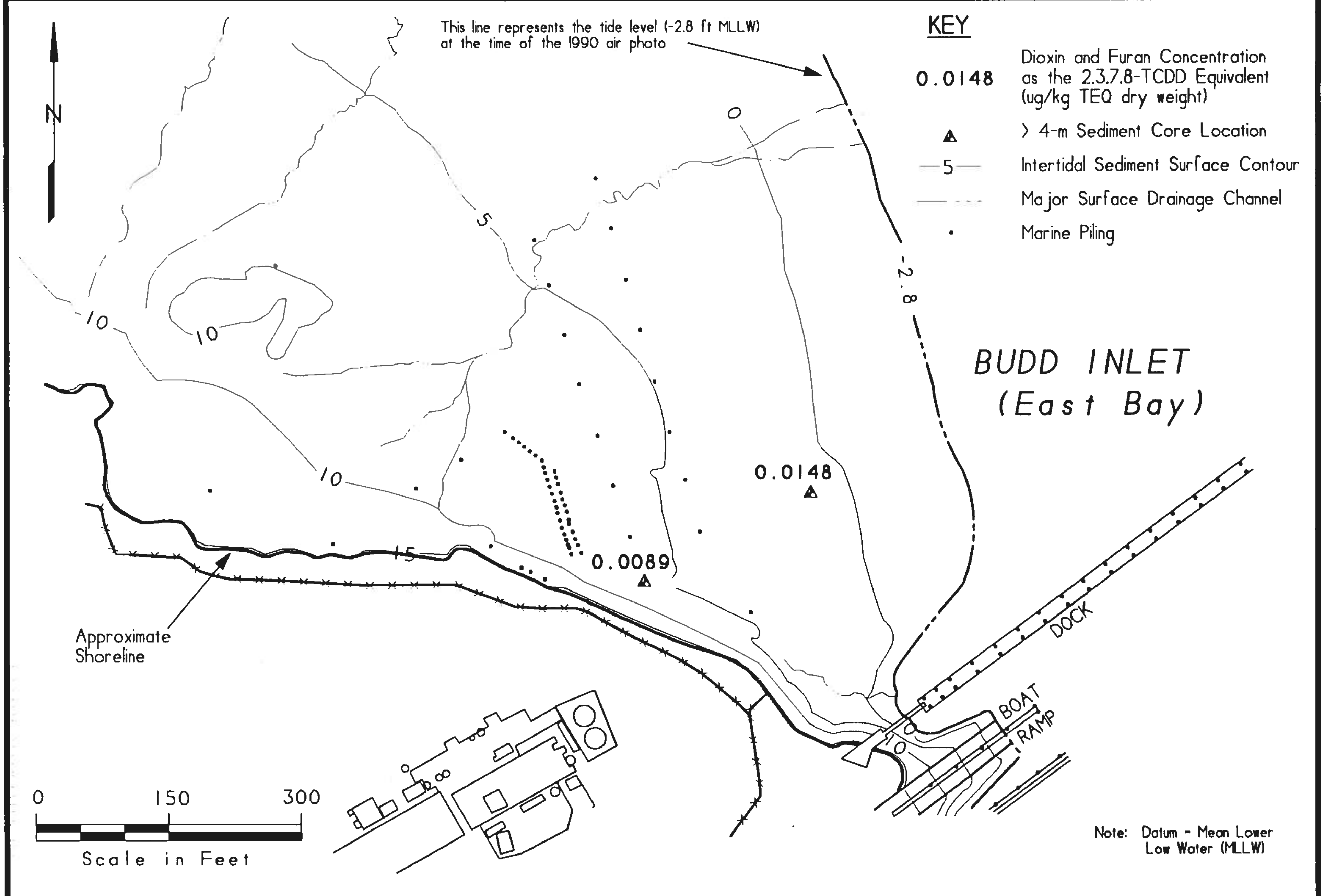
Approximate Scale in Feet

Source: Base map generated from July 1990 air photo (DeGross 1990)

Note: Datum = Mean Lower Low Water (MLLW).

Dioxins and Furans in the 55-100 cm Interval (C Zone)

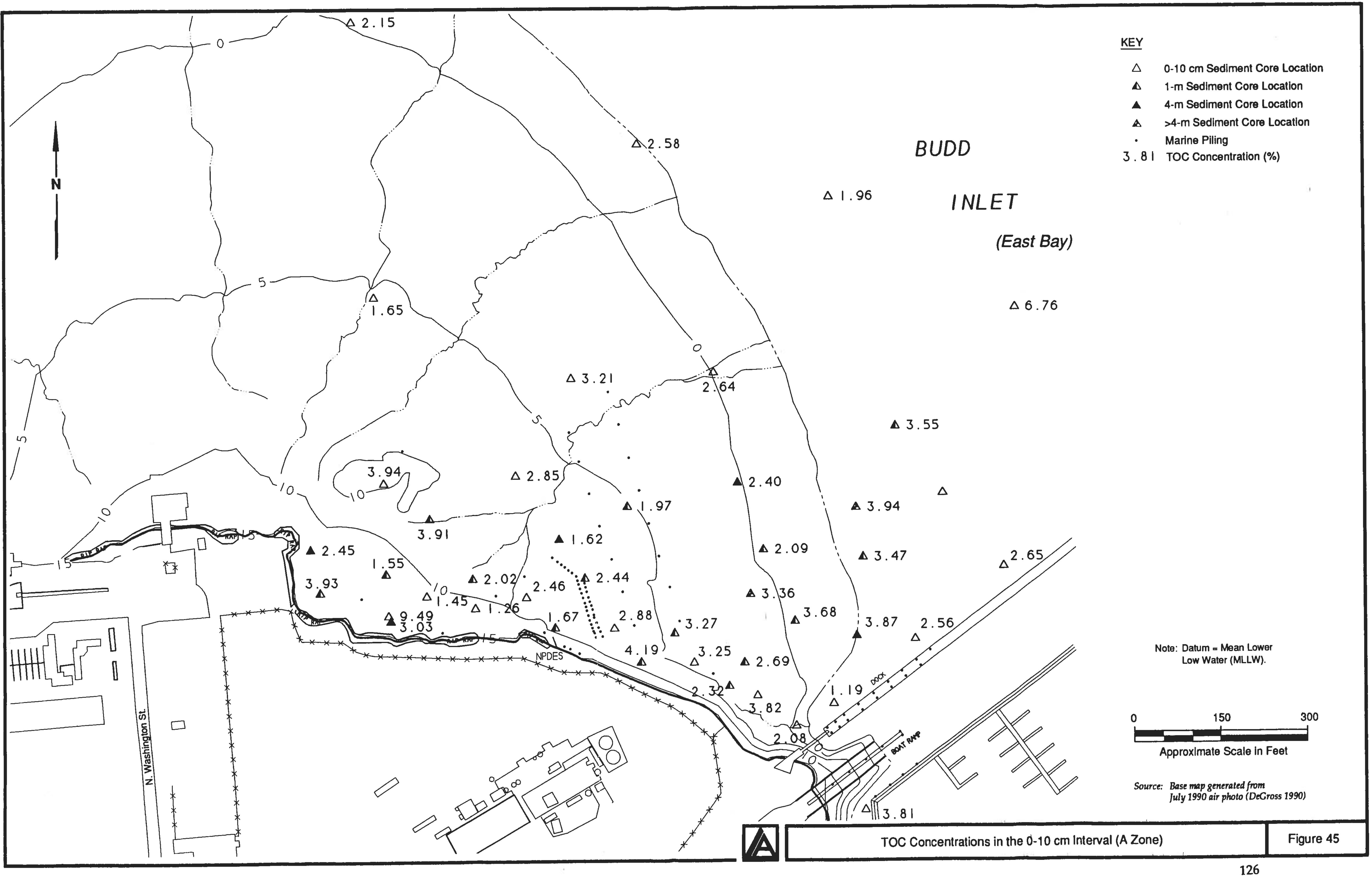
Figure 43



Source: Base map generated from July 1990 air photo (DeGross 1990)

Dioxins and Furans in the 100-150, 150-200, and 200-250 cm Intervals (D, E, and F Zones)

Figure 44



KEY

△ 0-10 cm Sediment Core Location
◭ 1-m Sediment Core Location
▲ 4-m Sediment Core Location
◬ >4-m Sediment Core Location
• Marine Piling
3.81 TOC Concentration (%)

Note: Datum = Mean Lower Low Water (MLLW).

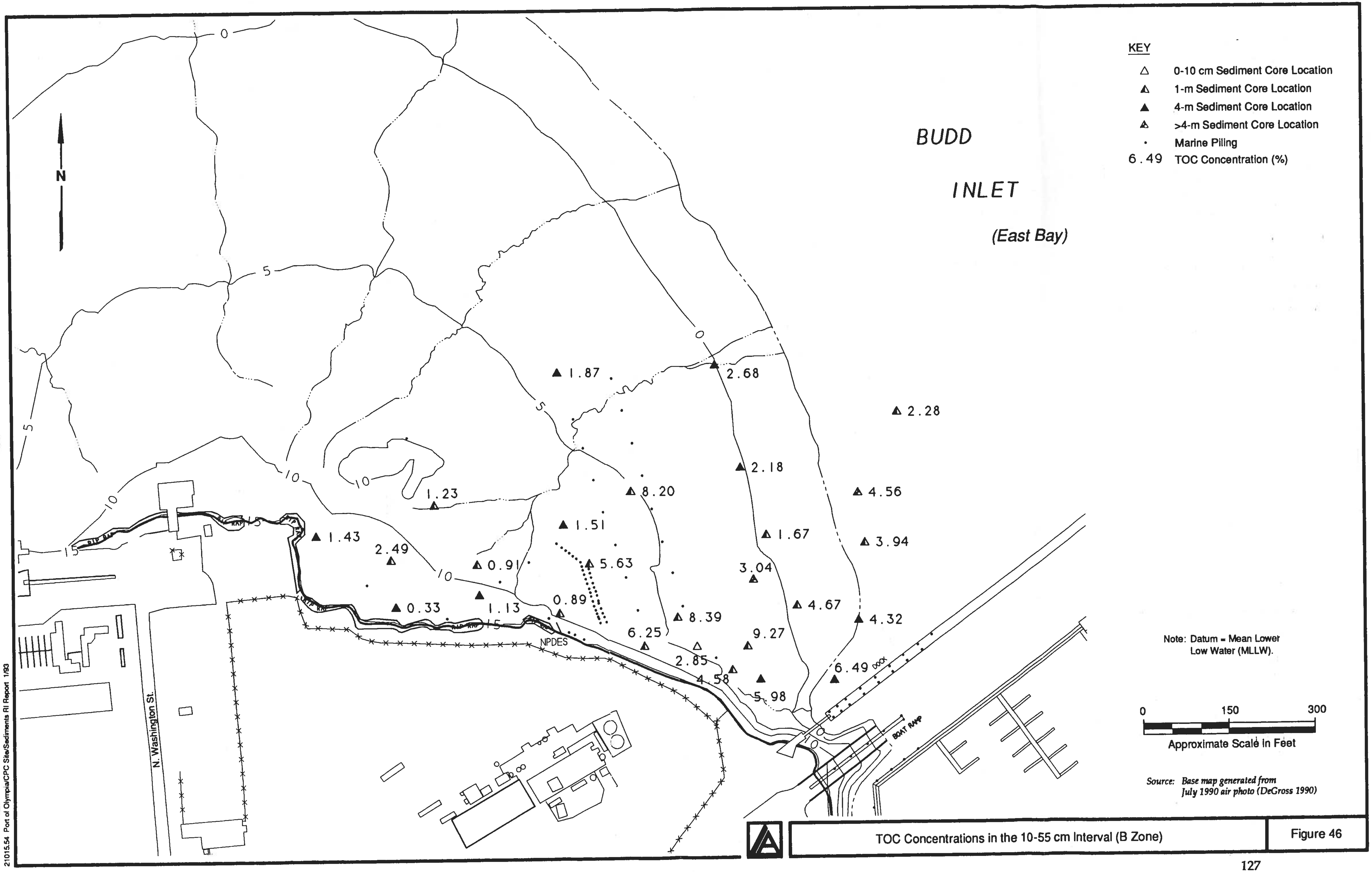
0 150 300
Approximate Scale in Feet

Source: Base map generated from July 1990 air photo (DeGross 1990)

TOC Concentrations in the 0-10 cm Interval (A Zone)

Figure 45

21015.54 Port of Olympia/CPC Site/Sediments RI Report 1/93



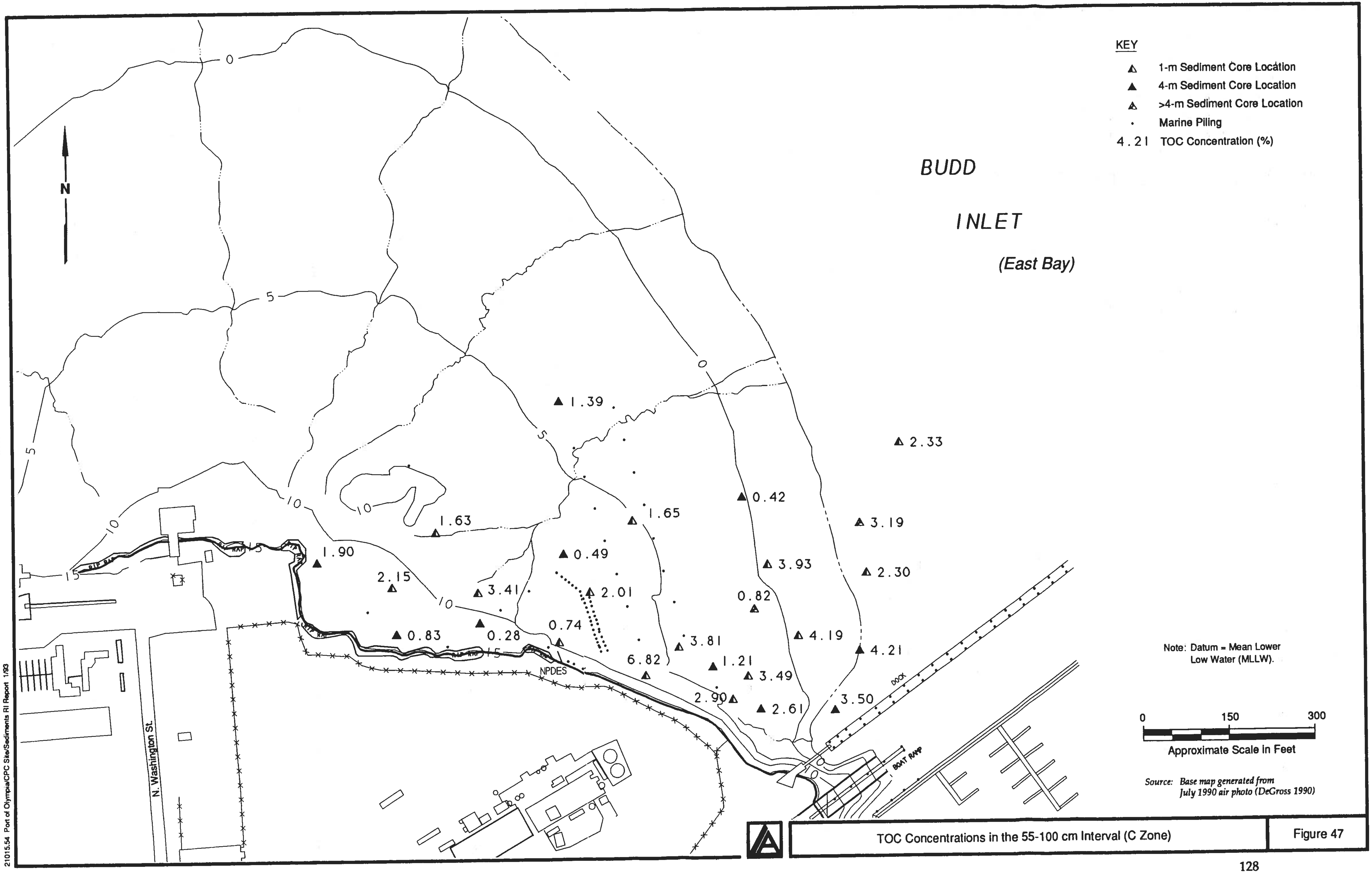
Note: Datum = Mean Lower Low Water (MLLW).

Source: *Base map generated from July 1990 air photo (DeGross 1990)*

TOC Concentrations in the 10-55 cm Interval (B Zone)

Figure 46

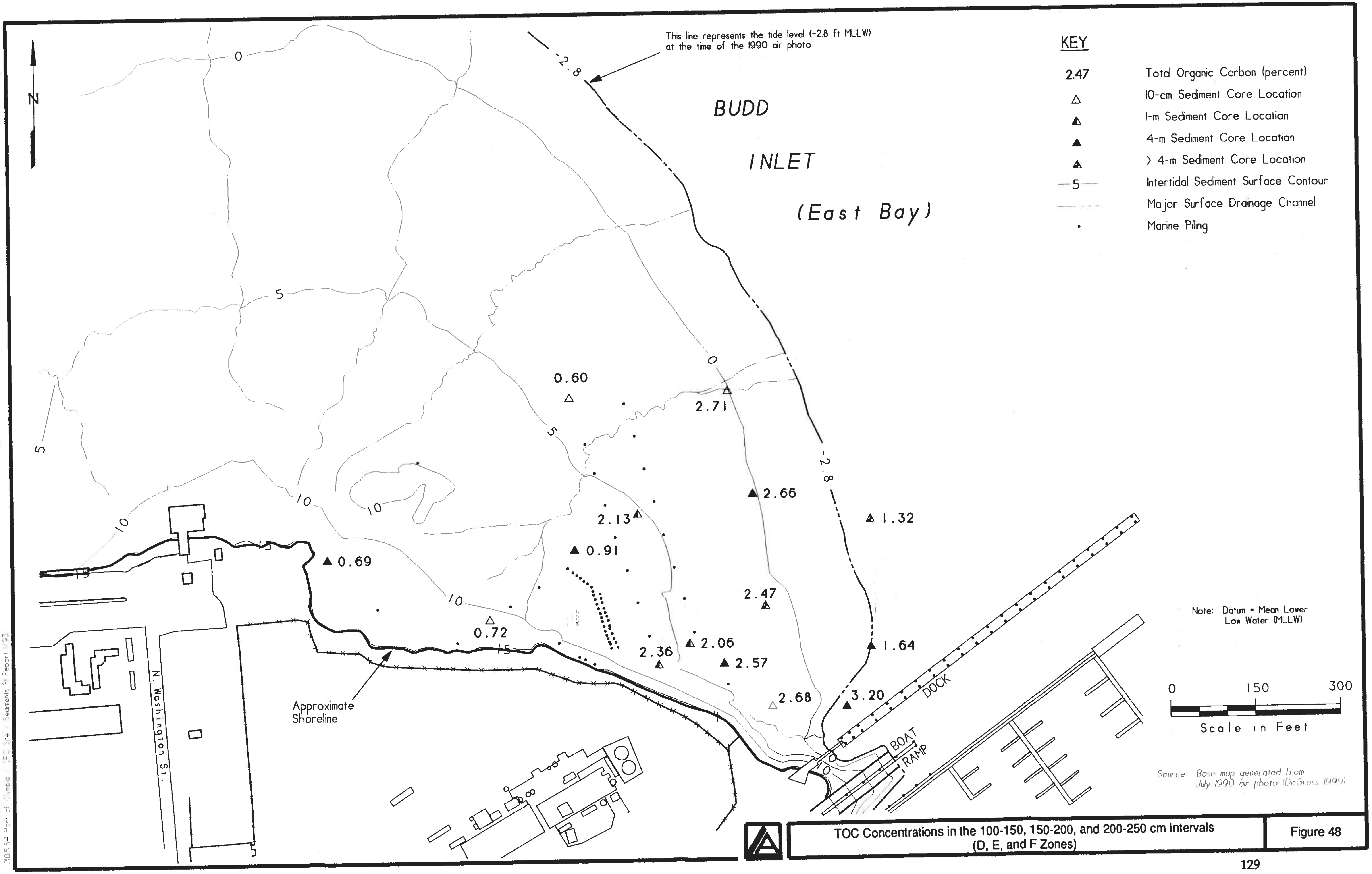
21015.54 Port of Olympia/CPC Site/Sediments RI Report 1/93



TOC Concentrations in the 55-100 cm Interval (C Zone)

Figure 47

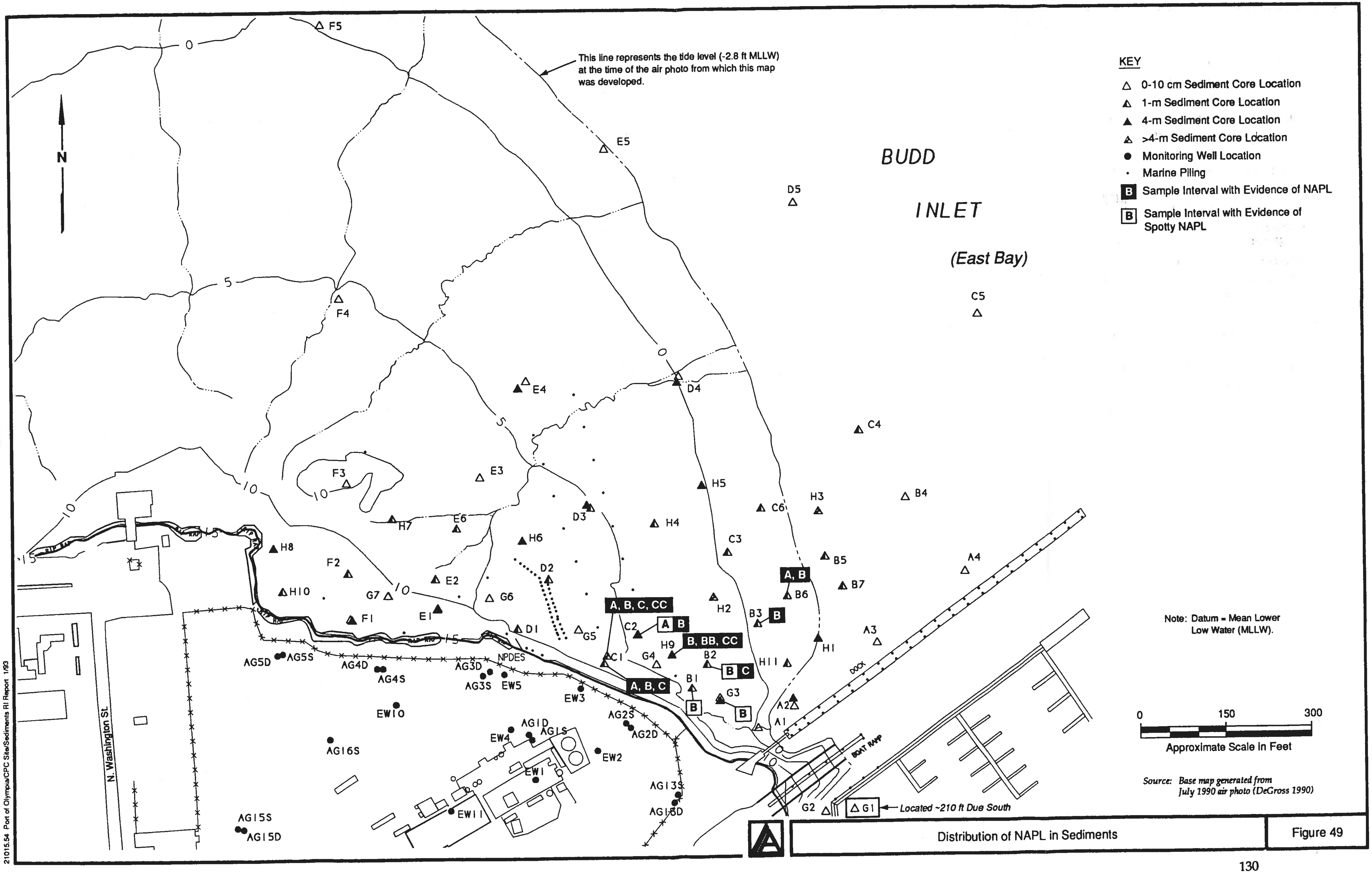
21015.54 Port of Olympia/CPC Site/Sediments RI Report 1/93



Source: Base map generated from July 1990 air photo (DeGross 1990)

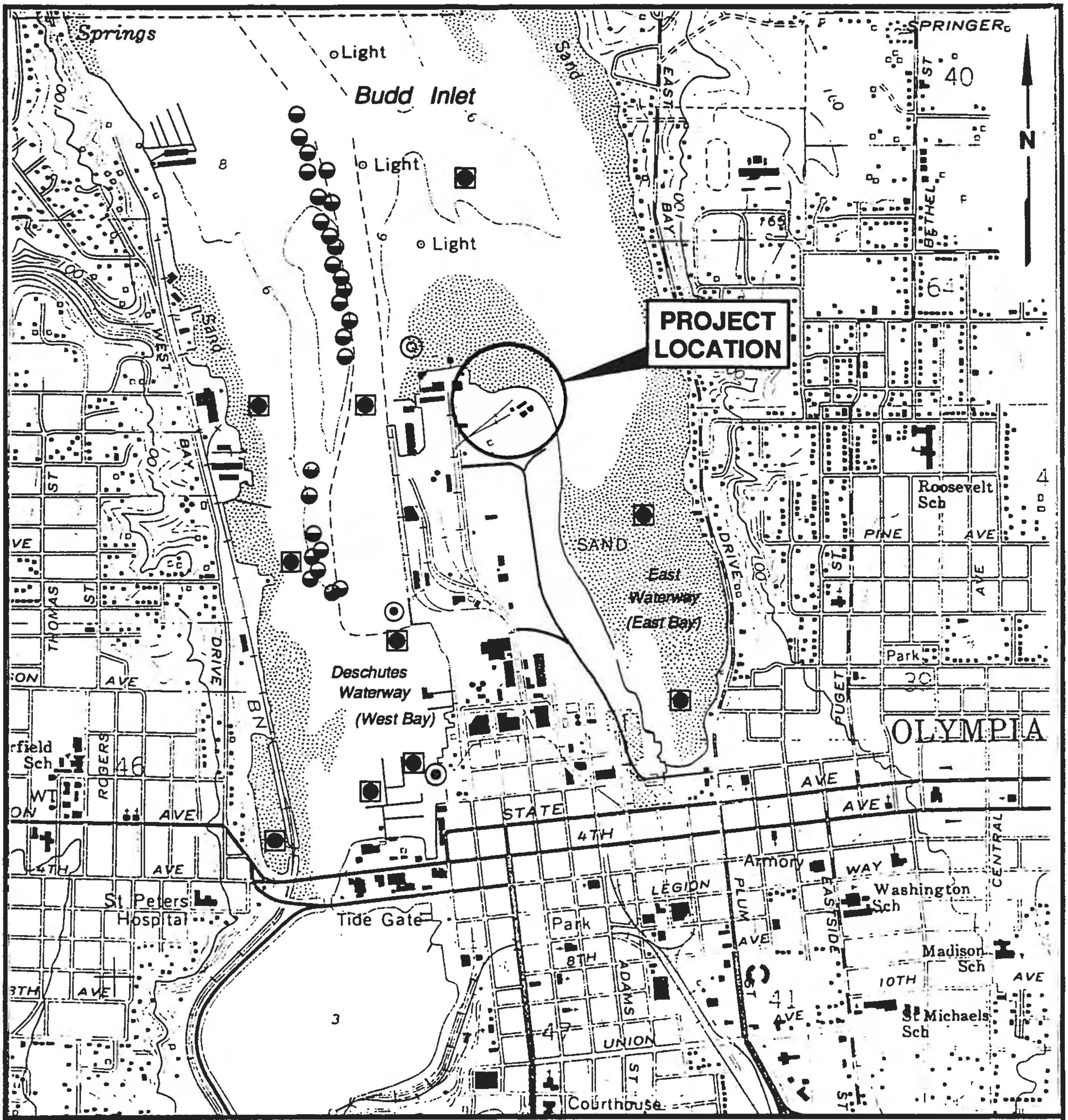
TOC Concentrations in the 100-150, 150-200, and 200-250 cm Intervals (D, E, and F Zones)

Figure 48



Distribution of NAPL in Sediments

Figure 49



Base map source: U.S.G.S. 7.5-min. Quad Series, Tumwater, WA (1959; photorevised 1981)

0 1500 3000

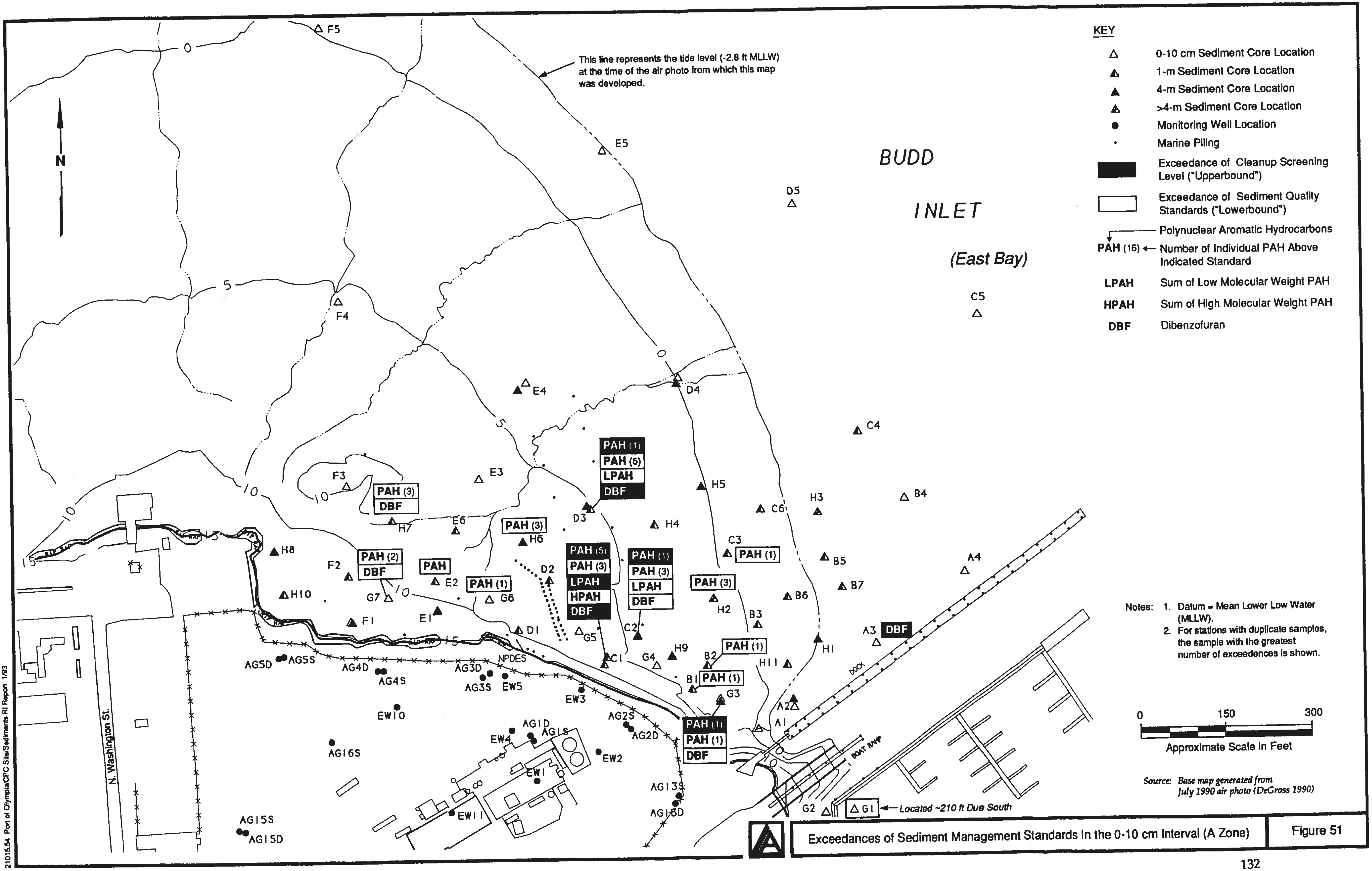
Approximate Scale in Feet

KEY

- ▣ Reconnaissance Survey, Budd Inlet Sampling Location (10 of 12 sample locations shown. Remaining two locations north of area shown on map.)
- ◎ LOTT Urban Area Wastewater Management Plan Outfall Site Sampling Location
- ⊙ LOTT Urban Area Wastewater Management Plan Fiddlehead Site Sampling Location
- ◉ One Tree Island Marina Sampling Location
- ◒ Olympia Harbor Navigation Improvement Project Sampling Location (Adjacent sampling locations are occasionally composited.)

Approximate Historical Sediment Sampling Locations in Lower Budd Inlet

Figure 50



This line represents the tide level (-2.8 ft MLLW) at the time of the air photo from which this map was developed.

△ G1 ← Located ~210 ft Due South

KEY

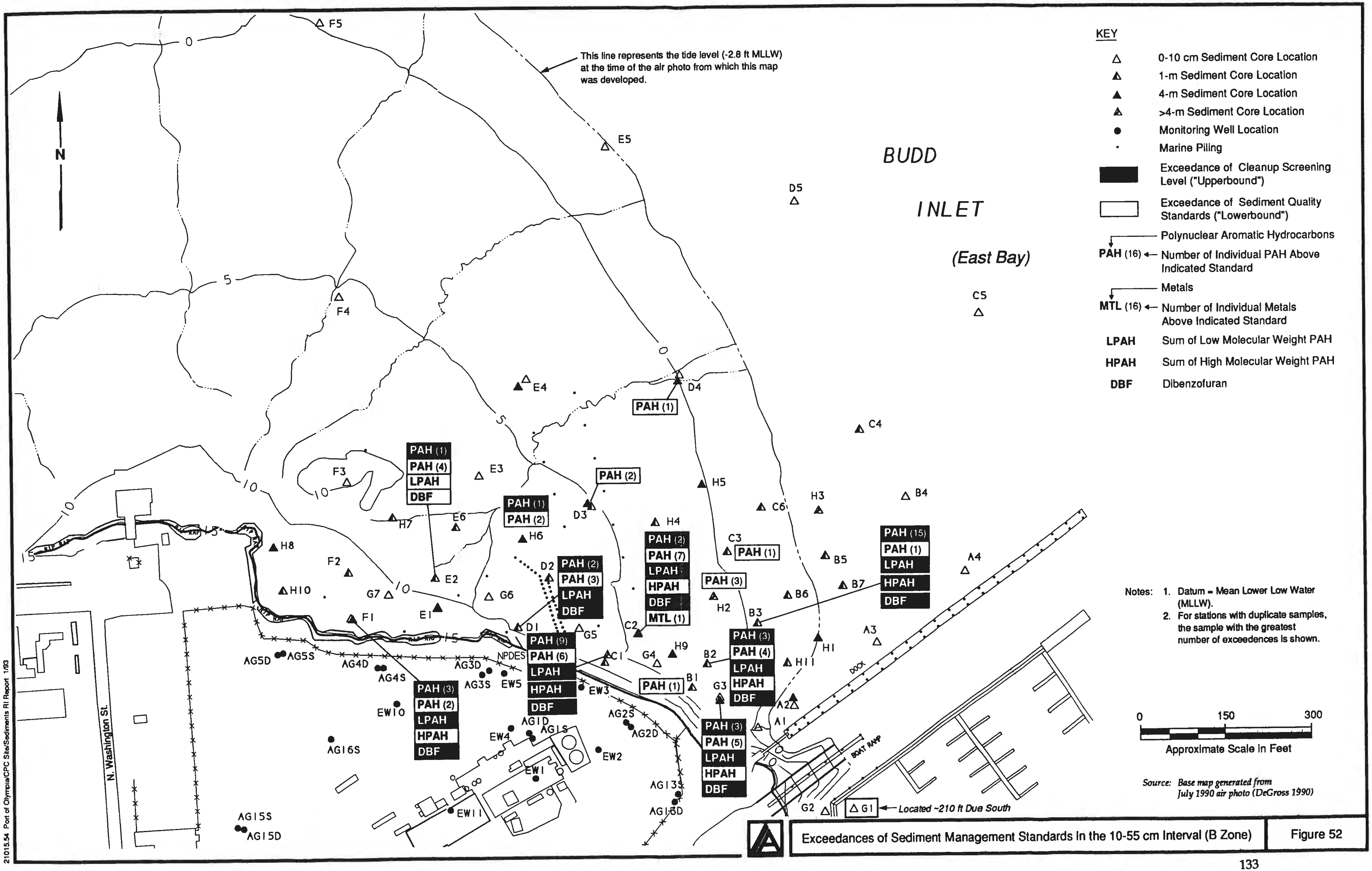
△	0-10 cm Sediment Core Location
▲	1-m Sediment Core Location
▲	4-m Sediment Core Location
▲	>4-m Sediment Core Location
●	Monitoring Well Location
·	Marine Piling
■	Exceedance of Cleanup Screening Level ("Upperbound")
□	Exceedance of Sediment Quality Standards ("Lowerbound")
PAH (16)	Polynuclear Aromatic Hydrocarbons ← Number of Individual PAH Above Indicated Standard
LPAH	Sum of Low Molecular Weight PAH
HPAH	Sum of High Molecular Weight PAH
DBF	Dibenzofuran

Notes:
1. Datum = Mean Lower Low Water (MLLW).
2. For stations with duplicate samples, the sample with the greatest number of exceedences is shown.

Source: Base map generated from July 1990 air photo (DeGross 1990)

Exceedances of Sediment Management Standards In the 0-10 cm Interval (A Zone)

Figure 51

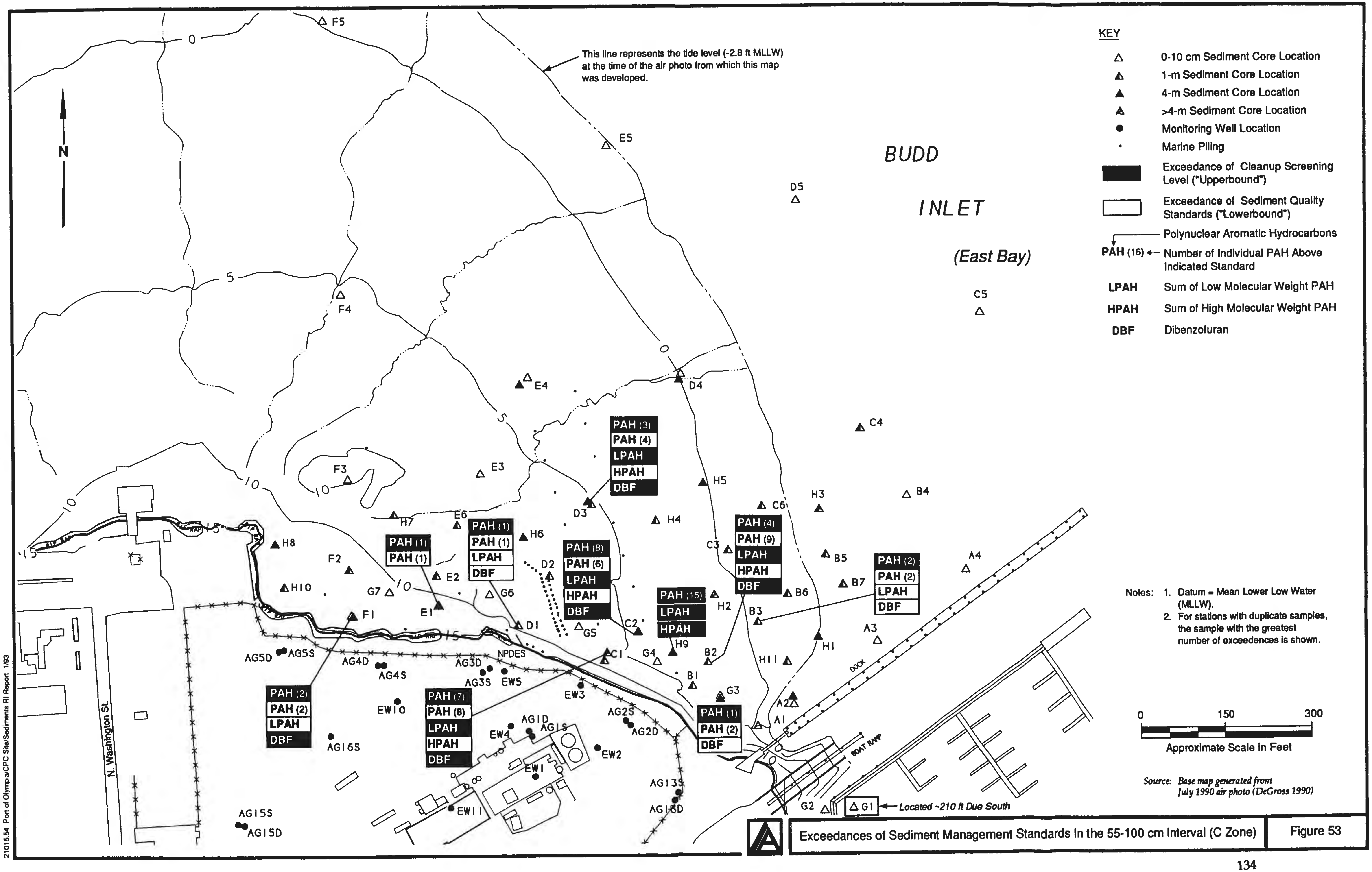


Notes:
1. Datum = Mean Lower Low Water (MLLW).
2. For stations with duplicate samples, the sample with the greatest number of exceedences is shown.

Source: Base map generated from July 1990 air photo (DeGross 1990)

Exceedances of Sediment Management Standards in the 10-55 cm Interval (B Zone)

Figure 52



KEY

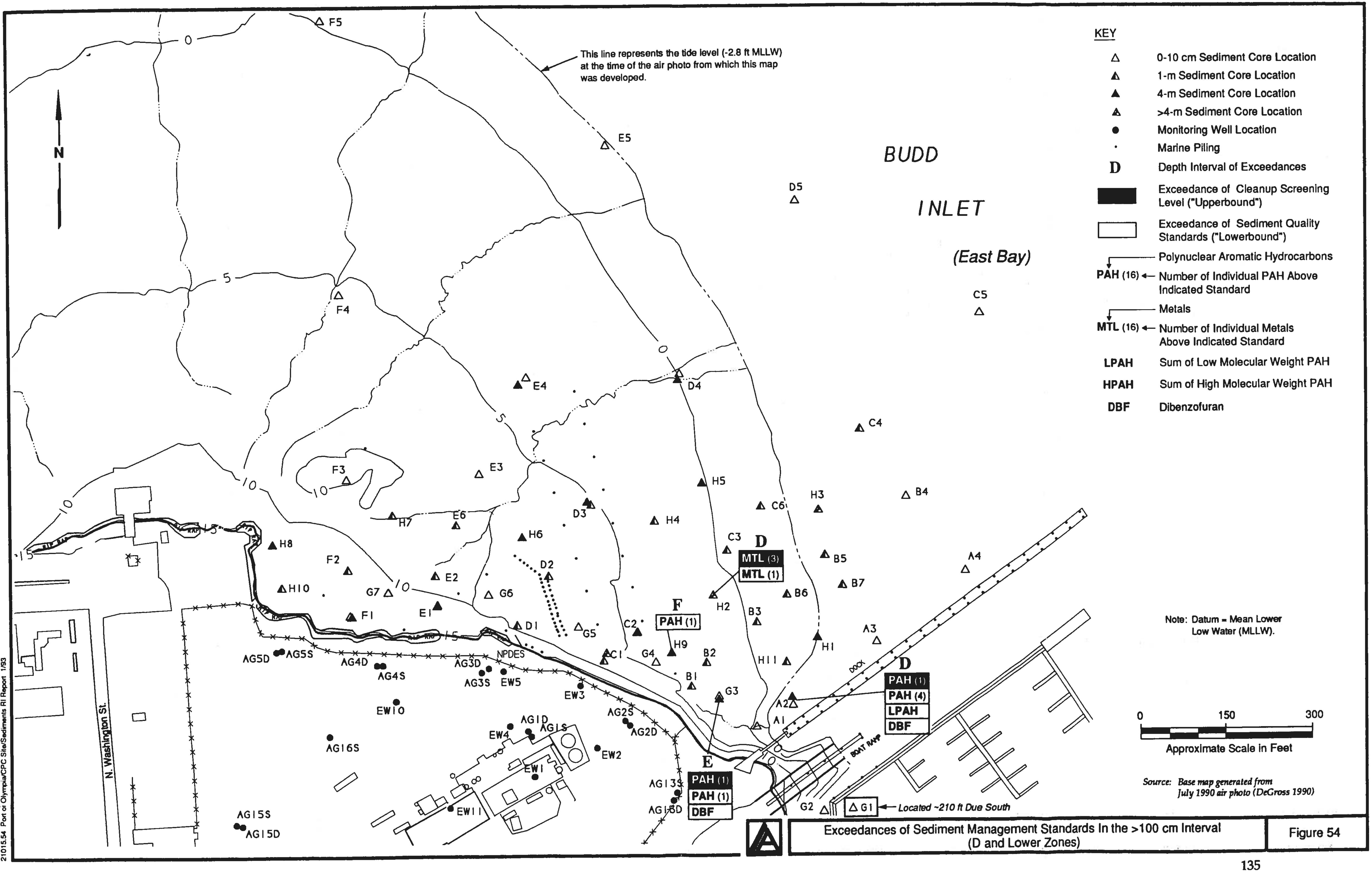
△	0-10 cm Sediment Core Location
▲	1-m Sediment Core Location
▲	4-m Sediment Core Location
▲	>4-m Sediment Core Location
●	Monitoring Well Location
·	Marine Piling
■	Exceedance of Cleanup Screening Level ("Upperbound")
☐	Exceedance of Sediment Quality Standards ("Lowerbound")
PAH	Polynuclear Aromatic Hydrocarbons
(16)	Number of Individual PAH Above Indicated Standard
LPAH	Sum of Low Molecular Weight PAH
HPAH	Sum of High Molecular Weight PAH
DBF	Dibenzofuran

Notes:
1. Datum = Mean Lower Low Water (MLLW).
2. For stations with duplicate samples, the sample with the greatest number of exceedences is shown.

Source: Base map generated from July 1990 air photo (DeGross 1990)

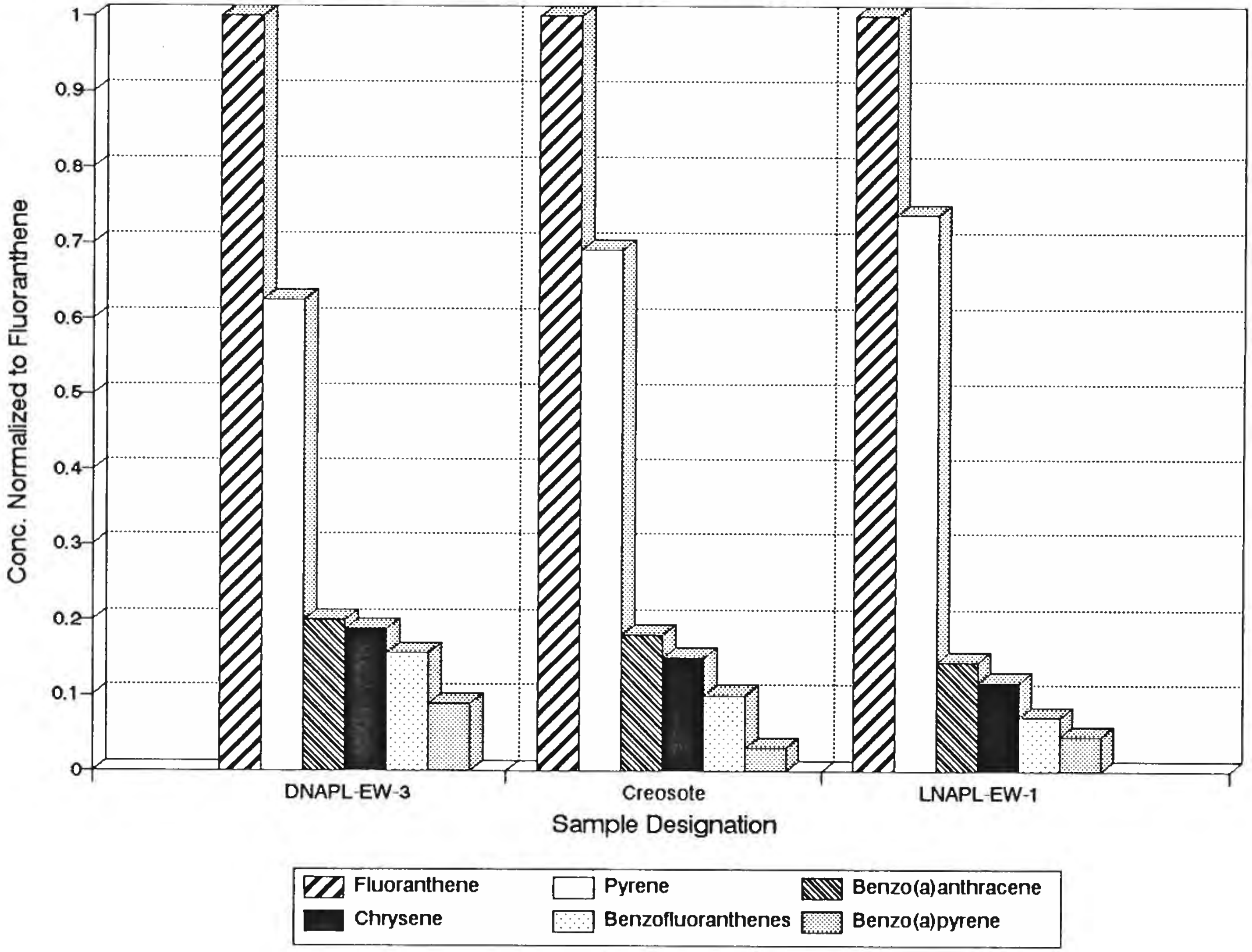
Exceedances of Sediment Management Standards In the 55-100 cm Interval (C Zone)

Figure 53



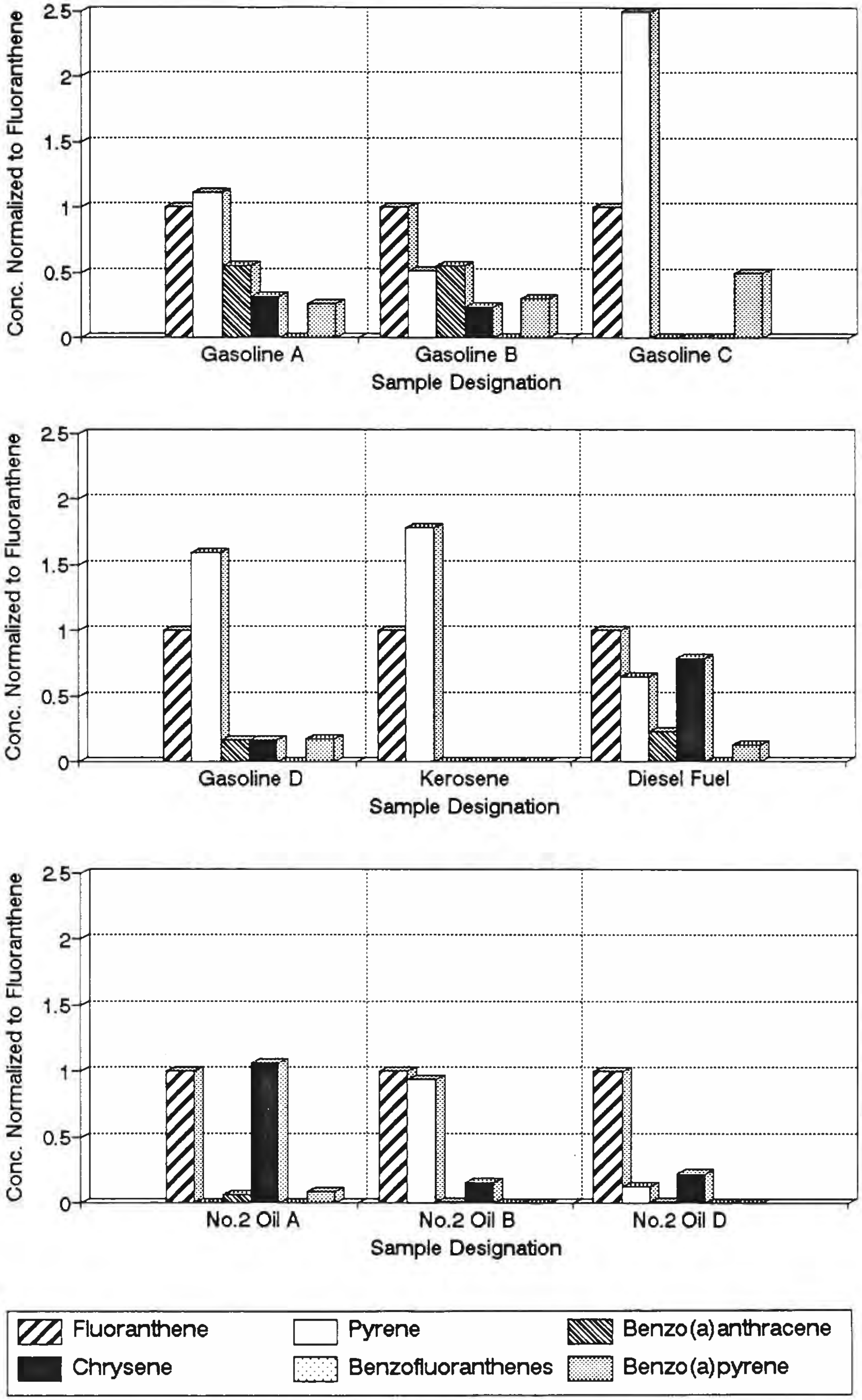
Exceedances of Sediment Management Standards In the >100 cm Interval (D and Lower Zones)

Figure 54



HPAH Ratios
CPC Creosote and NAPL Samples

Figure 55

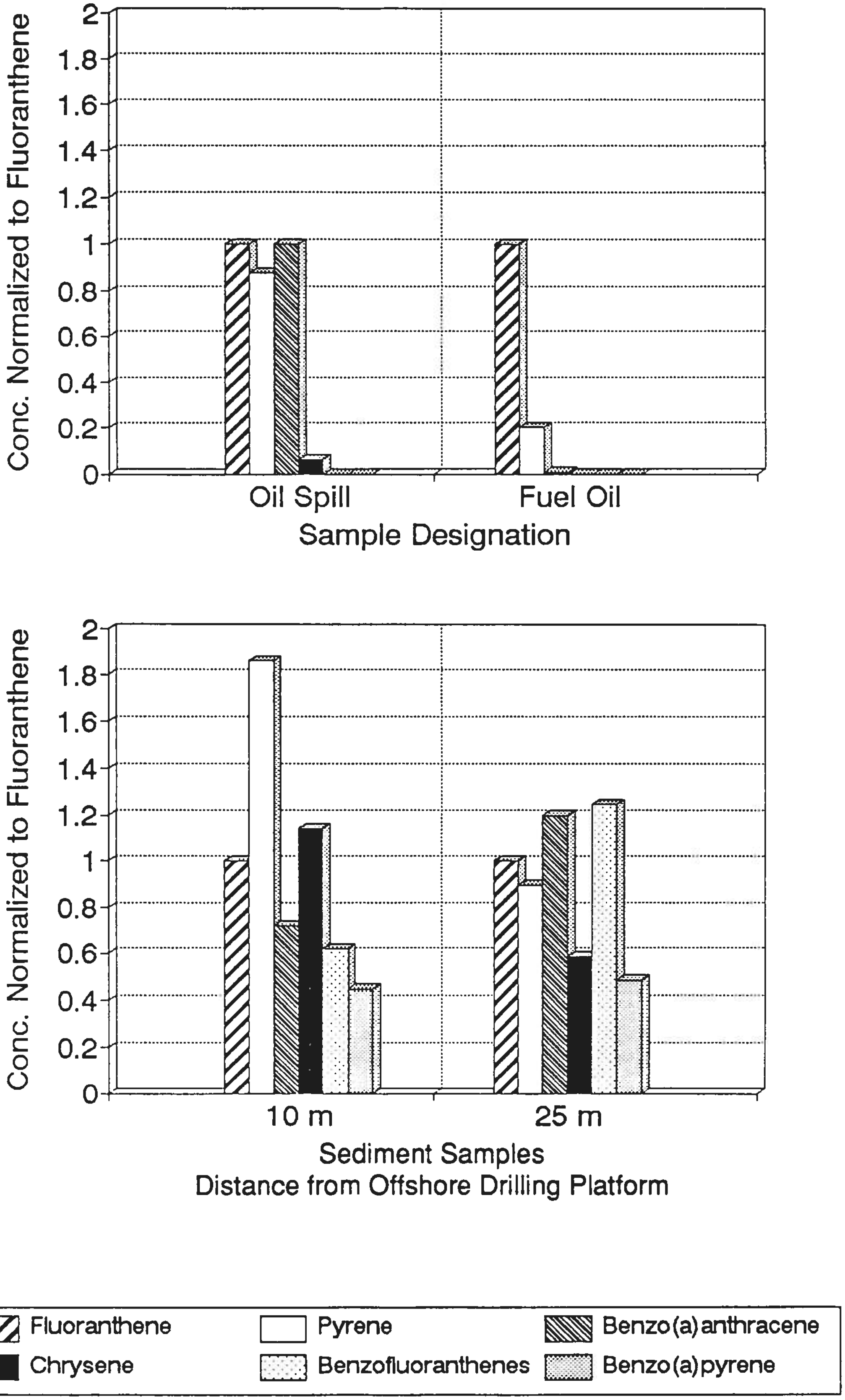


Note: Benzofluoranthenes were not analyzed.

Data Source: Gelboin and Ts'o (1978)

HPAH Ratios
Refined Petroleum Products

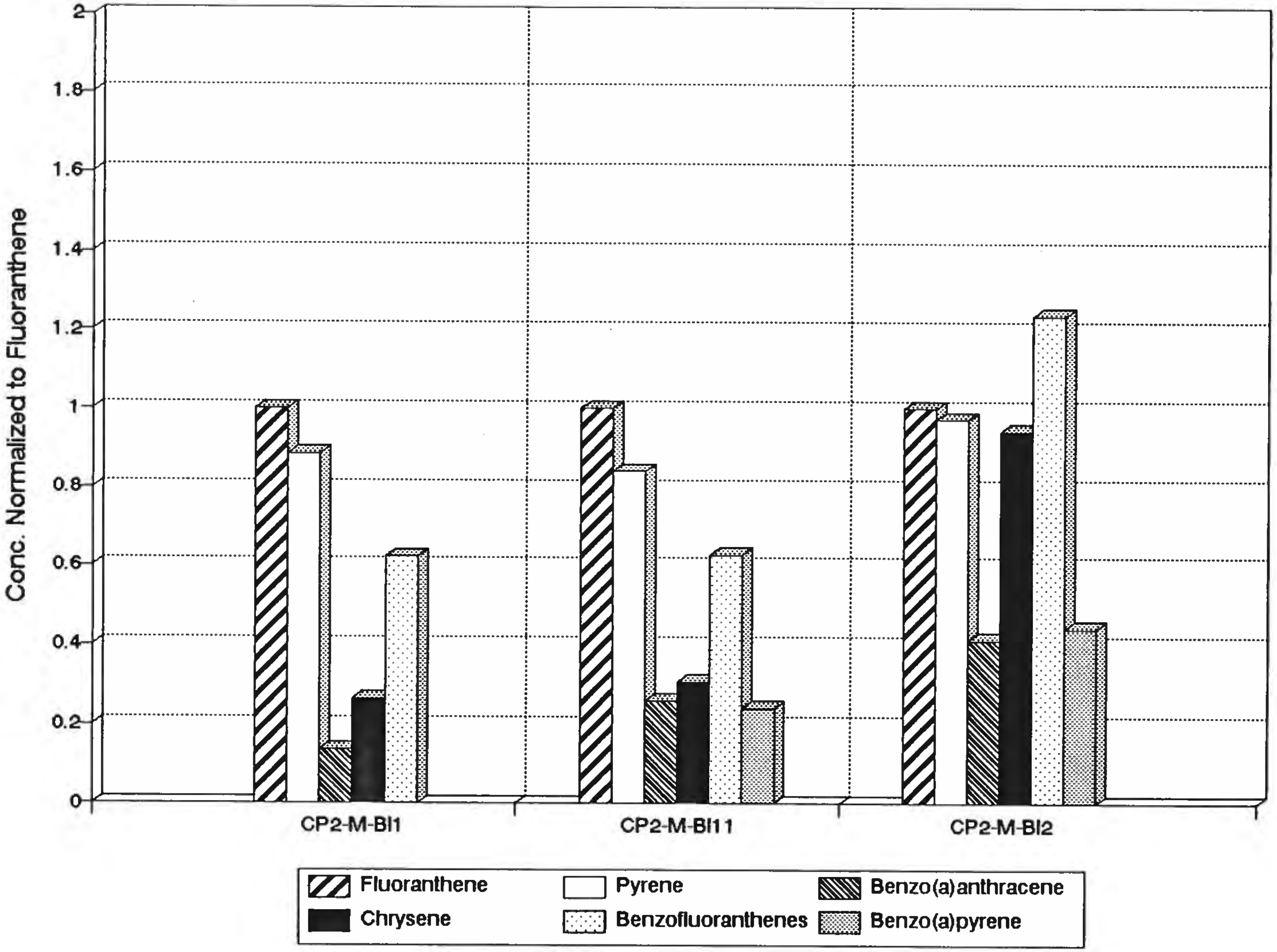
Figure 56



Data Sources: Brooks et al. (1990), Merrill and Wade (1985)

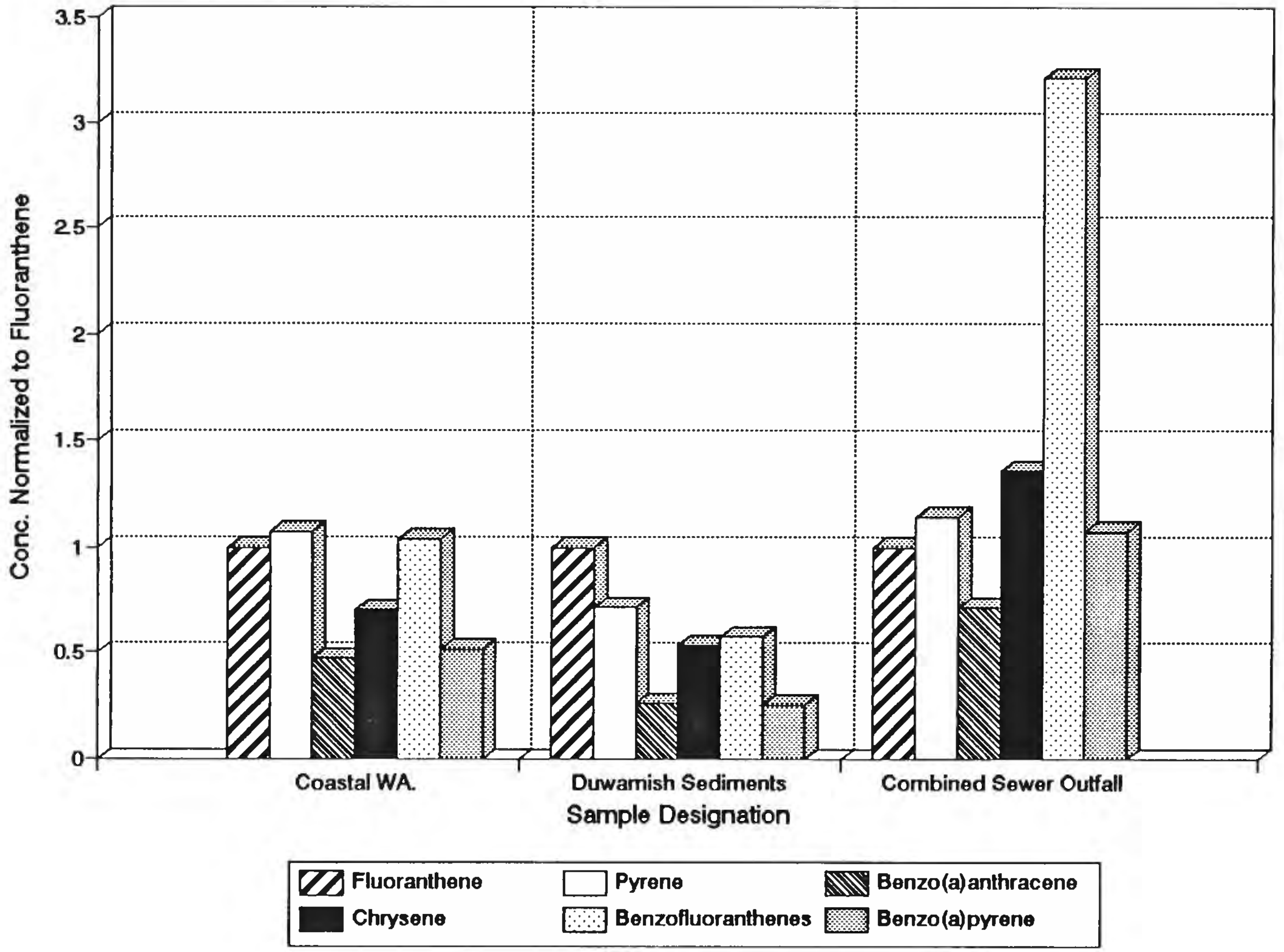
HPAH Ratios
Petroleum and Petroleum-Contaminated Sediments

Figure 57



HPAH Ratios
RI Background Sediment Samples: Budd Inlet

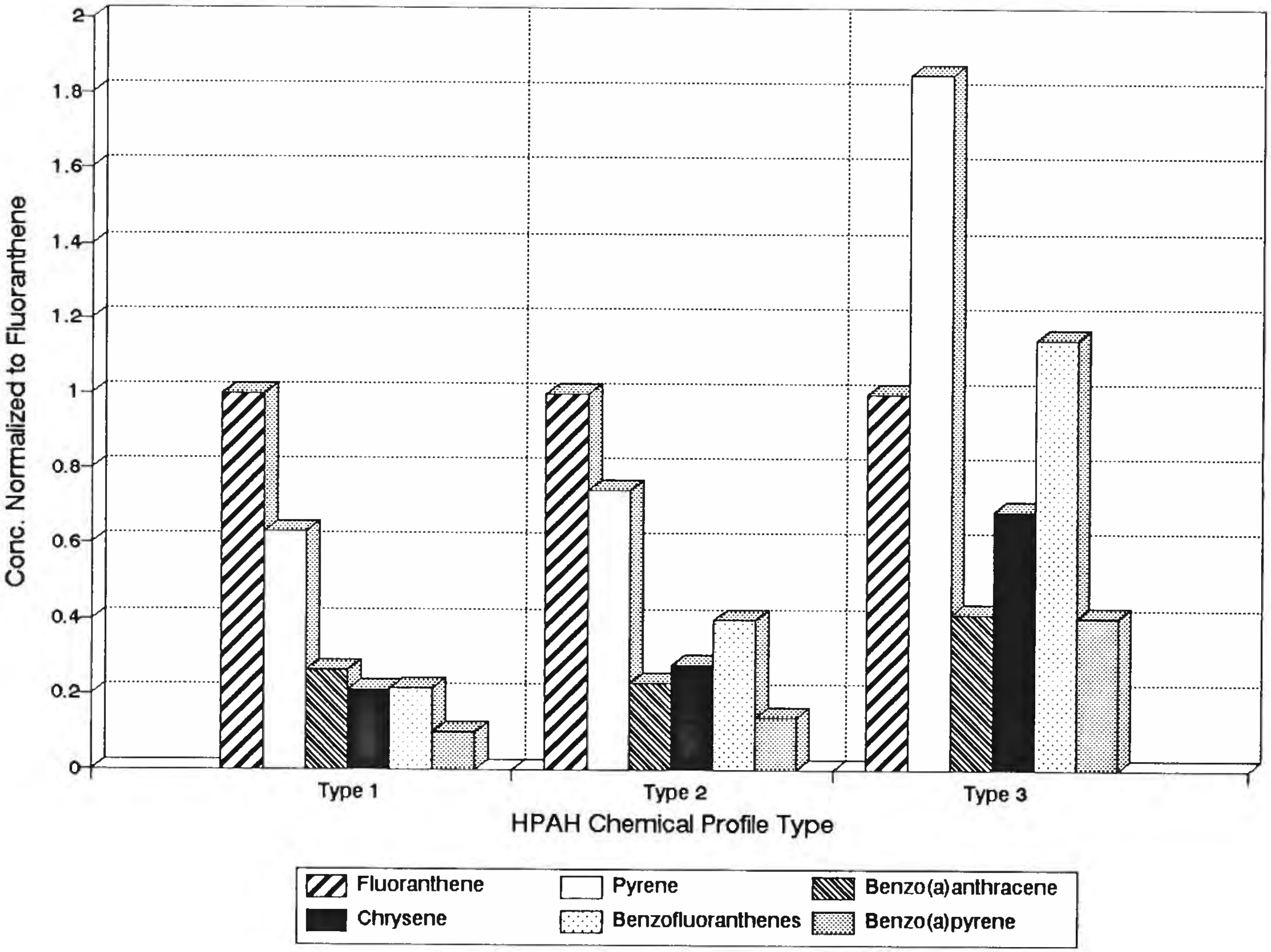
Figure 58



Data Sources: Prahl and Carpenter (1984),
Tetra Tech (1988b), Stuart et al. (1988)

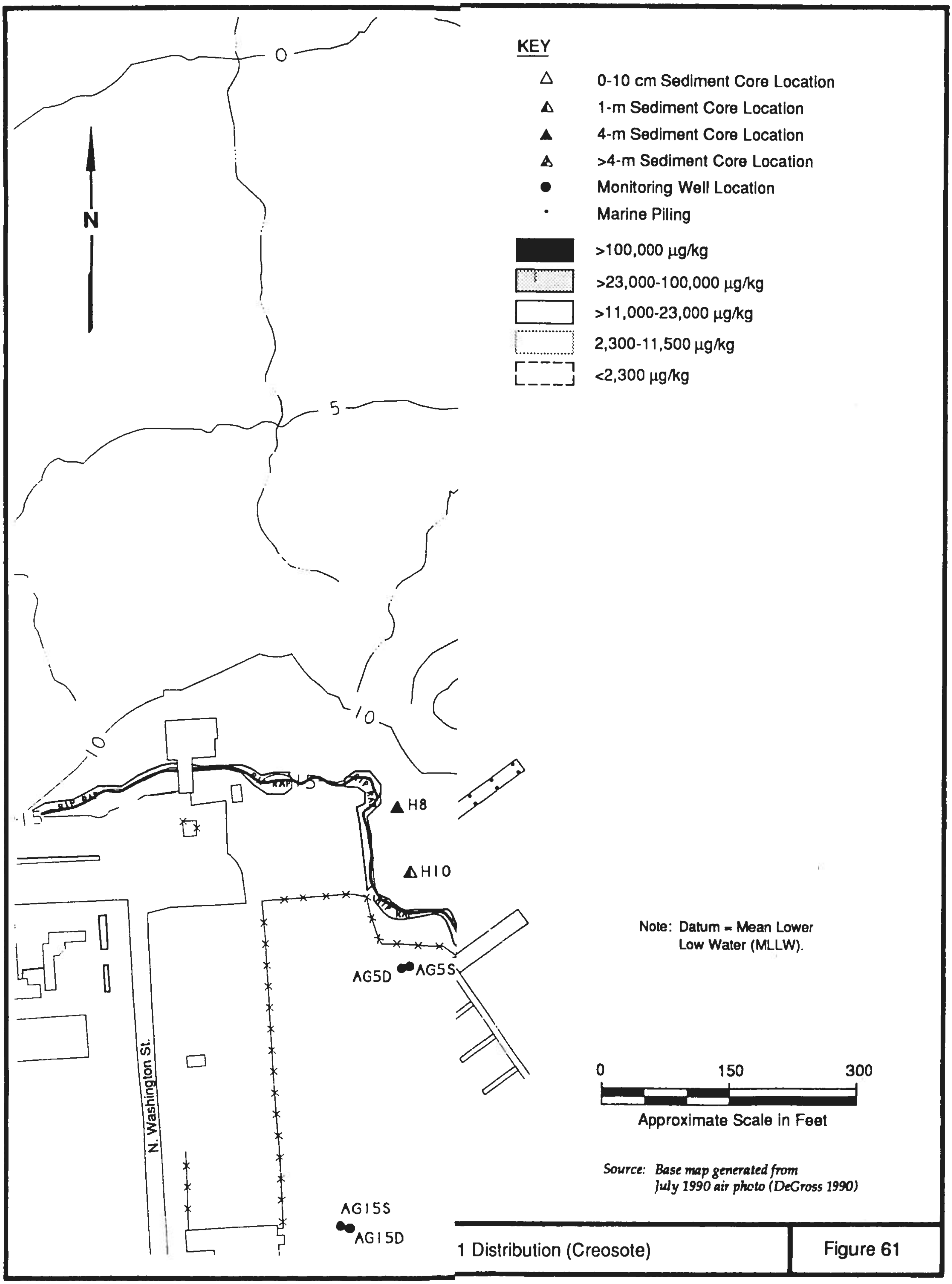
HPAH Chemical Profile
Non-CPC Sediments

Figure 59



HPAH Chemical Profile
CPC Sediments Operable Unit

Figure 60

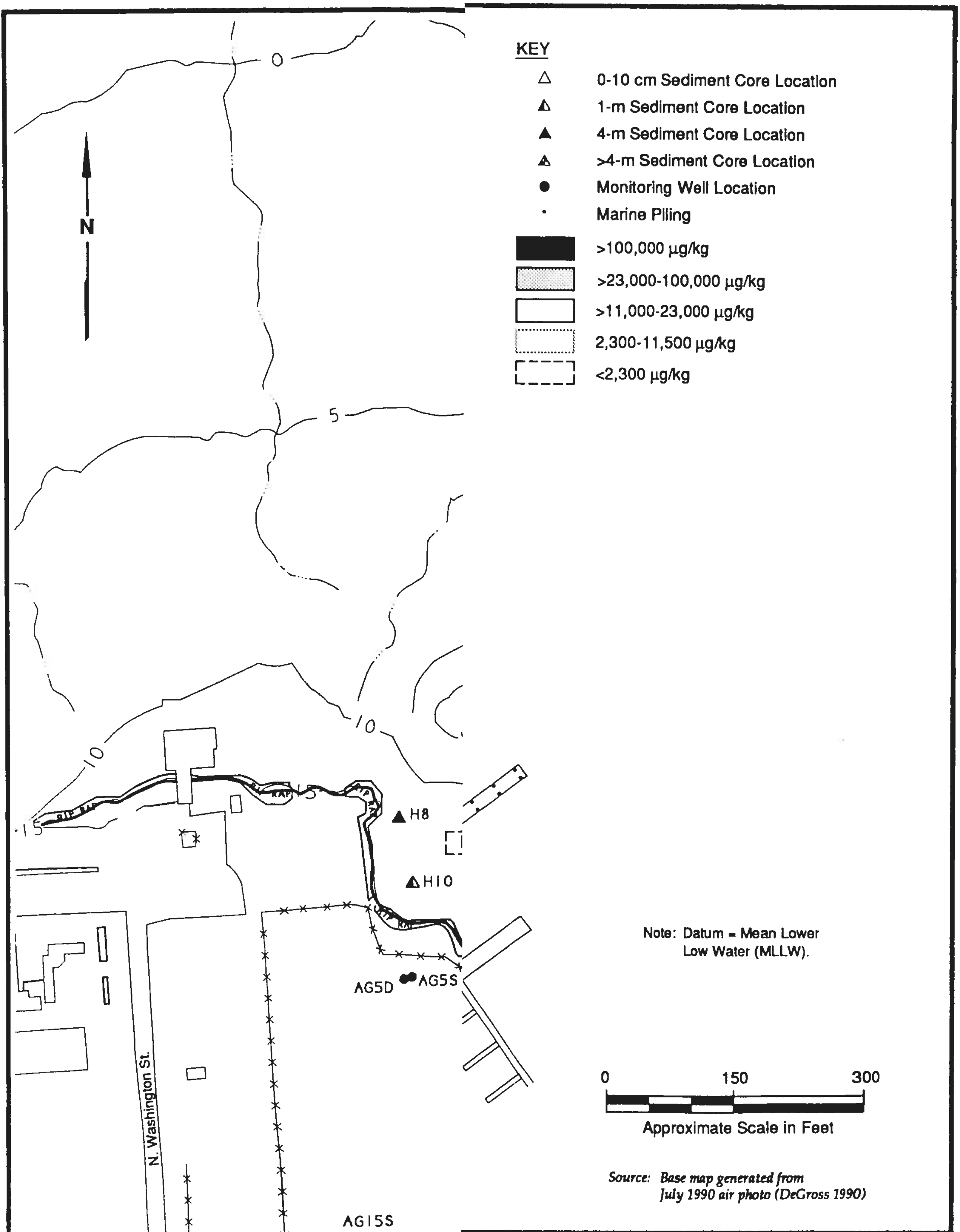


Note: Datum = Mean Lower Low Water (MLLW).

Source: Base map generated from July 1990 air photo (DeGross 1990)

1 Distribution (Creosote)

Figure 61

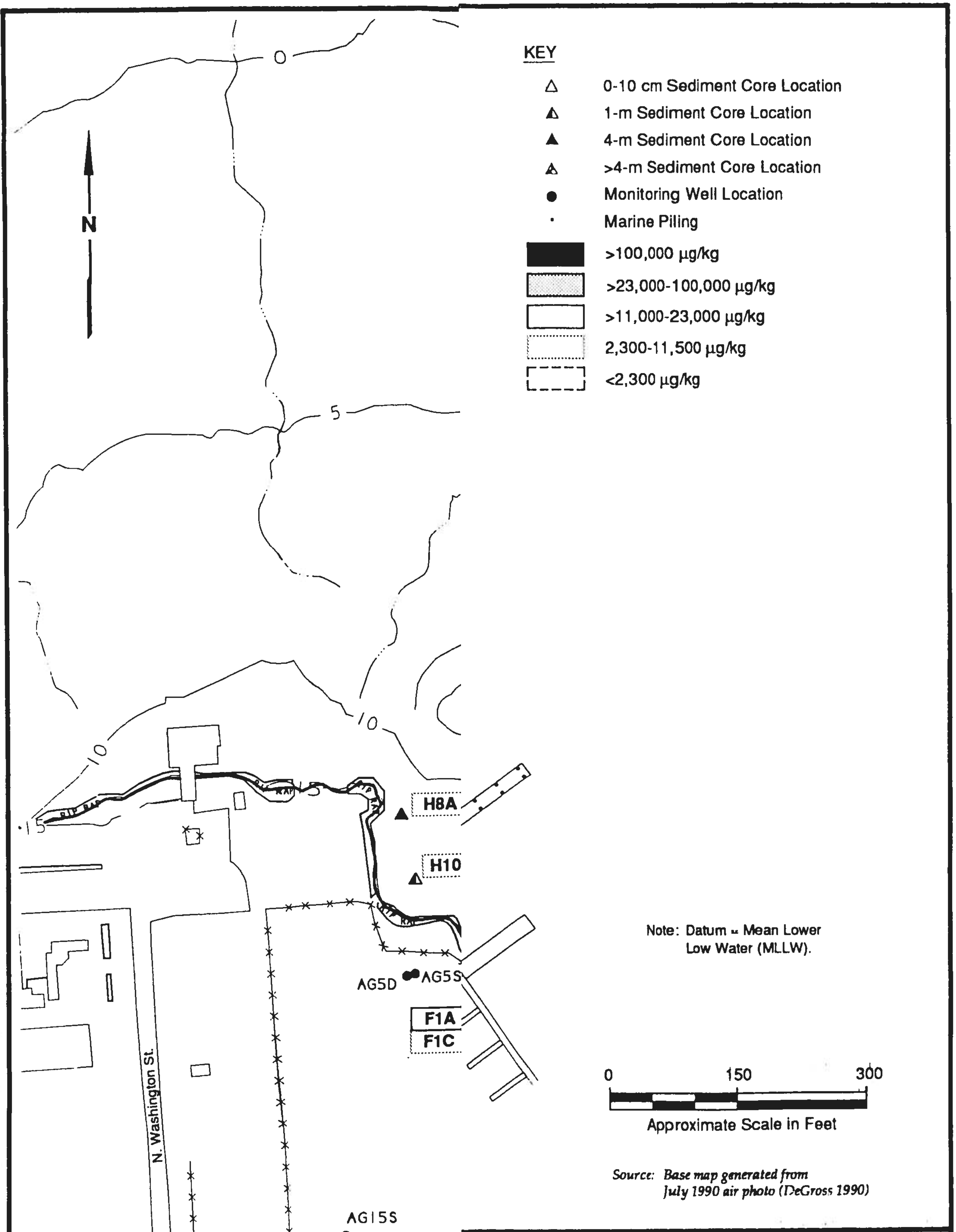


Note: Datum = Mean Lower Low Water (MLLW).

Source: Base map generated from July 1990 air photo (DeGross 1990)

Type 2 Distribution

Figure 62

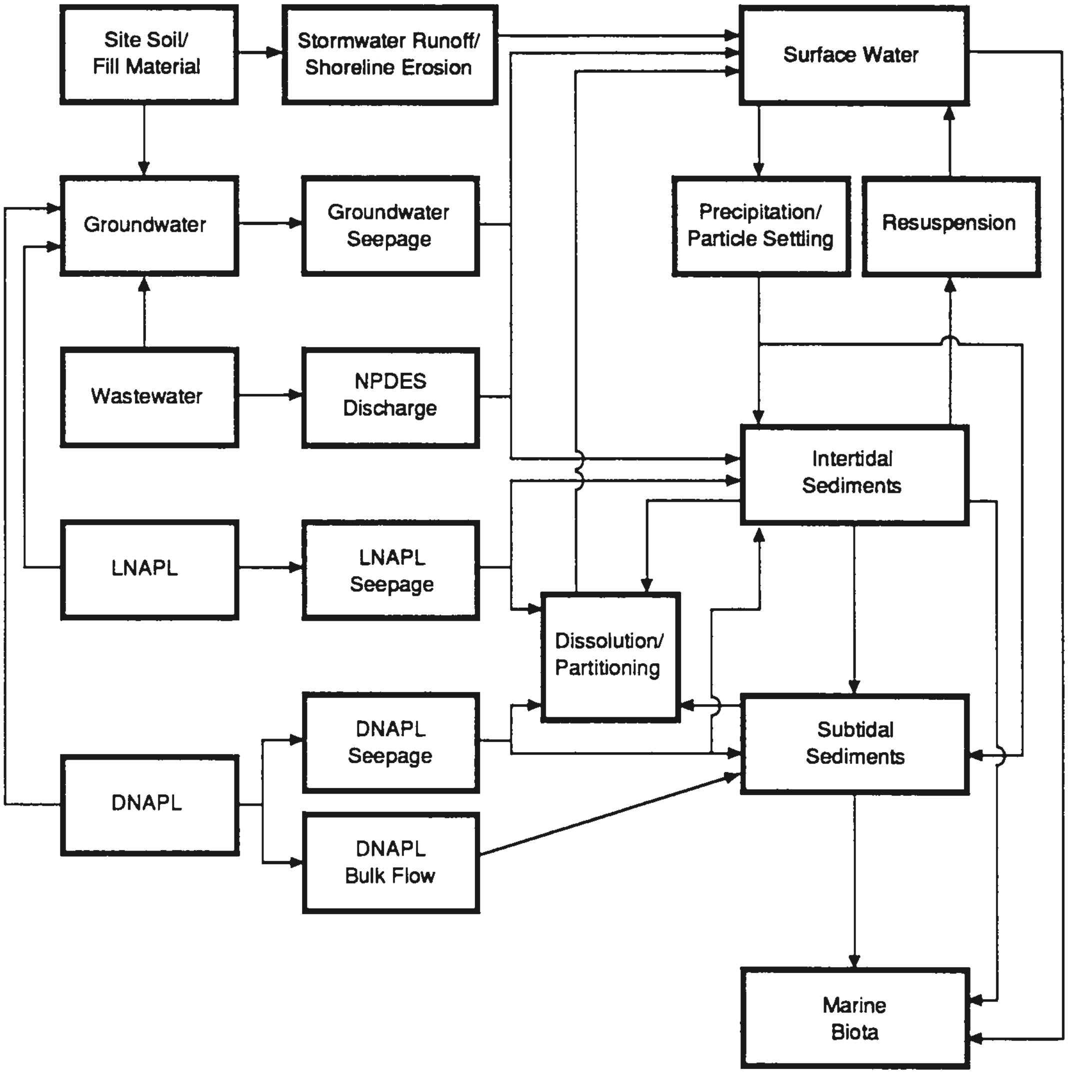


Note: Datum = Mean Lower Low Water (MLLW).

Source: Base map generated from July 1990 air photo (DeGross 1990)

Type 3 Distribution

Figure 63



Primary Contaminant Transport Pathways in the Sediments Operable Unit

Figure 64

Text Tables

TABLE 1
ANALYTICAL METHODS FOR CHEMICAL AND PHYSICAL PARAMETERS
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Parameter	Analytical Methods[a]	Comments	Detection Limit Goals		
			Sediment (µg/kg dry wt)	Tissue (µg/kg wet wt)	Seawater (mg/L)
Semivolatile Compounds/PAH	EPA Method 8270[b] EPA Method 8310	Sediments and tissue samples Surface water samples	25-150 —	25-150 —	-- 0.01-0.05
Chlorinated Phenols	Modified EPA Method 8040	Modified with a derivatization using diazomethane	5-50	5-50	0.05-0.5
PSEP Metals	EPA Methods Series 6000 and 7000	Sediments and tissue samples underwent a modified strong acid digestion using nitric acid and hydrogen peroxide	0.1-0.2 (mg/kg)	0.01-0.2 (mg/kg)	per PSEP
Dioxins/Furans	Modified EPA Method 8290	Modified using EPA Method 1613; extracts were acid/base washed, and subjected to silica gel, alumina, and carbon adsorption prior to analysis	0.001-0.01	0.001-0.01	0.001-0.01 (ng/L)
TOC	Furnace Combustion according to PSEP Protocol[c]	—	per PSEP	per PSEP	per PSEP
Percent Moisture	ASTM D 2216	--	per PSEP	per PSEP	per PSEP
Combined Grain Size Analysis	ASTM D 422	--	NA	NA	NA
Percent Lipid	Procedure in the Phase I SAP and Phase II Work Plan[d]	--	Not specified	Not specified	Not specified
Lead 210	Alpha Spectroscopy[e]	--	Not specified	Not specified	Not specified
Bioassays (microtox, amphipod, and echinoderm larvae)	PSEP Protocol[f]	--	NA	NA	NA

(a) Sources: EPA 1986d and ASTM 1991.

(b) Visually contaminated extracts were cleaned using the silica gel cleanup step specified in the Phase I SAP and the Phase II Work Plan (Landau Associates 1990a and 1991a).

(c) PSEP 1986a.

(d) Landau Associates 1990a and 1991a.

(e) After Chanton et al. (1983) and Carpenter et al. (1984).

(f) PSEP 1986b.

TABLE 2
SUMMARY OF SELECTED SEDIMENT ORGANIC DATA (a)
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Sample Number	Total LPAH(b)	Total HPAH(c)	PCP (d)		Dibenzofuran		PCDD/F (TEQ) (e)	TOC (%) (f)	
CP1-M-A1A	2600	5800	17		190			2.08	
CP1-M-A2A	1000	3000	11	B,(g)	50	J,		1.19	
CP2-M-A2A							0.154		
CP2-M-A2B	1300	3700	19	*,J	55	U	0.246	6.49	
CP2-M-A2C	2500	8900	9.2	*,J	180			3.50	
CP2-M-A2D	18000	30000	13	*,J	1500			3.20	
CP1-M-A3A	1500	2400	5.6	B,UJ	84			2.56	
CP1-M-A4A	1100	2500	3.6	B,UJ	73			2.65	
CP1-M-B1A	3700	5800	4.7		320		0.037	2.32	
CP1-M-B1B	5200	11000	1.9		46	U,		4.58	
CP1-M-B1C	1200	1300	2	U,	56			2.9	
CP1-M-B2A	5700	21000	15	B,	220			2.69	
CP1-M-B2B	160000	150000	14	JB,	16000			9.27	
CP1-M-B2C	73000	72000	15	B,	6600			3.49	
CP1-M-B3A	3500	6000	87	,	190			3.68	
CP1-M-B3B	970000	810000	7.5	U,	100000			4.67	
CP1-M-B3C	20000	2500	2	U,	2100			4.19	
CP1-M-B4A	4200	8500	6	B,UJ	140			2.99	U
CP1-M-B5A	1500	1900	8.4	,	120			3.47	
CP1-M-B5B	1500	3100	3.5	,	75			3.94	
CP1-M-B5C	300	470	2	U,	47	U,		2.3	
CP1-M-C1A	87000	61000	43	,J	6800		0.295	4.19	
CP1-M-C1B	880000	350000	100	,J	83000		1.290	6.25	
CP1-M-C1C	660000	280000	140	,J	50000		0.694	6.82	
CP2-M-C1E	840	1100	1.7	U	40	U	0.009	2.36	
CP2-M-C1PP	170	290	1	U	24	U		0.63	
CP1-M-C2A	6800	18000	18	,J	450		0.125	3.27	
CP1-M-C2B	110000	160000	220	,J	5900		0.833	8.39	
CP1-M-C2C	47000	34000	1.7	U,UJ	3200		0.017	3.81	
CP2-M-C2E	500	1300	1.9	U	46	U		2.06	
CP1-M-C3A	3000	3600	4.6		180		0.060	2.09	
CP1-M-C3B	3400	5100	4		200		0.025	1.67	
CP1-M-C3C	700	690	2	U,	48	U,	0.005	3.93	
CP1-M-C4A	2100	2300	9.3	,	110			3.55	
CP1-M-C4B	540	660	2.2	U,	52	U,		2.28	
CP1-M-C4C	350	520	2.1	U,	50	U,		2.33	
CP1-M-C5A	1200	1400	9	B,	44	J,		6.76	
CP1-M-D1A	2400	3200	24		72		0.108	1.67	
CP1-M-D1B	8000	7400	1.3		630			0.89	
CP1-M-D1C	3600	340	1.5	U,	350			0.74	
CP1-M-D2A	2200	1600	6.3		91			2.44	
CP1-M-D2B	3800	11000	1.2		210			5.63	
CP1-M-D2C	530	410	1.5	U,	36	U,		2.01	
CP1-M-D3A	15000	10000	14	,	1700			1.97	
CP1-M-D3B	20000	27000	14	,	1200			8.2	
CP1-M-D3C	15000	22000	1.5	U,	1100			1.65	
CP2-M-D3E	310	520	1.8	U	42	U		2.13	
CP1-M-D4A	2200	2600	14	JB,	120			2.64	
CP2-M-D4B	4500	3900	12	,J	270			2.68	
CP2-M-D4D	420	1200	4.2	*,J	46	U		2.71	
CP1-M-D5A	700	820	3.7	B,UJ	32	J,		1.96	
CP1-M-E1A	540	690	11	,	32	J,		1.26	
CP2-M-E1B	800	1300	8.8	,J	40			1.13	
CP2-M-E1C	760	360	4.5		24	U		0.28	
CP2-M-E1F	830	390	3.5	,J	24	U		0.72	
CP1-M-E2A	5700	3700	37	,	290			2.02	
CP1-M-E2B	6100	6300	2.6	,	280			0.91	
CP1-M-E2C	500	250	1	U,	24	U,		3.41	
CP1-M-E3A	1600	2600	9.7	,	110			2.85	
CP1-M-E4A	1100	1700	10	B,	69			3.21	
CP2-M-E4B	1700	1900	5.6	,J	71			1.87	
CP2-M-E4C	440	1000	1	U(e)	24	U		1.39	
CP2-M-E4E	170	330	1	U	24	U		0.60	
CP1-M-E5A	910	890	39	B,J	43	J,		2.58	
CP1-M-F1A	2900	7400	160	,	190			9.49	
CP2-M-F1A	5900	17000	120	D	230		0.384	3.03	
CP2-M-F1B	4500	3400	2.6	,J	370		0.007	0.33	

TABLE 2
SUMMARY OF SELECTED SEDIMENT ORGANIC DATA (a)
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Sample Number	Total LPAH(b)	Total HPAH(c)	PCP (d)		Dibenzofuran		PCDD/F (TEQ) (e)	TOC (%) (f)
CP2-M-F1C	4400	3200	21		630		0.050	0.83
CP1-M-F2A	1500	1800	8.1	,	95			1.55
CP1-M-F2B	260	370	1.4	U,	34	U,		2.49
CP1-M-F2C	170	240	1	U,	24	U,		2.15
CP1-M-F3A	2800	3000	12	,	190			3.94
CP1-M-F4A	320	450	3.6	B,	14	J,		1.65
CP1-M-F5A	680	940	9.1	JB,	31	J,		2.15
CP1-M-G1A	630	1800	5.4	,	41	J,		3.53
CP1-M-G2A	440	1800	7.5	,J	71	U,		3.81
CP1-M-G3A	12000	35000	89	B,	900			3.82
CP1-M-G3B	54000	43000	14	B,	4600			2.85
CP2-M-G3B	26000	85000	51	D	2500			5.98
CP2-M-G3C	7900	10000	4.8		490			2.61
CP2-M-G3E	8200	2300	1.7	U	710			2.68
CP1-M-G4A	4000	13000	14	,	280			3.25
CP1-M-G5A	3400	6300	34	,	44	U,		2.88
CP1-M-G6A	3500	2400	16	,	150			2.46
CP1-M-G7A	3200	13000	12	,	250			1.45
CP2-M-H10A	1800	4400	28	*,J	130			3.93
CP2-M-H1A	3700	6200	240	D	52	U	0.143	3.87
CP2-M-H1B	2300	4000	8.4	*,J	49	U	0.140	4.32
CP2-M-H1C	340	700	2	U	48	U		4.21
CP2-M-H1E	260	390	1.6	U	37	U		1.64
CP2-M-H2A	9300	14000	47	D	44	U		3.36
CP2-M-H2B	7400	12000	54	D	37	U		3.04
CP2-M-H2C	580	840	1	U	24	U		0.82
CP2-M-H2D	320	1100	1.9	U	45	U	0.017	2.47
CP2-M-H2M	270	540	1.6	U	38	U		1.61
CP2-M-H3A	1800	3600	8.7		47	U		3.94
CP2-M-H3B	1700	2400	5.9	*,J	46	U		4.56
CP2-M-H3C	330	470	2	U	47	U		3.19
CP2-M-H3E	300	430	1.8	U	43	U		1.32
CP2-M-H3L	300	430	1.6	U	43	U		1.23
CP2-M-H5A	2000	2100	7.2	*,J	120		0.044	2.40
CP2-M-H5B	2600	3000	14	*,J	150		0.032	2.18
CP2-M-H5CC	170	240	1.3		24	U		0.42
CP2-M-H5E	330	470	4.1	*,J	47	U		2.66
CP2-M-H6A	4800	4700	27	D,J	250		0.090	1.62
CP2-M-H6B	5400	4000	14	,J	200		0.061	1.51
CP2-M-H6C	230	320	5.4	,J	24	U		0.49
CP2-M-H6E	250	430	1.5	U	35	U		0.91
CP2-M-H7A	9600	7200	17	*,J	770		0.1004	3.91
CP2-M-H7B	660	830	1.2	*,J	32		0.0084	1.23
CP2-M-H7C	500	720	1	U	24			1.63
CP2-M-H8A	1300	4000	11	,J	70		0.054	2.45
CP2-M-H8B	450	670	1.7	U	40	U	0.012	1.43
CP2-M-H8C	430	570	1.7	U	40			1.90
CP2-M-H8E	210	320	1	U	24			0.69
CP2-M-H9CC	520000	240000	1	U	62000	D,U		1.21
CP2-M-H9F	4500	2000	1.9	U	290			2.57

(a) Units are ug/kg dry weight unless indicated otherwise.

(b) LPAH is the sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene. Nondetected compounds are included in the sum at the detection limit.

(c) HPAH is the sum of fluoranthene, pyrene, benzo(a)anthracene, chrysene, the benzo(b,j, and k)fluoranthenes, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene. Nondetected compounds are included in the sum at the detection limit.

(d) PCP = Pentachlorophenol

(e) PCDD/F = Polychlorodibenzo-p-dioxins and -furans, and is a sum of the individual isomers that are adjusted to 2,3,7,8-toxicity equivalents (TEQ). Nondetected compounds are included in the sum at the detection limit.

(f) TOC = Total organic carbon, reported as weight percent.

(g) Data qualifiers are explained in detail in Appendix D, and summarized in Table C-1.

TABLE 3
SUMMARY OF SEDIMENT METALS DATA (a)
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Sample Number	Antimony	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Silver	Zinc
CP1-M-A1A	0.5 U,UJ(b)	3.5 ,J	1.9	32	55	22	0.08	27	1 U	100
CP1-M-A2A	0.5 U,UJ	6.6 ,J	1.9	35	55	18	0.08	30	1 U	88
CP1-M-A3A	0.5 U,UJ	6.5 ,J	2.3	35	65	18	0.12	28	1 U	96
CP1-M-B1A	0.5 U,UJ	6.1 ,J	1.2	26	42	7.5 ,J	0.05	23	1 U	43
CP1-M-B1B	0.5 U,UJ	6.9 ,J	1.4	33	53	7.8 ,J	0.05	29	1 U	54
CP1-M-B1C	0.5 U,UJ	7.1 ,J	1.6	30	56	7.3 ,J	0.06	27	1 U	53
CP1-M-C1A	0.5 U,UJ	5.9 ,J	1.5	32	67	19	0.16	24	1 U	87
CP1-M-C1B	0.5 U,UJ	7.4 ,J	1.8	31	77	34	0.17	26	1 U	98
CP1-M-C1C	0.5 U,UJ	13 ,J	2	31	100	24	0.37	31	1 U	92
CP1-M-C2A	0.5 U,UJ	6.6 ,J	2.1	33	69	20	0.18	29	1 U	94
CP1-M-C2B	0.5 U,UJ	8.3 ,J	2.1	34	84	25	0.33	30	1 U	90
CP1-M-C2C	0.5 U,UJ	6.2 ,J	1.4	31	240	9.2 ,J	0.08	26	1 U	60
CP1-M-C3A	0.5 U,UJ	4.9 ,J	1	23	28	8.7 ,J	0.09	20	1 U	53
CP1-M-C3B	0.5 U,UJ	4.8 ,J	0.74	23	21	4.9 ,J	0.04	20	1 U	43
CP1-M-C3C	0.5 U,UJ	7 ,J	1.4	32	40	7 ,J	0.04	30	1 U	56
CP1-M-D1A	0.5 U,UJ	6.4 ,J	0.44	23	38	5.2 ,J	0.02	20	1 U	44
CP1-M-D1B	0.5 U,UJ	3 ,J	0.5	10	79	4.1 ,J	0.02 U,	14	1 U	21
CP1-M-D1C	0.5 U,UJ	3.7 ,J	0.5	18	8.8	2.2 ,J	0.02 U,	17	1 U	25
CP1-M-E1A	0.5 U,UJ	5.6 ,J	0.84	26	30	7 ,J	0.04	24	1 U	40
CP1-M-E2A	0.5 U,UJ	7.5 ,J	0.86	19	51	18	0.07	21	1 U	78
CP1-M-E3A	0.5 U,UJ	4.1 ,J	1.3	25	42	13 ,J	0.15	21	1 U,U	50
CP2-M-C1E	0.1 U,J	6.5 ,J	1	19	24 ,J	3	0.04	28	1 U	34
CP2-M-G3B	0.1 U,J	7.6 ,J	1.6	31	100 ,J	22	0.21	29	0.06 U	79
CP2-M-G3C	0.1 U,J	3.8 ,J	1	30	194 ,J	11	0.03	30	1 U	55
CP2-M-G3E	0.1 U,J	3.7 ,J	2	31	66 ,J	9	0.04	29	1 U	53
CP2-M-H2A	0.1 U,J	4.7 ,J	1.1	24	40 ,J	12	0.13	19	0.06 U	62
CP2-M-H2B	0.1 U,J	4.4 ,J	0.97	20	37 ,J	8.8	0.09	18	0.05 U	48
CP2-M-H2C	0.1 U,J	2.7 ,J	4	150	230 ,J	26	0.03	18	0.2 U	270
CP2-M-H2D	0.1 U,J	6.6 ,J	12	350	410 ,J	67	0.06	33	1 U	580

(a) Concentration data are reported in units of mg/kg dry weight.
(b) Data qualifiers are explained in detail in Appendix D, and are summarized in Table C-1.

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TABLE 4
COMPARISON OF SEDIMENT BACKGROUND AND REFERENCE AREA CONCENTRATIONS
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Analyte	RI Background Samples (Range)		Other Puget Sound Studies (a) (90th Percentile)				Proposed Reference Area Performance Standards (d)	Puget Sound Ambient Monitoring Program (b)			
			Reference Areas	Nonreference Areas		Urban Bays (c)		North Budd Inlet Sample		South Budd Inlet Sample	
<u>PAH (ug/kg DB)</u>											
Acenaphthene	65	U		740		670		20	UE	24	UE
Acenaphthylene	53 U - 86			340		390		20	UE	24	UE
Anthracene	84 - 110		36	1400		1300		7	NT	24	UE
Fluorene	58 U - 79		170	970		970		20	UE	24	UE
Naphthalene	180 - 490		94	1500		1600		20	UE	24	UE
Phenanthrene	170 - 340		150	2700		2800		20	UE	14	NT
2-Methylnaphthalene	58 U - 61		21	450		460					
Total LPAH	700 - 1100		160	5300		6200	200	110	L	130	L
Benzo(a)anthracene	58 U - 160		100	2100		5100		10	NT	8	NT
Benzo(a)pyrene	53 U - 150		70	2400		2600		8	NT	7	NT
Benzo(b)fluoranthene	130 - 260										
Benzo(k)fluoranthene	74 - 180										
Total Benzofluoranthene	200 - 420		100	5100		5900		21	NT	20	NT
Benzo(g,h,i)perylene	53 - 68		420	1100		1200		20	UE	24	UE
Chrysene	58 U - 320		67	2700				19	NT	14	NT
Dibenz(a,h)anthracene	65	U		550		540		20	UE	24	UE
Fluoranthene	340 - 620		98	4200		4300		20	E	20	E
Indeno(1,2,3-cd)pyrene	65	U	420	1400		1500		20	UE	24	UE
Pyrene	330 - 540		93	4700				21	T	20	E
Total HPAH	1400 - 2200		420	20100		21000	330	160	L	160	L
Total Carcinogenic PAH	490 - 1200										
Total PAH	2500 - 3200										
<u>CHLORINATED PHENOLS (ug/kg DB)</u>											
2-Chlorophenol	R							20	UE	24	UE
2,4-Dichlorophenol	54	U						60	UE	72	UE
2,4,5-Trichlorophenol	14	U						99	UE	120	UE
2,4,6-Trichlorophenol	14	U						99	UE	120	UE
Tetrachlorophenol	14	U									
Pentachlorophenol	3 - 6.1		0.1	380	(e)	380		99	UE	120	UE
<u>OTHER ORGANICS (ug/kg DB)</u>											
Dibenzofuran	58 - 65			610		560					
<u>DIOXINS (ug/kg TEQ DB)</u>											
2,3,7,8-tetra-CD-Dioxin	0.0012 - 0.0018			0.031		0.031					
<u>FURANS (ug/kg TEQ DB)</u>											
2,3,7,8-tetra-CD-Furan	0.0006 - 0.0009										
<u>METALS (mg/kg DB)</u>											
Antimony	0.13	U	5.86	29.9		36.5					
Arsenic	8.1 - 8.5		17.4	35.1		39.4	22	16	Q	9	Q
Cadmium	1.8 - 2.2		1.57	2.8		3.1	1.5	0.8		1.52	
Chromium	24 - 28		142	120		126	85	32.2		35.6	
Copper	43 - 49		52.9	175		191	53	41.6		53.7	
Lead	17 - 42		27.5	203		232	20	11.9	Q	25.3	Q
Mercury	0.10 - 0.12		0.176	0.74		0.799	0.15	0.15	G	0.17	G
Nickel	20 - 23		66	56.2		54.4	42	28		31	
Silver	0.37 - 0.71		0.38	1.8		1.9	0.32	0.44	E	0.49	
Zinc	70 - 79		99.7	315		359	103	80.6	E	80	E
<u>CONVENTIONALS (%)</u>											
Total Solids	43 - 50							30		25	
Total Organic Carbon	2.4 - 4.3						2.5	2.2		3	

(a) PTI 1991a.
(b) Tetra Tech 1989.
(c) The Urban Bays data set is a subset of the Nonreference Area data set.
(d) PTI 1991b.
(e) This value represents the only reported detection, not a 90th percentile.

TABLE 5
SUMMARY OF EVIDENCE OF NAPL IN SEDIMENT SAMPLES
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Sample Number(a)	Visual Observation(b)	UV Light Observation	Total LPAH(c)	Total HPAH(c)	Number of Constituents with Concentrations Exceeding Aqueous Solubility	Interpretation
Phase I						
CP1-M-A1A	ND(d)	ND	2600	5800	0	No NAPL
CP1-M-A2A	ND	ND	1000	3000	0	No NAPL
CP1-M-A3A	ND	ND	1500	2400	0	No NAPL
CP1-M-A4A	ND	ND	1100	2500	0	No NAPL
CP1-M-B14A	ND	ND	2400	3500	0	No NAPL
CP1-M-B1A	ND	ND	3700	5800	0	Inconclusive
CP1-M-B1B	Spotty Sheen	Solid at Sheen	5200	11000	0	Spotty NAPL
CP1-M-B1C	ND	ND	1200	1300	0	No NAPL
CP1-M-B2A	Light Sheen	ND	5700	21000	0	No NAPL
CP1-M-B2B	Sheen	Spotted	160000	150000	1	Spotty NAPL
CP1-M-B2C	ND	ND	73000	72000	0	NAPL
CP1-M-B3A	ND	ND	3500	6000	0	No NAPL
CP1-M-B3B	Oil	No UV test	970000	810000	4	NAPL
CP1-M-B3C	ND	ND	20000	2500	0	No NAPL
CP1-M-B4A	ND	ND	4200	8500	0	No NAPL
CP1-M-B5A	ND	ND	1500	1900	0	No NAPL
CP1-M-B5B	ND	ND	1500	3100	0	No NAPL
CP1-M-B5C	ND	ND	300	470	0	No NAPL
CP1-M-C12A	ND	ND	13000	17000	0	No NAPL
CP1-M-C12B	Sheen	Banded	66000	86000	1	Spotty NAPL*
CP1-M-C12C	Sheen	Banded	150000	100000	1	Spotty NAPL*
CP1-M-C13A	ND	ND	2300	3000	0	No NAPL
CP1-M-C1A	Oil	Blotches	87000	61000	1	NAPL
CP1-M-C1B	Oil	No UV test	880000	350000	4	NAPL
CP1-M-C1C	Oil	No UV test	660000	280000	3	NAPL
CP1-M-C2A	Sheen	Spotted	6800	18000	0	Spotty NAPL
CP1-M-C2B	Oil	Solid	110000	160000	1	NAPL*
CP1-M-C2C	ND	ND	47000	34000	0	No NAPL
CP1-M-C3A	ND	ND	3000	3600	0	No NAPL
CP1-M-C3B	ND	ND	3400	5100	0	No NAPL
CP1-M-C3C	ND	ND	700	690	0	No NAPL
CP1-M-C4A	ND	ND	2100	2300	0	No NAPL
CP1-M-C4B	ND	ND	540	660	0	No NAPL
CP1-M-C4C	ND	ND	350	520	0	No NAPL
CP1-M-C5A	ND	ND	1200	1400	0	No NAPL
CP1-M-D11A	ND	ND	2000	1100	0	No NAPL
CP1-M-D1A	ND	ND	2400	3200	0	No NAPL
CP1-M-D1B	ND	ND	8000	7400	0	No NAPL
CP1-M-D1C	ND	ND	3600	340	0	No NAPL
CP1-M-D2A	ND	ND	2200	1600	0	No NAPL
CP1-M-D2B	ND	ND	3800	11000	0	No NAPL
CP1-M-D2C	ND	ND	530	410	0	No NAPL
CP1-M-D3A	ND	ND	15000	10000	0	No NAPL
CP1-M-D3B	ND	ND	20000	27000	0	No NAPL
CP1-M-D3C	ND	ND	15000	22000	0	No NAPL
CP1-M-D4A	ND	ND	2200	2600	0	No NAPL
CP1-M-D5A	ND	ND	700	820	0	No NAPL
CP1-M-E1A	ND	ND	540	690	0	No NAPL
CP1-M-E2A	ND	ND	5700	3700	0	No NAPL
CP1-M-E2B	ND	ND	6100	6300	0	No NAPL
CP1-M-E2C	ND	ND	500	250	0	No NAPL
CP1-M-E3A	ND	ND	1600	2600	0	No NAPL
CP1-M-E4A	ND	ND	1100	1700	0	No NAPL
CP1-M-E5A	ND	ND	910	890	0	No NAPL
CP1-M-F1A	ND	ND	2900	7400	0	No NAPL
CP1-M-F2A	ND	ND	1500	1800	0	No NAPL
CP1-M-F2B	ND	ND	260	370	0	No NAPL
CP1-M-F3A	ND	ND	2800	3000	0	No NAPL
CP1-M-F4A	ND	ND	320	450	0	No NAPL
CP1-M-F5A	ND	ND	680	940	0	No NAPL
CP1-M-G14A	ND	ND	2300	12000	0	No NAPL
CP1-M-G1A	ND	ND	630	1800	0	No NAPL
CP1-M-G2A	ND	ND	440	1800	0	No NAPL
CP1-M-G3A	ND	ND	12000	35000	0	No NAPL
CP1-M-G3B	Sheen	Spotted	54000	43000	0	Spotty NAPL
CP1-M-G4A	ND	ND	4000	13000	0	No NAPL
CP1-M-G5A	ND	ND	3400	6300	0	No NAPL
CP1-M-G6A	ND	ND	3500	2400	0	No NAPL
CP1-M-G7A	ND	ND	3200	13000	0	No NAPL

*NAPL appears to be associated with wood debris in the sample.

TABLE 5
SUMMARY OF EVIDENCE OF NAPL IN SEDIMENT SAMPLES
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Sample Number(a)	Visual Observation(b)	UV Light Observation	Total LPAH(c)	Total HPAH(c)	Number of Constituents with Concentrations Exceeding Aqueous Solubility	Interpretation
Phase II						
CP2-M-A2B	ND	ND	1300	3700	0	No NAPL
CP2-M-A2C	ND	ND	2500	8900	0	No NAPL
CP2-M-A2D	ND	ND	18000	30000	0	No NAPL
CP2-M-B6A	Sheen	Spotted	NA(e)	NA	No Data	NAPL
CP2-M-B6B	Sheen	Spotted	NA	NA	No Data	NAPL
CP2-M-C1A	Oil	Spotted and Banded	NA	NA	No Data	NAPL
CP2-M-C1B	Oil	Spotted and Banded	NA	NA	No Data	NAPL
CP2-M-C1BB	Sheen	No UV test	NA	NA	No Data	Inconclusive
CP2-M-C1C	Oil	Spotted and Banded	NA	NA	No Data	NAPL
CP2-M-C1CC	Oil	Spotted and Banded	NA	NA	No Data	NAPL
CP2-M-C1D	Sheen	ND	NA	NA	No Data	Inconclusive
CP2-M-C1PP	ND	ND	170	290	0	No NAPL
CP2-M-C2A	ND	Spotted	NA	NA	No Data	No NAPL
CP2-M-C2B	ND	Spotted	NA	NA	No Data	No NAPL
CP2-M-C2C	Sheen	Spotted	NA	NA	No Data	Inconclusive
CP2-M-C2CC	Sheen	Spotted	NA	NA	No Data	Inconclusive
CP2-M-C2D	ND	Spotted	NA	NA	No Data	No NAPL
CP2-M-C2E	ND	ND	500	1300	0	No NAPL
CP2-M-D13E	ND	ND	290	480	0	No NAPL
CP2-M-D3E	ND	ND	310	520	0	No NAPL
CP2-M-D4B	ND	ND	4500	3900	0	No NAPL
CP2-M-D4D	ND	ND	420	1200	0	No NAPL
CP2-M-E1B	ND	ND	800	1300	0	No NAPL
CP2-M-E1C	ND	ND	760	360	0	No NAPL
CP2-M-E1F	ND	ND	830	390	0	No NAPL
CP2-M-E4B	ND	ND	1700	1900	0	No NAPL
CP2-M-E4C	ND	ND	440	1000	0	No NAPL
CP2-M-E4E	ND	ND	170	330	0	No NAPL
CP2-M-F11B	ND	ND	3500	2300	0	No NAPL
CP2-M-F1A	ND	ND	5900	17000	0	No NAPL
CP2-M-F1B	ND	ND	4500	3400	0	No NAPL
CP2-M-F1C	ND	ND	4400	3200	0	No NAPL
CP2-M-G3B	ND	ND	26000	85000	0	No NAPL
CP2-M-G3C	ND	ND	7900	10000	0	No NAPL
CP2-M-G3E	ND	ND	8200	2300	0	No NAPL
CP2-M-H10A	ND	ND	1800	4400	0	No NAPL
CP2-M-H12B	ND	ND	7800	13000	0	No NAPL
CP2-M-H1A	ND	ND	3700	6200	0	No NAPL
CP2-M-H1B	ND	ND	2300	4000	0	No NAPL
CP2-M-H1C	ND	ND	340	700	0	No NAPL
CP2-M-H1E	ND	ND	260	390	0	No NAPL
CP2-M-H2A	ND	ND	9300	14000	0	No NAPL
CP2-M-H2B	ND	ND	7400	12000	0	No NAPL
CP2-M-H2C	ND	ND	580	840	0	No NAPL
CP2-M-H2D	ND	ND	320	1100	0	No NAPL
CP2-M-H2M	ND	ND	270	540	0	No NAPL
CP2-M-H3A	ND	ND	1800	3600	0	No NAPL
CP2-M-H3B	ND	ND	1700	2400	0	No NAPL
CP2-M-H3L	ND	Wood Chunk(f)	300	430	0	No NAPL
CP2-M-H5A	ND	ND	2000	2100	0	No NAPL
CP2-M-H5B	ND	ND	2600	3000	0	No NAPL
CP2-M-H6A	ND	ND	4800	4700	0	No NAPL
CP2-M-H6B	ND	ND	5400	4000	0	No NAPL
CP2-M-H6C	ND	ND	230	320	0	No NAPL
CP2-M-H6E	ND	ND	250	430	0	No NAPL
CP2-M-H7A	ND	ND	9600	7200	0	No NAPL
CP2-M-H7B	ND	ND	660	830	0	No NAPL
CP2-M-H7C	ND	ND	500	720	0	No NAPL
CP2-M-H8A	ND	ND	1300	400	0	No NAPL
CP2-M-H8B	ND	ND	450	670	0	No NAPL
CP2-M-H8C	ND	ND	430	570	0	No NAPL
CP2-M-H8E	ND	ND	210	320	0	No NAPL
CP2-M-H9A	ND	ND	NA	NA	No Data	No NAPL
CP2-M-H9B	Oil	Spotted and Banded	NA	NA	No Data	NAPL
CP2-M-H9BB	Sheen	Spotted and Banded	NA	NA	No Data	NAPL
CP2-M-H9C	ND	Spotted and Banded	NA	NA	No Data	Inconclusive
CP2-M-H9CC	Sheen	Spotted and Banded	520000	240000	5	NAPL
CP2-M-H9D	ND	Spotted and Banded	NA	NA	No Data	Inconclusive
CP2-M-H9E	ND	ND	NA	NA	No Data	Inconclusive
CP2-M-H9F	ND	ND	4500	2000	0	No NAPL
CP2-M-H11A	Sheen	ND	NA	NA	No Data	Inconclusive
CP2-M-H11B	Sheen	Slightly spotted	NA	NA	No Data	Inconclusive

(a) Samples listed include only those samples with visible NAPL and /or samples with detected concentrations of PAH.

(b) Yellow and /or milky white discoloration of the sediment ocurred as spots, bands, or blotches under ultraviolet light or as a solid overall discoloration.

(c) ug/kg DB; nondetected compounds are included in the sum at the detection limit.

(d) ND = Not detected.

(e) NA = Not analyzed.

(f) White discoloration to wood chunk under ultraviolet light.

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TABLE 6
SPEARMAN'S RANK CORRELATION COEFFICIENTS
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

		LPAH	HPAH	PCP	DBF	OCDD_F	PCDD_F	PCDDTEQ	TOC	Cd	Cr	Cu	Pb	Hg	Zn
LPAH	Coefficient	1.00	0.9253	0.534	0.844	0.6203	0.6374	0.6459	0.4152	-0.0554	0.0169	0.3655	0.1927	0.4821	0.1261
	Sample size	136	136	136	136	136	136	136	136	136	136	136	136	136	136
	Sig. level	1.00	0	0	0	0.0016	0.0012	0.001	0	0.743	0.9203	0.0306	0.2543	0.0043	0.4557
HPAH	Coefficient	0.9253	1.00	0.6072	0.7963	0.721	0.7399	0.754	0.5035	0.0012	0.1132	0.3875	0.2756	0.5884	0.2416
	Sample size	136	136	136	136	136	136	136	136	136	136	136	136	136	136
	Sig. level	0	1.00	0	0	0.0002	0.0002	0.0001	0	0.9945	0.5031	0.0219	0.103	0.0005	0.1529
PCP	Coefficient	0.534	0.6072	1.00	0.4812	0.9061	0.8951	0.8938	0.4974	0.0485	0.026	0.0459	0.3753	0.7276	0.2984
	Sample size	136	136	136	136	136	136	136	136	136	136	136	136	136	136
	Sig. level	0	0	1.00	0	0	0	0	0	0.7739	0.878	0.7862	0.0264	0	0.0775
DBF	Coefficient	0.844	0.7963	0.4812	1.00	0.4971	0.5197	0.5118	0.416	0.1416	0.0232	0.4381	0.2807	0.3972	0.173
	Sample size	136	136	136	115	115	115	115	115	115	115	115	115	115	115
	Sig. level	0	0	0	1.00	0.0113	0.0081	0.0091	0	0.4537	0.9021	0.0204	0.1374	0.0356	0.3599
OCDD_F	Coefficient	0.6203	0.721	0.9061	0.4971	1.00	0.9962	0.977	0.5102	0.3366	0.1808	0.2967	0.5495	0.7403	0.4759
	Sample size	136	136	136	115	28	28	28	28	28	28	28	28	28	28
	Sig. level	0.0016	0.0002	0	0.0113	1.00	0	0	0.0093	0.2437	0.5311	0.304	0.057	0.0103	0.0992
PCDD_F	Coefficient	0.6374	0.7399	0.8951	0.5197	0.9962	1.00	0.9869	0.5517	0.3366	0.1808	0.2967	0.5495	0.7403	0.4759
	Sample size	136	136	136	115	28	28	28	28	28	28	28	28	28	28
	Sig. level	0.0012	0.0002	0	0.0081	0	1.00	0	0.0049	0.2437	0.5311	0.304	0.057	0.0103	0.0992
PCDDTEQ	Coefficient	0.6459	0.754	0.8938	0.5118	0.977	0.9869	1.00	0.6271	0.3448	0.2086	0.2912	0.5549	0.7348	0.4704
	Sample size	136	136	136	115	28	28	28	28	28	28	28	28	28	28
	Sig. level	0.001	0.0001	0	0.0091	0	0	1.00	0.0014	0.2323	0.4698	0.3131	0.0546	0.0109	0.1032
TOC	Coefficient	0.4152	0.5035	0.4974	0.416	0.5102	0.5517	0.6271	1.00	0.3885	0.3512	0.3852	0.3741	0.6841	0.3742
	Sample size	136	136	136	115	28	28	28	134	134	134	134	134	134	134
	Sig. level	0	0	0	0	0.0093	0.0049	0.0014	1.00	0.0215	0.0377	0.0227	0.0269	0.0001	0.0268
Cd	Coefficient	-0.0554	0.0012	0.0485	0.1416	0.3366	0.3366	0.3448	0.3885	1.00	0.8013	0.6316	0.7661	0.4632	0.8393
	Sample size	136	136	136	115	28	28	28	134	36	36	36	36	36	36
	Sig. level	0.743	0.9945	0.7739	0.4537	0.2437	0.2437	0.2323	0.0215	1.00	0	0.0002	0	0.0061	0
Cr	Coefficient	0.0169	0.1132	0.026	0.0232	0.1808	0.1808	0.2086	0.3512	0.8013	1.00	0.6854	0.6078	0.2719	0.7931
	Sample size	136	136	136	115	28	28	28	134	36	36	36	36	36	36
	Sig. level	0.9203	0.5031	0.878	0.9021	0.5311	0.5311	0.4698	0.0377	0	1.00	0.0001	0.0003	0.1077	0
Cu	Coefficient	0.3655	0.3875	0.0459	0.4381	0.2967	0.2967	0.2912	0.3852	0.6316	0.6854	1.00	0.6275	0.2619	0.6882
	Sample size	136	136	136	115	28	28	28	134	36	36	36	36	36	36
	Sig. level	0.0306	0.0219	0.7862	0.0204	0.304	0.304	0.3131	0.0227	0.0002	0.0001	1.00	0.0002	0.1213	0
Pb	Coefficient	0.1927	0.2756	0.3753	0.2807	0.5495	0.5495	0.5549	0.3741	0.7661	0.6078	0.6275	1.00	0.6555	0.9044
	Sample size	136	136	136	115	28	28	28	134	36	36	36	36	36	36
	Sig. level	0.2543	0.103	0.0264	0.1374	0.057	0.057	0.0546	0.0269	0	0.0003	0.0002	1.00	0.0001	0
Hg	Coefficient	0.4821	0.5884	0.7276	0.3972	0.7403	0.7403	0.7348	0.6841	0.4632	0.2719	0.2619	0.6555	1.00	0.5428
	Sample size	136	136	136	115	28	28	28	134	36	36	36	36	36	36
	Sig. level	0.0043	0.0005	0	0.0356	0.0103	0.0103	0.0109	0.0001	0.0061	0.1077	0.1213	0.0001	1.00	0.0013
Zn	Coefficient	0.1261	0.2416	0.2984	0.173	0.4759	0.4759	0.4704	0.3742	0.8393	0.7931	0.6882	0.9044	0.5428	1.00
	Sample size	136	136	136	115	28	28	28	134	36	36	36	36	36	36
	Sig. level	0.4557	0.1529	0.0775	0.3599	0.0992	0.0992	0.1032	0.0268	0	0	0	0	0.0013	1.00

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TABLE 7

COMPARISON OF CASCADE POLE SITE SEDIMENT DATA WITH THAT FROM OTHER BUDD INLET STUDIES
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

	CPC Site Sediments (0-4 ft)		EPA Reconnaissance Survey Budd Inlet(b) (12 Samples)	LOTT Urban(a) Area Wastewater Management Plan		One Tree Island Marina(c) (2 Samples)	Olympia Harbor Navigation Improvement Project(d) (12 Samples)	Puget Sound Ambient Monitoring Program (2 Samples)(e)
				Outfall Site (3 Samples)	Fiddlehead Site (2 Samples)			
	Average	Maximum	(Range)	(Range)	(Range)	(Range)	(Range)	(Range)
Total LPAH (µg/kg)	5,500(f)	970,000(f)	220-480(f)	99-100(f)	170-1,100(f)	1,100-43,000(g)	58-500(f)	110L-130L(h)
Total HPAH (µg/kg)	2,700(f)	810,000(f)	380-2,000(f)	130-150(f)	410-2,600(f)	5,400-160,000(g)	49-1,100(f)	160L-160L
PCP (µg/kg)	20	240	70 U-150 U(i)	30 U-40 U	34 U-41 U	Not sampled	2 U-32	99UE-120UE(j)
Metals (mg/kg)								
Antimony	0.4	0.5	0.39 U-1.3U	0.46 U-0.48 U	0.49 U-0.50 U	Not sampled	0.006-0.32	
Arsenic	6	13	7.6-16	8.1-12.3	19.8-25.1	37-160	3.72-10	9Q-16Q(k)
Cadmium	2	12	0.59-1.6	0.48-1.2	1.6-1.7	9.4-250	1.22-2.58	0.8-1.52
Chromium	44	350	51-61	Not sampled	Not sampled	50-174	35.3-95.6	32.3-35.6
Copper	86	410	40-69	11.8-26.7	52.2-64.9	270-2,990	17.1-103	41.6-53.7
Lead	16	67	17-78	3.5-13.5	14-15.5	129-1,015	2.3-33.5	11.9Q-25.3Q
Mercury	0.105	0.38	0.11-0.37	0.05 U-0.06 U	0.08 U-0.10 U	0.032-0.065	0.016 U-0.37	0.15G-0.17G(l)
Nickel	25	33	25-33	17-26	35-38	Not sampled	17.5-39.9	28-31
Silver	1	1.05	0.45-1.4	0.096-0.154	0.25-0.90	Not sampled	0.084-0.68	0.44E-0.49(m)
Zinc	91	580	78-114	28.4-45.3	83.2-107	275-1,525	40-129	80E-80.6E

(a) Concentrations expressed on a dry weight basis; samples homogenized over depth. Sampled using piston sampler or gravity corer (LOTT 1989).

(b) Concentrations expressed on a dry weight basis; 12 locations sampled in Budd Inlet. Top 2 cm sampled using a 0.1-m^2 vanVeen bottom grab sampler. Samples homogenized prior to analysis (PTI 1991c).

(c) Two 4-ft core samples taken by diver (Benlab 1985).

(d) Concentrations expressed on a dry weight basis; composite samples collected using a vibracore sampler from 0 to 4 ft.

(e) Concentrations expressed on a dry weight basis; samples from #48 and #49, in north and south Budd Inlet, respectively (TetraTech 1989).

(f) Concentrations expressed on a dry weight basis; nondetected PAH values assumed to be at detection limit for purposes of summing total LPAH and HPAH values.

(g) Nondetected PAH values assumed to be zero for purposes of summing total LPAH and HPAH values.

(h) L = value is less than the maximum shown.

(i) 70 U = not detected. Detection limit = 70.

(j) UE = not detected at the estimated detection limit shown.

(k) Q = questionable value.

(l) G = estimated value is greater than value shown.

(m) E = estimate.

TABLE 8
EXCEEDANCES OF SEDIMENT MANAGEMENT STANDARDS
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Analytes	Sediment Quality Standard		Cleanup Screening Level		CP2-M-A2D 07/25/1991 100 to 150 cm	CP1-M-A3A 12/06/1990 Surface to 10 cm	CP1-M-B1A 12/12/1990 Surface to 10 cm	CP1-M-B1B 12/12/1990 10 to 55 cm	CP1-M-B2A 12/10/1990 Surface to 10 cm	CP1-M-B2B 12/10/1990 10 to 55 cm	CP1-M-B2C 12/10/1990 55 to 100 cm	CP1-M-B3B 12/11/1990 10 to 55 cm
PAH (mg/kg organic carbon DB)												
Acenaphthene	16		57		170		29	39		480	400	2100
Acenaphthylene	66		66									300
Anthracene	220		1200							280	320	5100
Fluorene	23		79		75					320	290	2600
Naphthalene	99		170		120						290	3900
Phenanthrene	100		480		120					540	720	4900
2-Methylnaphthalene	38		64								63	1800
Total LPAH	370	(c)	780	(c)	550					1700	2000	19000
Benzo(a)anthracene	110		270							190	240	2400
Benzo(a)pyrene	99		210								170	770
Total Benzofluoranthenes	230		450								340	1500
Benzo(g,h,i)perylene	31		78								57	280
Chrysene	110		460							170	230	1600
Dibenz(a,h)anthracene	12		33									21
Fluoranthene	160		1200		220				250	570	950	7500
Indeno(1,2,3-cd)pyrene	34		88								57	280
Pyrene	1000		1400									3000
Total HPAH	960	(d)	5300	(d)						1600	2100	17000
Furans (mg/kg organic carbon DB)												
Dibenzofuran	15		58		47	84				170	190	2100
METALS (mg/kg DB)												
Arsenic	57		93									
Cadmium	5.1		6.7									
Chromium	260		270									
Copper	390		390									
Lead	450		530									
Mercury	0.41		0.59									
Silver	6.1		6.1									
Zinc	410		960									

TABLE 8
EXCEEDANCES OF SEDIMENT MANAGEMENT STANDARDS
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Analytes	Sediment Quality Standard	Cleanup Screening Level	CP1-M-B3C 12/11/1990 55 to 100 cm	CP1-M-C1A 12/13/1990 Surface to 10 cm	CP1-M-C1B 12/13/1990 10 to 55 cm	CP1-M-C1C 12/13/1990 55 to 100 cm	CP1-M-C2A 12/13/1990 Surface to 10 cm	CP1-M-C2B 12/13/1990 10 to 55 cm	CP1-M-C2C 12/13/1990 55 to 100 cm	CP2-M-C3A 12/12/1990 Surface to 10 cm
<u>PAH (mg/kg organic carbon DB)</u>										
Acenaphthene	16	57	79	310 J(e)	2400 J	1600 J	26 J	440 J	140 J	17
Acenaphthylene	66	66								
Anthracene	220	1200			960 J	660 J		320 J		
Fluorene	23	79	50	260 J	1600 J	980 J		220 J	130 J	
Naphthalene	99	170	200	290 J	3000 J	2800 J		160 J	340 J	
Phenanthrene	100	480		840 J	3700 J	2200 J		170 J	390 J	
2-Methylnaphthalene	38	64	55	160 J	2400 J	1400 J			110 J	
Total LPAH	370 (c)	780 (c)	430	1900	12000	8300		1300	1100	
Benzo(a)anthracene	110	270		170 J	540 J	350 J		210 J	120 J	
Benzo(a)pyrene	99	210			200 J	140 J				
Total Benzofluoranthenes	230	450			480	320				
Benzo(g,h,i)perylene	31	78			59 J	45 J		35 J		
Chrysene	110	460		110 J	380 J	290 J		170 J		
Dibenz(a,h)anthracene	12	33			16 J	13 J				
Fluoranthene	160	1200		570 J	2400 J	1800 J	190 J	670 J	310 J	
Indeno(1,2,3-cd)pyrene	34	88			62 J	45 J				
Pyrene	1000	1400			1500 J	1100 J				
Total HPAH	960 (d)	5300 (d)		1400	5600	4100		1900		
Furans (mg/kg organic carbon DB)										
Dibenzofuran	15	58	50	160	1300	730		70	84	
METALS (mg/kg DB)										
Arsenic	57	93								
<u>Cadmium</u>	5.1	6.7								
Chromium	260	270								
Copper	390	390								
Lead	450	530								
Mercury	0.41	0.59								
Silver	6.1	6.1								
Zinc	410	960								

TABLE 8
EXCEEDANCES OF SEDIMENT MANAGEMENT STANDARDS
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Analytes	Sediment Quality Standard	Cleanup Screening Level	CP1-M-C3B 12/12/1990 10 to 55 cm	CP1-M-C12A 12/13/1990 Duplicate of C2A	CP1-M-C12B 12/13/1990 Duplicate of C2B	CP1-M-C12C 12/13/1990 Duplicate of C2C	CP1-M-D1B 12/12/1990 10 to 55 cm	CP1-M-D1C 12/12/1990 55 to 100 cm	CP1-M-D3A 12/11/1990 Surface to 10 cm	CP1-M-D3B 12/11/1990 10 to 55 cm
PAH (mg/kg organic carbon DB)										
Acenaphthene	16	57	25	61 J	220 J	740 J	130	91	38	32
Acenaphthylene	66	66								
Anthracene	220	1200				700 J	250			
Fluorene	23	79		47 J	120 J	740 J	70	35	61	26
Naphthalene	99	170			100 J	1400 J	300 B		160	
Phenanthrene	100	480		170 J	230 J	2500 J			370	
2-Methylnaphthalene	38	64				170 J			76	
Total LPAH	370 (c)	780 (c)		380	810	6100	850	480	670	
Benzo(a)anthracene	110	270			140 J	400 J				
Benzo(a)pyrene	99	210				200 J				
Total Benzofluoranthenes	230	450				370				
Benzo(g,h,i)perylene	31	78				82 J				
Chrysene	110	460				330 J				
Dibenz(a,h)anthracene	12	33				27 J				
Fluoranthene	160	1200		180 J	370 J	1700 J	350		210	
Indeno(1,2,3-cd)pyrene	34	88				74 J				
Pyrene	1000	1400								
Total HPAH	960 (d)	5300 (d)			1100	4200				
Furans (mg/kg organic carbon DB)										
Dibenzofuran	15	58		29	63	450	71	47	86	
METALS (mg/kg DB)										
Arsenic	57	93								
Cadmium	5.1	6.7								
Chromium	260	270								
Copper	390	390								
Lead	450	530								
Mercury	0.41	0.59			0.43					
Silver	6.1	6.1								
Zinc	410	960								

TABLE 8
EXCEEDANCES OF SEDIMENT MANAGEMENT STANDARDS
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Analytes	Sediment Quality Standard		Cleanup Screening Level		CP1-M-D3C 12/11/1990 55 to 100 cm	CP2-M-D4B 07/26/1991 10 to 70 cm	CP2-M-E1C 07/31/1991 61 to 100 cm	CP1-M-E2A 12/11/1990 Surface to 10 cm	CP1-M-E2B 12/11/1990 10 to 55 cm	CP2-M-F1B 08/01/1991 10 to 51 cm	CP2-M-F1C 08/01/1991 55 to 100 cm	CP2-M-F11B 08/01/1991 Duplicate of F1B
PAH (mg/kg organic carbon DB)												
Acenaphthene	16		57		120	18	18		55	230	96	
Acenaphthylene	66		66									
Anthracene	220		1200									
Fluorene	23		79		100				54	140	86	
Naphthalene	99		170		220		200	110	310	690	110	
Phenanthrene	100		480		290				120	180	180	
2-Methylnaphthalene	38		64									
Total LPAH	370	(c)	780	(c)	850				630	1300	510	
Benzo(a)anthracene	110		270		140							
Benzo(a)pyrene	99		210									
Total Benzofluoranthenes	230		450									
Benzo(g,h,i)perylene	31		78									
Chrysene	110		460		160							
Dibenz(a,h)anthracene	12		33									
Fluoranthene	160		1200		460				230	420		
Indeno(1,2,3-cd)pyrene	34		88									
Pyrene	1000		1400									
Total HPAH	960	(d)	5300	(d)	1400					1000		
Furans (mg/kg organic carbon DB)												
Dibenzofuran	15		58		67				31	110	76	
METALS (mg/kg DB)												
Arsenic	57		93									
Cadmium	5.1		6.7									
Chromium	260		270									
Copper	390		390									
Lead	450		530									
Mercury	0.41		0.59									
Silver	6.1		6.1									
Zinc	410		960									

TABLE 8
EXCEEDANCES OF SEDIMENT MANAGEMENT STANDARDS
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Analytes	Sediment Quality Standard	Cleanup Screening Level	CP1-M-G3A 12/10/1990 Surface to 10 cm	CP1-M-G3B 12/10/1990 10 to 55 cm	CP2-M-G3B 07/25/1991 10 to 55 cm	CP2-M-G3C 07/25/1991 55 to 100 cm	CP2-M-G3E 07/25/1991 150 to 200 cm	CP1-M-G6A Surface to 10 cm	CP1-M-G7A Surface to 10 cm	CP2-M-H2A 07/23/1991 Surface to 10 cm
PAH (mg/kg organic carbon DB)										
Acenaphthene	16	57	140	490	150	65	67	17	24	36
Acenaphthylene	66	66								
Anthracene	220	1200		250						
Fluorene	23	79		300	67	29	45			24
Naphthalene	99	170		130		120				110
Phenanthrene	100	480		670						
2-Methylnaphthalene	38	64								
Total LPAH	370 (c)	780 (c)		1900	420					
Benzo(a)anthracene	110	270		210	140					
Benzo(a)pyrene	99	210								
Total Benzofluoranthenes	230	450							330	
Benzo(g,h,i)perylene	31	78								
Chrysene	110	460		210	140					
Dibenz(a,h)anthracene	12	33								
Fluoranthene	160	1200	340	740						
Indeno(1,2,3-cd)pyrene	34	88								
Pyrene	1000	1400								
Total HPAH	960 (d)	5300 (d)		1500	1400					
Furans (mg/kg organic carbon DB)										
Dibenzofuran	15	58	24	160	42	19	27		17	
METALS (mg/kg DB)										
Arsenic	57	93								
Cadmium	5.1	6.7								
Chromium	260	270								
Copper	390	390								
Lead	450	530								
Mercury	0.41	0.59								
Silver	6.1	6.1								
Zinc	410	960								

TABLE 8
EXCEEDANCES OF SEDIMENT MANAGEMENT STANDARDS
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Analytes	Sediment Quality Standard	Cleanup Screening Level	CP2-M-H2B 07/23/1991 10 to 55 cm	CP2-M-H2D 07/23/1991 100 to 150 cm	CP2-M-H6A 07/29/1991 Surface to 10 cm	CP2-M-H6B 07/29/1991 10 to 55 cm	CP2-M-H7A 08/12/1991 Surface to 10 cm	CP2-M-H9CC 07/25/1991 84 to 100 cm	CP2-M-H9F 07/25/1991 200 to 250 cm	CP2-M-H12B 07/23/1991 Duplicate of H2B
<u>PAH (mg/kg organic carbon DB)</u>										
Acenaphthene	16	57	36		34	40	31	7400 D	26	44
Acenaphthylene	66	66								
Anthracene	220	1200						1500		
Fluorene	23	79			24	25	26	7000 D		28
Naphthalene	99	170			130	180	100	12000 D		120
Phenanthrene	100	480						12000 D		
2-Methylnaphthalene	38	64						2700		
Total LPAH	370 (c)	780 (c)						40000		
Benzo(a)anthracene	110	270						1900		
Benzo(a)pyrene	99	210						780		
Total Benzofluoranthenes	230	450						1700		
Benzo(g,h,i)perylene	31	78						200		
Chrysene	110	460						1500		
Dibenz(a,h)anthracene	12	33						79		
Fluoranthene	160	1200						8300 D		
Indeno(1,2,3-cd)pyrene	34	88						220		
Pyrene	1000	1400						5500 D		
Total HPAH	960 (d)	5300 (d)						20000		
Furans (mg/kg organic carbon DB)										
Dibenzofuran	15	58					20			
METALS (mg/kg DB)										
Arsenic	57	93								
<u>Cadmium</u>	5.1	6.7		12						
Chromium	260	270		350						
Copper	390	390		410 ,J						
Lead	450	530								
Mercury	0.41	0.59								
Silver	6.1	6.1								
Zinc	410	960		580						

(a) All results listed on this table exceed Sediment Quality Standards (WAC 173-204-320).
(b) Shaded results also exceed Cleanup Screening Levels (WAC 173-204-520).
(c) The Total LPAH criterion represents the sum of the following "low molecular weight PAH" compounds: naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene. The LPAH criterion is not the sum of the criteria values for the individual LPAH compounds as listed.
(d) The Total HPAH criterion represents the sum of the following "high molecular weight PAH" compounds: fluoranthene, pyrene, benzo(a)anthracene, chrysene, total benzofluoranthenes, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene. The HPAH criterion is not the sum of the criteria values for the individual HPAH compounds as listed.
(e) Data qualifiers are explained in detail in Appendix D, and summarized in Table C-1.

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TABLE 9
EXCEEDANCES OF SURFACE WATER QUALITY CRITERIA (a)
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Constituent	Fish Consumption Only Criterion (µg/L)	Sample CP2-WP-H12 8/124/91 Drainage Channel (ug/L)
Benzo(a)anthracene	0.031	0.89
Benzo(a)pyrene	0.031	0.42
Benzo(b)fluoranthene	0.031	0.49
Benzo(k)fluoranthene	0.031	0.31
Chrysene	0.031	0.96
Indeno(1,2,3-c,d)pyrene	0.031	0.21

(a) 40 CFR 131 as revised by 57FR60848 (final rule effective February 5, 1993) and WAC 173-201A.

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TABLE 10

RESULTS OF SEDIMENT BIOASSAY TESTS
AND COMPARISON TO SEDIMENT MANAGEMENT STANDARDS
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

		Bioassay Tests		
		Amphipod (Mean Survivorship ±Standard Deviation)	Echinoderm Larvae (Survivorship of Normal Larvae)	Microtox (Decrease in Luminescence)
<u>Test Sediment Bioassay Results</u>				
Station C3	Onsite Sediment	20 ±0 [passes SQS and CSL]	63.7% of control 56 % of reference [fails SQS and CSL]	None [passes SQS and CSL]
Station D3	Onsite Sediment	17.6 ±1.5 [passes SQS and CSL]	88.4% of control 77.8% of reference [fails SQS; passes CSL]	None [passes SQS and CSL]
Station EI1	Reference Sediment	19 ±0.7	–	None [passes SQS and CSL]
Control	–	20 ±0	–	–
<u>Sediment Management Standards</u>				
<u>Sediment Quality Standards (SQS)</u> Sediments are determined to have adverse effects on biological resources when any one of the biological tests demonstrate the following:		The test sediment has a higher (statistically significant, t test, $p \leq 0.05$) mean mortality than the reference sediment and the test sediment mean mortality exceeds 25 percent, on an absolute basis.	The test sediment has a mean survivorship of normal larvae that is less (statistically significant, t test, $p \leq 0.05$) than the mean normal survivorship in the reference sediment and the test sediment mean normal survivorship is less than 85 percent of the mean normal survivorship in the reference sediment (i.e., the test sediment has a mean combined abnormality and mortality that is greater than 15 percent relative to time-final in the reference sediment).	The mean light output of the highest concentration of the test sediment is less than 80 percent of the mean light output of the reference sediment, and the two means are statistically different from each other (t test, $p \leq 0.05$).
<u>Cleanup Screening Levels (CSL)</u> The CSL is exceeded when any two of the biological tests exceed the SQS criteria, or one of the following test determinations is made:		The test sediment has a higher (statistically significant, t test, $p \leq 0.05$) mean mortality than the reference sediment and the test sediment mean mortality is more than 30 percent higher than the reference sediment mean mortality, on an absolute basis.	The test sediment has a mean survivorship of normal larvae that is less (statistically significant, t test, $p \leq 0.05$) than the mean normal survivorship in the reference sediment and the test sediment mean normal survivorship is less than 70 percent of the mean normal survivorship in the reference sediment (i.e., the test sediment has a mean combined abnormality and mortality that is greater than 30 percent relative to time-final in the reference sediment).	No criteria.

TABLE 11

HPAH RATIOS OF OFFSITE SEDIMENT SAMPLES
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Sample Designation	Fluoranthene	Pyrene	Benzo(a) anthracene	Chrysene	Benzo(b and k) fluoranthene	Benzo(a) pyrene
DNAPL-EW-3(a)	1	0.63	0.20	0.19	0.16	0.09
DNAPL-EW-5(a)	1	0.60	0.19	0.18	0.16	0.08
LNAPL-EW-1(a)	1	0.74	0.15	0.12	0.07	0.05
Gasoline A(b)	1	1.11	0.56	0.32	0.00	0.26
Gasoline B(b)	1	0.51	0.55	0.24	0.00	0.30
Gasoline C(b)	1	2.50	0.00	0.00	0.00	0.50
Gasoline D(b)	1	1.59	0.17	0.17	0.00	0.17
Kerosene(b)	1	1.78	0.00	0.00	0.00	0.00
Diesel Fuel(b)	1	0.65	0.23	0.79	0.00	0.12
No. 2 Oil A(b)	1	0.00	0.06	1.06	0.00	0.09
No. 2 Oil B(b)	1	0.94	0.01	0.16	0.00	0.00
No. 2 Oil D(b)	1	0.13	0.01	0.23	0.00	0.00
Sed. 10 m from Drill Plt.(c)	1	1.86	0.72	1.14	0.62	0.45
Sed. 25 m from Drill Plt.(c)	1	0.90	1.20	0.59	1.25	0.48
Oil Spill(d)	1	0.88	1.00	0.06	0.00	0.00
Fuel Oil(d)	1	0.20	0.00	0.00	0.00	0.00
Offshore Coastal WA Sediments(e)	1	1.07	0.48	0.70	1.04	0.51
Duwamish Sediments(f)	1	0.71	0.26	0.54	0.58	0.25
Denny Way Combined Sewer Outfall(g)	1	1.14	0.71	1.36	3.21	1.07
Phase II Budd Inlet Background						
CP2-M-BI1	1.000	0.885	0.134	0.262	0.623	–
CP2-M-BI11 (duplicate of BI1)	1.000	0.839	0.258	0.306	0.629	0.242
CP2-M-BI2	1.000	0.971	0.412	0.941	1.235	0.441

(a) ESE 1992a.
(b) Gelboin and Ts'o 1978.
(c) Brooks et al. 1990.
(d) Merrill and Wade 1985.
(e) Prahl and Carpenter 1984.
(f) Tetra Tech 1988b,c.
(g) Stuart et al. 1988.

TABLE 12
HPAH RATIOS OF ONSITE SEDIMENT SAMPLES
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Sample No.	Fluoranthene	Pyrene	Benzo(a) anthracene	Chrysene	Benzo(b and k) fluroanthene	Benzo(a) pyrene
Type 1						
CP1-M-C2B	1	0.714	0.321	0.250	0.298	0.114
CP1-M-B1B	1	0.711	0.198	0.191	0.156	0.069
CP1-M-B2B	1	0.679	0.340	0.302	0.287	0.142
CP1-M-C1A	1	0.667	0.292	0.196	0.2	0.096
CP2-M-H9CC	1	0.66	0.23	0.18	0.202	0.094
CP1-M-C1C	1	0.642	0.2	0.167	0.18	0.079
CP1-M-C1B	1	0.62	0.227	0.16	0.202	0.087
CP1-M-D1B	1	0.581	0.203	0.245	0.206	0.081
CP1-M-B3B	1	0.4	0.314	0.22	0.194	0.103
CP1-M-C2C[(a)]	1	0.647	0.310	0.228	0.238	0.122
Type 1 Average	1	0.632	0.263	0.214	0.216	0.099
Type 2						
CP1-M-B1A	1	0.944	0.261	0.367	0.356	0.144
CP1-M-C2A[(a)]	1	0.806	0.258	0.242	0.322	0.134
CP1-M-G4A[(a)]	1	0.700	0.233	0.255	0.316	0.132
CP1-M-B2A	1	0.773	0.288	0.409	0.5	0.135
CP1-M-C12B	1	0.759	0.379	0.203	0.314	0.162
CP2-M-H7A	1	0.750	0.217	0.383	0.338	0.146
CP2-M-G3C	1	0.737	0.213	0.221	0.363	0.087
CP1-M-D3A	1	0.732	0.098	0.293	0.271	0.061
CP1-M-D1A	1	0.7	0.236	0.291	0.391	0.136
CP1-M-G3A	1	0.692	0.254	0.315	0.216	0.1
CP1-M-D3B	1	0.677	0.188	0.250	0.375	0.167
CP1-M-E2B	1	0.667	0.219	0.371	0.390	0.148
CP1-M-D3C	1	0.632	0.316	0.342	0.364	0.145
CP2-M-F1B[(a)]	1	0.590	0.169	0.191	0.394	0.068
CP1-M-E3A	1	0.738	0.250	0.388	0.475	0.150
CP1-M-B3C	1	0.509	0.136	0.118	0.327	0.072
CP1-M-F2A	1	0.827	0.146	0.250	0.865	0.138
CP1-M-G1A	1	0.807	0.263	0.246	0.447	0.175
CP1-M-D2A	1	0.902	0.196	0.175	0.429	0.159
CP1-M-B1C	1	0.721	0.256	0.279	0.326	0.167
CP2-M-E4C	1	0.889	0.319	0.341	0.544	0.222
CP2-M-H7B	1	0.679	0.2	0.282	0.389	0.15
CP1-M-E1A	1	0.857	0.219	0.210	0.438	0.171
Type 2 Average	1	0.743	0.231	0.279	0.398	0.138

TABLE 12
HPAH RATIOS OF ONSITE SEDIMENT SAMPLES
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Sample No.	Fluoranthene	Pyrene	Benzo(a) anthracene	Chrysene	Benzo(b and k) fluroanthene	Benzo(a) pyrene
Type 3						
CP1-M-F1A	1	1.212	0.333	0.576	3.202	0.444
CP2-M-A2C	1	5.455	1.382	3.273	2.764	1.400
CP1-M-B3A	1	1.149	0.391	0.701	2.678	0.368
CP1-M-G7A	1	1.263	0.632	0.789	2.526	0.489
CP2-M-F1A	1	1.391	0.522	0.609	2.478	0.565
CP1-M-B5B	1	2.185	1.630	2.481	2.148	1.111
CP2-M-H3A	1	2.195	0.854	1.439	1.805	0.829
CP2-M-H1B	1	3.864	0.455	0.705	1.727	0.705
CP1-M-A2A	1	3.939	0.455	0.909	1.515	0.667
CP2-M-H1A	1	2.597	0.532	1.299	1.455	0.571
CP2-M-F1C	1	1.154	0.218	0.244	1.192	0.167
CP1-M-B14A	1	2.586	0.224	0.379	1.034	0.362
CP2-M-A2B	1	2.456	0.404	0.895	1.018	0.368
CP2-M-H2B	1	2.722	0.317	0.489	1	0.433
CP2-M-H8A	1	1.064	0.287	0.596	0.936	0.181
CP1-M-C3A[(a)]	1	1.257	0.322	0.425	0.720	0.295
CP2-M-H10A	1	1.327	0.347	0.469	0.847	0.245
CP2-M-H2A	1	1.552	0.345	0.655	0.700	0.310
CP2-M-H5B	1	2.281	0.298	0.491	0.719	0.263
CP2-M-D4B	1	1.573	0.270	0.404	0.640	0.236
CP1-M-E2A	1	1.000	0.220	0.350	0.600	0.210
CP1-M-D2B	1	1.241	0.414	0.345	0.572	0.224
CP1-M-G5A	1	1.000	0.300	0.471	0.553	0.176
CP1-M-C3B	1	1.071	0.243	0.407	0.529	0.193
CP2-M-A2D	1	1.408	0.451	0.479	0.479	0.239
CP1-M-A1A	1	1.250	0.175	0.444	0.450	0.181
CP2-M-H6A	1	1.000	0.193	0.253	0.433	0.140
CP2-M-H6B	1	1.250	0.175	0.250	0.425	0.150
CP1-M-D4A	1	1.145	0.188	0.493	0.565	0.174
CP1-M-A4A	1	1.577	0.327	0.346	0.731	0.346
CP1-M-G6A	1	1	0.176	0.176	0.474	0.162
CP1-M-A3A	1	2.6	0.514	0.686	1.2	0.543
CP1-M-C4A	1	1.595	0.286	0.429	1.014	0.5
CP2-M-H5A	1	2.545	0.545	0.636	0.876	0.364
CP1-M-B5A	1	2.333	0.583	0.875	1.667	0.75
CP2-M-E4B	1	2.147	0.382	0.559	0.844	0.324
CP1-M-E4A	1	1.351	0.249	0.405	1	0.251
CP1-M-C5A	1	1.654	0.319	0.808	0.55	0.423
CP2-M-E1B	1	1.769	0.262	0.538	0.677	0.381
Type 3 Average	1	1.850	0.416	0.687	1.147	0.404

(a) Average of sample and duplicate results.

TABLE 13

MAJOR COMPONENTS OF CREOSOTE REPORTED IN SEVERAL SOURCES
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

	Approximate Percentage of Whole Creosote								
Component	(a)	(a)	(b)	(c)	(d)	(e)	(f)	(g)	Boiling Point (h)
Acenaphthene	9.0	14.7	7.8	4.1	3.1	9.0	5.5	3.4	279
Acenaphthylene	-	-	0.5	-	-	-	-	-	265-275 (i)
Anthracene	2.0	17.4 (j)	2.5	-	1.5	7.0	-	11.1	340
Biphenyl	0.8	1.6	1.9	-	-	1.0	-	6.8	255.9
Benzofluorenes	2.0	1.0	-	4.6	-	-	-	0.85	413
Carbazole	2.0	1.2	5.1	-	2.4	-	1.2	-	355
Chrysene	3.0	2.6	4.2 (k)	2.8	-	-	-	1.7	448
Dibenzofuran	5.0	7.5	5.2	9.6	1.1	4.0	6.4	-	287
Dimethylnaphthalenes	2.0	2.3	-	3.2	-	-	-	6.8	268
Fluoranthene	10.0	7.6	11.8	6.8	3.4	3.0	10.4	3.4	382
Fluorene	10.0	7.3	6.0	9.6	3.1	9.0	8.3	6.8	293-295
Methylfluorenes	3.0	2.3	-	-	-	-	-	-	318
Methylanthracenes	4.0	3.9 (l)	-	-	-	-	-	0.85	360
2-Methylnaphthalene	1.2	2.8	6.5	2.1 (m)	3.9	12.0 (m)	7.3 (m)	11.1	214.05
1-Methylnaphthalene	0.9	1.7	3.5	2.1 (m)	3.0	12.0 (m)	7.3 (m)	6.8	244.64
Methylphenanthrenes	3.0	3.9 (l)	-	5.4	-	-	-	-	-
Naphthalene	3.0	1.3	17.0	7.3	15.8	18.0	8.5	11.1	218
Phenanthrene	21.0	17.4 (j)	19.4	12.6	10.7	16.0	19.6	11.1	340
Pyrene	8.5	7.0	8.4	5.0	2.2	1.0	8.5	1.7	393
9,10-Dihydroanthracene	-	-	-	-	0.2	-	-	-	313 (i)
Percent of Creosote	90.4	82.2	99.8	73.1	50.4	80.0	75.7	83.5	

(a) Lorenz, L.F. and Gjovik, L.R. 1972.
(b) USDA. 1980.
(c) Becker, G. 1977.
(d) Stasse, H.L. 1954.
(e) Andersson et al. 1983.
(f) Petrowitz, H.J., and Becker, G. 1964.
(g) Mueller, James G. et al. 1989.
(h) CRC 1971.
(i) CRC 1968.
(j) Value is sum of anthracene and phenanthrene.
(k) Value is sum of chrysene and 1,2-benzanthracene.
(l) Value is sum of methylanthracenes and methylphenanthrenes.
(m) Value is sum of methylnaphthalenes.

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TABLE 14

PHYSICAL-CHEMICAL PARAMETERS FOR PAH, PCP, DIOXIN, AND DIBENZOFURAN
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Compound	Melting Point (°C)	Mole Weight (g/mole)	Water Solubility (mg/L)	Vapor Pressure (mm Hg)	Henry's Law Constant (atm-m^3/mol)	Log K_{ow}
LPAH						
Naphthalene	80(M)	128(M)	3.1E+01(M)	2.34E-01(E)	4.82E-04(E)	3.1/3.3(E)
Acenaphthylene	92(M)	152(M)	3.93E+00(M)	2.90E-02(M)	1.48E-03(E)	3.70(E)
Acenaphthene	96(M)	154(M)	2.42E+00(M)	1.55E-03(M)	9.20E-05(E)	4.00(E)
Fluorene	116(M)	166(M)	1.69E+00(M)	7.10E-04(E)	6.42E-05(E)	4.20(E)
Phenanthrene	101(M)	178(M)	1.00E+00(M)	6.80E-04(M)	1.59E-04(E)	4.46(M)
Anthracene	218(E)	178(M)	4.50E-02(M)	1.95E-04(M)	1.02E-03(E)	4.45(M)
HPAH						
Fluoranthene	111(M)	202(M)	2.06E-01(M)	5.00E-06(M)	6.46E-06(E)	4.90(E)
Pyrene	156(M)	202(M)	1.32E-01(M)	2.50E-06(M)	5.04E-06(E)	4.88(M)
Benzo(a)anthracene	162(M)	228(M)	5.70E-03(M)	2.20E-08(M)	1.16E-06(E)	5.61(M)
Chrysene	254(E)	228(M)	1.80E-3(M)	6.30E-09(M)	1.05E-06(E)	5.61(M)
Benzo(b)fluoranthene	168(M)	252(M)	1.40E-02(M)	5.00E-07(M)	1.2E-05(M)	6.06(E)
Benzo(k)fluoranthene	217(M)	252(M)	4.30E-03(E)	5.10E-07(E)	3.94E-05(E)	6.06(E)
Benzo(a)pyrene	179(M)	252(M)	1.20E-03(M)	5.60E-09(M)	1.55E-06(E)	6.06(E)
Dibenz(a,h)anthracene	270(M)	278(M)	5.00E-04(M)	1.00E-10(M)	7.33E-09(M)	6.80(E)
Benzo(g,h,i)perylene	277(M)	276(M)	7.00E-04(E)	1.03E-10(E)	5.34E-08(E)	6.51(E)
Indeno(1,2,3-c,d)pyrene	163(M)	276(M)	5.30E-04(E)	1.00E-10(M)	6.86E-08(E)	6.50(E)
OTHERS						
Pentachlorophenol	191(M)	266(M)	1.4E+01(M)	1.1E-4(M)	3.4E-06(M)	5.24(E)
Dioxin (2,3,7,8-TCDD)	295/305(M)	322(M)	2.0E-04/ 1.93E-05(M)	6.4E-10(M)	5.4E-23(M)	6.20(M)
Dibenzofuran	86/87(M)	168(M)	1.0E+01(M)	--	--	4.17/4.12/ 4.31(M)

Sources: (M) = Montgomery & Welkom 1990; (E) = EPA 1986c.

TABLE 15

INPUT PARAMETERS FOR POTENTIAL DNAPL MIGRATION CALCULATIONS
SEDIMENTS OPERABLE UNIT RI
CASCADE POLE SITE
OLYMPIA, WASHINGTON

Critical NAPL Height for Downward Penetration of a NAPL From a Coarse-Grained Medium into a Finer-Grained Medium
(Equation 1, Section 5.3.2)[a]

Aquitard Grain Diameter (cm)	Aquifer Grain Diameter (cm)	Critical Height (ft)
0.0075	0.01	29
0.001	0.1	299

Hydraulic Gradient Required to Move A DNAPL Pool Downdip
(Equation 2, Section 5.3.2)[a]

Pool Length (ft)	Aquitard Dip (degrees)	Grain Diameter (cm)	Hydraulic Gradient (ft/ft)
400	0.5	0.01	0.0011
400	2	0.01	0.0004
400	0.5	0.1	-0.0001
400	2	0.1	-0.0009
50	0.5	0.01	0.0107
50	2	0.01	0.0099
50	0.5	0.1	0.0008
50	2	0.1	0.0001
5	0.5	0.01	0.1090
5	2	0.01	0.1082
5	0.5	0.1	0.0107
5	2	0.1	0.0099

(a) The following input parameters were common to both Equations 1 and 2.

σ = 20 dynes/cm (Mercer and Cohen 1990)
ϕ = 60° (estimate)
g = 980.7 cm/sec^2 (CRC 1991)
ρ_n = 1.054 g/cm^3 (SSI report)
ρ_w = 1.025 g/cm^3 (Gross 1972)
r_t = ½ (0.154d) (Berg 1975)
r_p = ½ (0.414d) (Berg 1975)
d = grain diameter
grad p = hydraulic gradient/$\rho_w g$