PRELIMINARY FINAL

KING COUNTY DEPARTMENT OF NATURAL RESOURCES
YEAR 2000 CSO PLAN UPDATE PROJECT
SEDIMENT MANAGEMENT PROGRAM

SEDIMENT MANAGEMENT PLAN

Literature and Project Review

Task 3
Technical Memorandum

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TABLE OF CONTENTS

"Virtually no area of Puget Sound is pristine and free from contamination. The worst chemical contamination problems show up in the bottom sediments, where particles associated with toxic chemicals settle. The urban bays contain areas of the most contaminated sediments, which are associated with harm to biological populations living in the sediments, bottomfish disease, and contamination in the flesh of fish and shellfish." 1991 Puget Sound Update[1]

1.0 INTRODUCTION

During spring and summer it is common to see Seattle area residents boating, swimming and fishing in areas of Elliott Bay and the Duwamish River. So it is easy to understand that protecting and enhancing water quality in the region is a very high priority for residents.

Since the early 1980's water quality studies have been conducted in and around Puget Sound to monitor pollutant loadings into the Sound and to assess adverse effects from this contamination. The results of many of these investigations show that contamination of marine sediments is a significant environmental issue in this region. Sediment chemistry studies have shown that marine sediments are the repository for many toxic pollutants including metals and organic compounds. PCBs (polychlorinated biphenyls) and PAHs (polycyclic aromatic hydrocarbons)[2] have been found in sediments throughout Puget Sound, mostly in urban areas.[3] Both substances have been found in English sole tissue[4] and PAH concentrations have been associated with liver lesions in English sole. Arsenic, lead, mercury, and DDT have also been found in streambed sediments at Thornton Creek as well as in Sculpin (a predatory bottom fish) feeding at this site.[5]

The United States Environmental Projection Agency (USEPA) recently evaluated data from 1,372 of 2,111 watersheds in the continental U.S. Of these, 96 were identified as "areas of probable concern" (APCs) where potential adverse effects of sediment contamination are more likely to be found.[6] Puget Sound and the Duwamish River were both identified in this study as APCs.[7] The USEPA recommends continued monitoring and evaluation of these two waterways.

Despite the evidence demonstrating that many urban areas in Puget Sound possess contaminated sediments, the state of sediments within the watershed as a whole remains unclear. Recent monitoring data, collected by the USEPA, Washington State Department of Ecology (Ecology), the National Oceanic and Atmospheric Administration (NOAA) and the Washington State Department of Fish and Wildlife indicates that sediment contamination does not appear throughout the Sound.[8] No trends of increasing or decreasing contaminants in fish and sediments in Puget Sound were

[1]Puget Sound Water Quality Authority 1991, pages 2-3.
[2]PCBs are by-products of a variety of industrial processes. Although manufacture was stopped in the 1970's , PCBs are still present in soils, groundwater, and surface water. PAHs are produced by the steel and petroleum industries, through the manufacture of coal tar and asphalt. They are also natural by-products of combustion.
[3]Over the past two years, two large comprehensive studies were completed. In 1997, the National Resource Trustees for the Duwamish River initiated an investigation to evaluate the extent and severity of PCB and PCT (polychlorinated terphenyl) contamination in the sediments of the Duwamish River. NOAA sampled over 200 stations and found that concentrations of PCBs in sediments are potentially sufficient to cause injuries to natural resources (NOAA 1998). In 1998, EPA sampled over 300 different stations throughout the lower Duwamish River to determine if the Duwamish River should be considered for inclusion on the National Priorities List. The study analyzed sediment samples for a full range of chemicals.
[4]Puget Sound Water Quality Action Team 1998, pages 40-45.
[5]USGS 1998, page 1.
[6]USEPA 1997, page xviii.
[7]Ibid. pages 1-4.
[8]Puget Sound Water Quality Action Team 1998, pages 38-39.

observed from the late 1980s to the mid-1990s. In addition, the amounts of PCBs measured in mussel tissue declined during the 1990s in the Duwamish River and in Elliott Bay.[9,10] Also, only 0.3% of the total submerged surface area of Puget Sound seems to have sediment concentrations above state cleanup screening levels.[11] This indicates that there are "hotspots" of sediment contamination, identified in urban areas, which may warrant remediation activities, though most of the sediments in Puget Sound may not require remediation.

Many of the hotspots of sediment contamination identified in Puget Sound are found in urban areas located near or around combined sewer overflows (CSOs). In 1984, Metro (now King County) examined toxic pollutants in its wastewater system and the regional aquatic environment. Metro concluded that a toxicant problem existed in the urban bay areas of Elliott Bay and the Duwamish River and began evaluating the contribution of CSOs to this problem. As part of 1988 Puget Sound Water Quality Management Plan, CSOs were identified as a point source of contaminants found in sediments. Since that time, King County (formerly Metro), has instituted two programs to control discharges from known sources into the Duwamish River and Elliott Bay: the CSO Program which addresses volume reductions of CSO discharged, and the Industrial Waste Program which focuses on controlling industrial discharges to the sewer system.

In 1990, the City of Seattle and King County (formerly Metro) responded to a federal lawsuit alleging that sediment contamination and habitat loss in and around CSO and storm drain outfalls were due to discharges from these outfalls. In 1991, the City and King County agreed to a combined settlement of 24 million dollars, half of which was dedicated to sediment remediation. As part of this agreement, four sites were identified for sediment cleanup (Norfolk CSO, Duwamish/Diagonal, Pier 53/55, and Seattle Waterfront). In May 1996, Ecology released its "Contaminated Sediment Site List" which identifies sites with contaminated sediments around the state. Of the 49 sites listed in Puget Sound, 19 are in Elliott Bay. Of these 19 sites, seven are associated with King County CSO outfalls (Denny Way, King, Lander, Hanford #2, Chelan, Duwamish/Diagonal, and Brandon).

The Sediment Management Plan developed by King County outlines a long-range strategy to remediate each of these CSO sites. It will be implemented as part of the County's CSO Program. The following section is a literature review of historical and current sediment management actions in Puget Sound.

2.0 HISTORY OF SEDIMENT MANAGEMENT IN THE PUGET SOUND REGION

Since the mid-1980s, several state and regional programs were established to address contaminated sediment issues. Although individual programs have different goals and regulatory authorities, the various jurisdictions overseeing sediment management have been working together in a coordinated fashion to facilitate the cleanup of Puget Sound and its environs.

- 1983 – 1989 - Three embayments in Puget Sound with sediment contamination were designated as federal Superfund sites: Commencement Bay, Eagle Harbor and Harbor Island. The first

[9]Ibid.
[10]It should be noted however, that much of the sediment contamination monitored during this time period resulted from past practices and from chemicals no longer used. The outlook for currently used chemicals is unknown.
[11]Puget Sound Water Quality Action Team 1998, pages 40-45.

sediment cleanup action in Commencement Bay was the Simpson project and was completed in 1989. Cleanup is still continuing at other sites. Eagle Harbor and Harbor Island are in the process of being cleaned up.

- 1984 – Metro (now King County) completed a five year study (*Toxicant Pretreatment Planning Study*)[12] of toxic pollutants in its wastewater system and the regional aquatic environment. This study concluded that a toxicant problem existed in the urban bay areas of Elliott Bay and the Duwamish River due to significantly elevated levels of metal and organic priority pollutants in sediments. This work set the stage for subsequent planning activities in Elliott Bay and the Duwamish River by recommending that USEPA and Ecology develop an action plan to address the toxicant problem with sediments in urban bays.

- 1985 – The Puget Sound Water Quality Authority was established by the Washington State Legislature to develop and oversee the implementation of a comprehensive management plan for Puget Sound.

- 1986 – Initial Puget Sound Water Quality Management Plan was adopted by the Puget Sound Water Quality Authority. The plan included the goal of reducing and eliminating adverse environmental effects of contaminated sediments. The plan also required Ecology to develop statewide sediment quality standards and to develop and maintain an inventory of contaminated sediments in Puget Sound that do not meet the sediment quality standards.

- 1988 – Puget Sound becomes a part of the National Estuary Program as USEPA designated Puget Sound an estuary of national significance. The Puget Sound Estuary Program was established to implement the National Estuary Program and address several water quality issues including the management of contaminated sediments. One of the activities of the Puget Sound Estuary Program is the Urban Bay Action Program, which is conducted jointly by USEPA, Ecology and other state and local agencies. The Urban Bay Action Program manages data compilation, identification of problem areas, development of source control programs, and implementation of sediment cleanup activities in Puget Sound.

- 1988-1989 – The Puget Sound Dredged Disposal Analysis (PSDDA) was designed to develop environmentally safe and publicly acceptable options for the unconfined, open-water disposal of dredged materials. Open-water disposal sites for clean dredged material were established by rule. The U.S. Army Corp of Engineers (COE) is the lead agency managing the sediment evaluation and approval process for dredgers wishing to use the sites.

- 1989 – Model Toxics Control Act passed, by voter initiative.

- 1990 – Metro performed a voluntary sediment capping project at Denny Way CSO as a demonstration project and interim solution for improving sediment quality in Elliott Bay.

- 1990 – Damage Assessment and Restoration Program (NOAA) – NOAA's Damage Assessment and Restoration Program was established to fulfill natural resource trustee responsibilities

[12]Municipality of Metropolitan Seattle 1984, pages xi-xii.

assigned in the Clean Water Act, CERCLA, Superfund Act, Oil Pollution Act of 1990, and National Marine Sanctuaries Act.

- 1991 – Ecology adopts state Sediment Management Standards.

- 1991-1992 – Metro facilitated interagency meetings and funded a report titled *Metro Toxicant Sediment Remediation Project*[13] which prioritized the risks due to contaminated sediments in Elliott Bay and the Duwamish River. This report identified the Pier 53-55 area as a high priority for site cleanup.

- 1991 – The Elliott Bay/Duwamish Restoration Program (EBDRP) was initiated as a result of a Natural Resource Damage Assessment lawsuit initiated by NOAA (*United States et. al. v. City of Seattle and the Municipality of Metropolitan Seattle*, Case 90-395). The lawsuit was filed to recover damages for injury to resources caused by contaminants in storm drains and CSOs. A Consent Decree was agreed to by the City of Seattle and King County (as Metro) which allocates money for the cleanup of storm drains and CSO sites identified through the EBDRP.

- 1991 – 1994 - The Puget Sound Water Quality Management Plan is updated establishing an ambient monitoring program for contaminated sediments.

- 1995 – King County (formerly Metro) began implementing the CSO Sediment Baseline Monitoring Plan, developed as a condition of its NPDES permits, that provides for the monitoring of marine sediments in the vicinity of wastewater treatment plant outfalls and CSOs.

- 1996 – Puget Sound Water Quality Protection Act passed, restructuring management of the estuary. The Puget Sound Water Quality Authority was replaced with a new Puget Sound Water Quality Action Team and a Puget Sound Council. Biennial work plans are now required.

- 1996 – Ecology publishes Sediment Management Standards Contaminated Sediment Site List – seven sites associated with King County's CSO outfalls were included on this list.

3.0 CONTAMINATION ASSOCIATED WITH CSO SITES

There are a number of sediment remediation projects and activities associated with King County CSOs that have recently been completed, are being planned or are in progress. These include EDBRP projects being conducted by King County and the City of Seattle, in-water projects near King County CSOs being completed by other agencies, and current or potential projects associated with CSOs on Ecology's contaminated sediments site list. The following describes these activities.

[13] Parametrix Inc. et al. 1992.

3.1 EDBRP Projects

The EBDRP was initiated as a result of a Natural Resource Damage Assessment lawsuit initiated by NOAA. The lawsuit was filed to recover damages for injury to resources caused by contaminants in storm drains and CSOs with money allocated for the cleanup of CSO sites identified through the EBDRP.

In 1992, a technical working group to the EBDRP identified 24 potential sediment remediation sites associated with King County and City of Seattle CSOs and storm drains. Of these 24 sites, four were selected for further investigation: Norfolk CSO, Seattle Waterfront, Pier 53/55 Sediment Capping Project and Duwamish Pump Station CSO/Diagonal Way CSO/Storm Drain. Theses sites were prioritized based on criteria that included:

- The presence of contaminants at concentrations that exceeded Washington State Sediment Management Standards;
- Adequate control of sewer overflows, storm drains, and industrial input to prevent recontamination;
- Potential for addressing injury to target species/fish; and
- Potential for reducing risks to human health.

Cleanup studies and work plans were developed for all four sites. In addition, a number of cleanup projects have been started and others completed. The Pier 53/55 sediment capping project has been completed and is undergoing monitoring. A recontamination study has been completed for the Seattle Waterfront site and the site assessment remains to be concluded. The Norfolk remediation project was completed in early 1999. The Duwamish/Diagonal site investigation has been completed and an evaluation of cleanup alternatives will follow.

Each site has been characterized to identify potential contaminants of concern that will require cleanup. The following describes contaminants found at each site.

Pier 53/55 Sediment Capping Project - The Seattle Waterfront was identified as a problem spot in the early 1980s due to sediment contamination. It is located near a historic untreated sewer outfall and offshore of the Pier line for Pier 53-55. High levels of PCBs, mercury, cadmium, silver, LPAHs and PAHs were identified. The Pier 53/55 site was remediated with a sediment cap in 1992.[14,15] Monitoring was conducted in 1992, 1993, and 1996.

Norfolk CSO - Discharge from the Norfolk CSO outfall includes discharges from the Norfolk overflow regulator which collects sewage and stormwater from residential, industrial and commercial areas in the southern portions of the City of Seattle and the western part of the City of Tukwila. In addition, separated storm water from five drainage lines connects the outfall line after

[14]The Pier 53-55 sediment remediation project was initiated as part of Metro's Toxic Sediment Remediation Program. The planning phase of the project was interrupted by the NOAA lawsuit and was revived when the lawsuit was settled. King County Department of Natural Resources 1996, page 3-1 to 3-9.
[15]Municipality of Metropolitan Seattle 1993, page vi.

the Norfolk overflow regulator. The service lines for these areas collect discharges from industrial roof drains, street drains and parking lots. There were four contaminants of concern for sediment remediation near the Norfolk CSO outfall: mercury; 1,4-dichlorobenzne; bis (2-ethylhexyl) phthalate; and PCBs. Other chemicals found in the sediments near the outfall include: benzoic acid; benzylbutylphthalate; diethylphthalate; acetone; and tetrachloroethylene. With the exception of PCBs, all of the chemicals of concern originated from past and current activities. PCBs were thought to be from past activities.[16]

Seattle Waterfront - The Seattle Waterfront study area boundaries are defined on the north by Pier 59 to the north, and on the south by the north face of the ferry terminal (Pier 52). Two City of Seattle CSOs are located in the project area as well as four City of Seattle storm drains. There is also a permitted industrial discharge of backwash water from the City of Seattle's Western Avenue Steam Plant's water treatment system. Contaminants that are known to be elevated are: PCBs; PAHs; chlorinated benzene; phthalate acid esters; benzoic acid; mercury; copper; silver; zinc; and lead.[17]

Duwamish Pump Station CSO/Diagonal Way CSO/Storm Drain - The Duwamish Pump Station CSO, the Diagonal Way CSO and Stormwater outfall and the Diagonal Avenue Storm Drain outfall all receive surface waters draining from the Diagonal and Hanford drainage basins into the Duwamish River. They are situated within 300 feet from each other. Runoff collected by these sites is predominantly commercial and industrial. Four contaminants of concern were identified for sediment remediation through a site assessment: mercury; bis (2-ethylhexyl) phthalate; PCBs and benzyl butyl phthalate.[18] Arsenic was considered a potential chemical of concern based on the results of a preliminary human health risk assessment.[19]

3.2 In-Water Projects Near King County CSOs

A number of different sediment cleanup projects are currently being performed within the Elliott Bay/Duwamish River area by other entities without direct King County Wastewater Treatment Division involvement. However, some of these dredging or other sediment remediation activities are occurring or may occur in areas potentially contaminated by King County CSOs. A brief description of some of the more relevant projects is provided below.

- South Downtown Waterfront Redevelopment Project - Long-term redevelopment plans for an expanded Colman Dock Ferry Terminal in the immediate vicinity of the King Street CSO site are currently being developed and evaluated as part of the ongoing South Downtown Waterfront Master Development Plan and Environmental Impact Statement (EIS). The Plan and EIS are being developed by Washington State Ferries, in coordination with the Port of Seattle and City of Seattle. Conceptual alternatives being considered include construction of new auto ferry slips positioned offshore (near the outer harbor line) and slightly north of the existing slips. An expanded passenger-only ferry terminal, potentially including a cruise ship terminal, may be located within the existing Pier 48 area immediately offshore of the King Street CSO outfall. Under this scenario, expanded ferry operations would be located within the existing King Street

[16] King County Water Pollution Control Division 1996. pages xiv, 5-1 to 5-12
[17] Aura Nova Consultants Inc. 1995.
[18] King County Department of Natural Resources 1997, pages E-1, 5-1 to 5-12.
[19] King County Department of Natural Resources 1997, pages 5-15.

CSO footprint. As part of the EIS process, WSDOT and the Port of Seattle will be collecting and analyzing additional sediment samples (including confirmatory bioassays as appropriate) at the King Street CSO site to complete the site characterization and to support an evaluation of combined cleanup and redevelopment alternatives. Consistent with earlier planning documents prepared for the area by EBDRP, WSDOT, and the Port of Seattle, the presumptive cleanup remedy for this site is capping. However, the MTCA Cleanup Action Plan for the site will be developed with Ecology and Washington Department of Natural Resources (WADNR) following more detailed analysis of alternative cleanup and redevelopment options. The EIS and Cleanup Action Plan are currently scheduled to be completed in mid-2000, when they will be provided for public review.

- East Waterway Dredging Project - The East Waterway, including the Hanford and Lander CSO areas, is a critical element of the Port of Seattle's Container Terminal Development Plan. Stage I of the East Waterway project, resulting in the dredging of key approach channels and berthing areas near Harbor Island to a depth of 51 feet mean lower low water, is expected to be completed within approximately one year. Stage II of the project, which will include dredging of most of the rest of the East Waterway, including nearly all of the Hanford and Lander Street CSO footprints, is currently in the design phase. In consideration of these navigation improvement plans, the presumptive remedy for the Hanford Street CSO site is dredging and confined disposal. As part of Stage II planning efforts, the U.S. Army Corps of Engineers (COE) recently collected 86 composite sediment cores from the greater Hanford and Lander CSO site area, and submitted the samples for detailed chemical and biological analyses following Puget Sound Dredge Disposal Analysis (PSDDA) guidelines. Sediment chemistry, bioassay, and bioaccumulation analyses were conducted on most of the surface composite samples collected (0 to 4 feet depth), and also on subsurface samples (below 4 feet). These determinations, which are expected to greatly improve the characterization of sediment contaminants and disposal requirements within the Stage II area, are expected to be available by summer, 1999. Prospective disposal sites currently being considered by the Port of Seattle include the PSDDA open-water disposal site in Elliott Bay (for suitable materials), and a range of nearshore confined disposal facilities (CDF), confined aquatic disposal (CAD), or upland disposal sites for materials found to be unsuitable for open-water PSDDA disposal.

3.3 Sediment Management Standards Contaminated Site List

In 1996, Ecology published the Sediment Management Standards Contaminated Sediment Site List.[20] Seven sites associated with King County CSO outfalls were identified. The contaminants found at each site are listed in Table 1. King County's SMP addresses all seven sites.

[20] Washington State Department of Ecology 1996, pages 15-24.

TABLE 1
King County CSOs Listed on Ecology's
Contaminated Sediment Site List

CSO Site	*Ecology Site ID #*	*Contaminant Groups of Concern*
Denny Way	EB26	Silver, mercury
King Street	EB27	Metals, benzyl alcohol
Lander Street	EB7	Mercury, PCBs
Hanford #2	EB8	Mercury, PCBs, cadmium, phthalates, PAHs, benzene, benzene, arsenic
Chelan Ave	EB13	PAHs
Duwamish/Diagonal	DR31	Phthalates, benzoic acid, mercury
Brandon Street	DR32	Phthalate, mercury

Source: Washington State Department of Ecology Sediment Management Standards Contaminated Sediment Site List, May 1996.

4.0 OTHER SITES OF INTEREST IN PUGET SOUND

There are a number of sites throughout Puget Sound, that have undergone or are in the process of conducting site remediation to clean up sediment contamination. These include federal Superfund sites: areas within Commencement Bay, Wyckoff/Eagle Harbor, Harbor Island, Bainbridge Island and Bremerton Harbor; and state-lead MTCA sites such as the Bellingham Bay Pilot Project. In addition, COE and Ecology are evaluating the feasibility of developing a multi-user disposal site (MUDS) for permanent containment of contaminated sediments. The following summarizes these activities.

4.1 Superfund Sites

Commencement Bay - In the mid-1980's, Commencement Bay and the South Tacoma channel were included on the first Superfund National Priorities List. EPA and the Washington Department of Ecology agreed to conduct remedial investigations of hazardous substance contamination of the Nearshore Tideflats Industrial areas and the ASARCO smelter. A comprehensive study was conducted which included evaluations of: surface and subsurface sediment; water column chemistry; benthic macro-invertebrates; sediment bioassays; fish histopathology; and bioaccumulation for eight study areas. Chemicals of concern identified from these investigations included: arsenic; cadmium; copper; lead; zinc; mercury; nickel; phenol; pentachlorophenol; LPAH; PAH; chlorinated benzenes; chlorinated butadienes; phthalates; PCBs; 4-Methylphenol; benzyl alcohol; benzoic acid; dibenzofuran; nitrosodiphenylamine; and tetrachloroethene.[21] The Commencement Bay Nearshore/Tideflats Record of Decision (ROD) was issued in 1989. It set forth a cleanup plan addressing control of upland sources of contamination followed by sediment remediation by dredging, capping, or natural recovery within contaminated sediment problem areas in St. Paul, Sitcum, Hylebos, Thea Foss, Wheeler Osgood, and Middle Waterways.[22] Source control and sediment remediation within the St. Paul and Sitcum Waterways has been completed. Cleanup is progressing in the other waterways and is anticipated to be completed by 2002 to 2004.

In 1991 the damage assessment and restoration planning process was initiated by the Commencement Bay Natural Resource Trustees[23] with the issuance of a Preassessment Screen,

[21] Tetra Tech 1985a, pages 53-64.
[22] USEPA Region 10 1997.
[23] The Trusstees are: NOAA, the U.S. Department of the Interior including the U.S. Fish and Wildlife Service and the Bureau of Indian Affairs; the Washington Department of Ecology, the Washington Department of Fish and Wildlife,

Determination to Perform Assessment and Notice of Intent to Perform Assessment. A compilation of existing information was completed in 1995 and the Commencement Bay Natural Resource Trustees negotiated an agreement with ASARCO Inc. and a Bay-wide natural resource damages settlement with the Port of Tacoma. Independent injury assessment and quantification studies have been completed for a number of geographic focus areas and are being conducted at others. Settlement negotiations between the Trustees and Potentially Responsible Parties are underway.

Wyckoff/Eagle Harbor– The south shore of Eagle Harbor, Bainbridge Island was the location of a former wood treating plant (Wyckoff) that operated for 80 years. A shipyard operated on the north shore of the harbor. The harbor, wood treating facility, and other upland sources were included as one site on the National Priorities List (Superfund) on July 22, 1987.

The Wyckoff/Eagle Harbor Superfund site is divided into four work areas called "operable units." Two operable units, East Harbor and West Harbor required remediation of sediments that exceeded state SMS criteria. Sediments in portions of the East Harbor were contaminated with creosote and other wood treatment chemicals. Sediments near the former shipyard in the West Harbor operable unit contained elevated concentrations of mercury and other bottom-paint chemicals. In 1994 a cap of clean sediments dredged from the Snohomish River was placed at the East Harbor site. The West Harbor cleanup project was completed in 1998.[24] Contaminated sediments were dredged from the harbor and disposed in a one-acre, confined disposal facility. Long-term monitoring of both the East and West Harbor caps are ongoing.[25]

Harbor Island – The Harbor Island Superfund site is located near downtown Seattle where the Duwamish River enters Elliott Bay. Harbor Island was created in the early 1900's by filling over 400 acres of tidelands. It has been used by numerous commercial and industrial enterprises since that time. In 1983 Harbor Island was placed on the National Priorities List when hazardous substances were found in soils on the island and in sediments near the island.

An initial investigation of marine sediments around Harbor Island, completed in 1988, found high concentrations of PCBs, PAHs, arsenic, cadmium, copper, lead, mercury, and zinc. Major sources of sediment contamination are believed to have come from sandblasting ship hulls to remove paint containing toxic substances, direct disposal of industrial waste to the Duwamish River, storm drain discharges and surface runoff.[26]

The Harbor Island Superfund site was initially divided into operable units, including the Marine Sediments Unit, addressing contaminated sediments around the site. An initial site investigation of the Marine Sediments Unit completed in 1995 identified areas in the East and West Waterways, and to the North of Harbor Island that exceeded state Sediment Quality Standards.[27] Contaminants of potential concern identified from these earlier studies included arsenic, mercury, PCBs, petroleum products, and tributyl tin (TBT).[28] Since that time, the site has been divided into project areas. Of

the Washington Department of Natural Resources, the Puyallup Tribe of Indians and the Muckelshoot Indian Tribe.

[24] USEPA Region 10 1998, pages 1 and 3.

[25] COE 1995, USEPA Region 10 1997, pages 1-3.

[26] USEPA Region 10 1995 October.

[27] USEPA Region 10 1995 June.

[28] USEPA Region 10 1997.

interest to the proposed King County Sediment Management Plan are the Shipyard Sediment and Waterway Sediment projects.

A Record of Decision (ROD) was issued for the Shipyard Sediment project in November 1996. The ROD requires all sediments exceeding state Cleanup Screening Levels of the Sediment Management Standards (SMS) to be dredged and placed in either a confined aquatic disposal (CAD) facility or an upland disposal facility. Remaining areas, which exceed the Sediment Quality Standards of the SMS, will be capped. The project also requires long-term monitoring. Remedial design efforts to implement the ROD are underway at the Todd Shipyard and former Lockheed Shipyard No. 1. Cleanup is anticipated to be completed by 2002 to 2004.

A Waterway Sediment ROD was issued in 1997 addressing sediments not associated with the Shipyard Sediment ROD. The Waterway Sediment project area includes both the East and West Waterways. As described above, dredging and disposal of contaminated sediments in the East Waterway in being planned as part of the Port of Seattle's Container Terminal Development Plan. more detailed studies of sediment contamination within the West Waterway were recently completed by EPA, the Port of Seattle, and Lockheed.[29] EPA is currently evaluating the scope of the West Waterway operable unit ROD. Based on recently released human health and ecological risk data and evaluations, EPA is apparently considering a no-action ROD for the West Waterway. A formal determination is forthcoming.

Sinclair Inlet - The U.S. Navy plans to improve the Puget Sound Naval Shipyard (PSNS) in Bremerton to become a future homeport facility for deep draft vessels, including nuclear-powered aircraft carriers. A National Environmental Policy Act (NEPA) Environmental Impact Statement (EIS) has been prepared and public comment received on the homeport plan and alternatives. Under the Navy's preferred plan, navigation channels, turning basins, and pier berths at PSNS would require dredging to accommodate the deeper draft vessels. Approximately 490,000 cubic yards (CY) of navigation improvement materials would be dredged under this plan, of which 340,000 CY is currently assumed suitable for open water disposal at a Puget Sound Dredge Disposal Analysis (PSDDA) Program site. The remaining 150,000 CY is assumed to be unsuitable under PSDDA, pending confirmation with ongoing PSDDA chemical and biological analyses. Additionally, approximately 230,000 CY of contaminated sediments located within Operable Unit B (OUB) of the PSNS Superfund (CERCLA) Site could be dredged concurrently with the deepening project, and all contaminated material disposed within a single disposal facility. Based on existing data, the total volume of contaminated sediments that will require confined disposal has been estimated at approximately 380,000 CY; additional testing is underway to refine this estimate.

A contained disposal facility study performed for the purposes of the homeport project, along with preliminary analyses performed for the forthcoming OUB Feasibility Study, identified a range of upland, nearshore fill, nearshore CAD, and deeper-water CAD disposal options for contaminated sediments. However, based on screening-level evaluations of these alternatives and initial discussions with agency representatives and other stakeholders, the Navy has determined that upland and nearshore CAD disposal alternatives are clearly the most promising with respect to a combined homeport and Superfund action. A decision on the cleanup and sediment disposal action at PSNS is expected by the end of 1999. Construction will be completed in 2000, prior to the scheduled arrival of the aircraft carriers.

[29] Ibid.

4.2 ***Bay-Wide Approach***

The Bellingham Bay Demonstration Pilot Project is a comprehensive planning effort being performed by a diverse assemblage of local municipalities, Indian tribes, and several state and federal agencies. The Pilot is attempting to integrate bay-wide source control, sediment cleanup, habitat restoration, and aquatic land use in managing Bellingham Bay.

The Bellingham Bay Demonstration Pilot draft environmental impact statement (DEIS), released for public review in June 1999, evaluates a comprehensive strategy for the bay. Near-term and long-term actions were identified and evaluated based on four main project elements – Habitat; Land Use; Sediment Cleanup and Source Control; and Disposal Siting. A Comprehensive Strategy developed for the bay summarizes the recommended actions to improve environmental health throughout Bellingham Bay, and then provides greater detail through two key elements:

- Subarea Strategy. A separate strategy for nine geographic subareas was developed that provides greater detail on priorities and recommended actions for primary use, land use, habitat, sediment sites, cleanup, disposal, and source control.

- Near-Term Remedial Action Alternatives. A range of alternatives was developed that focus on cleanup, habitat restoration, source control and land use for critical sediment cleanup sites in the bay.

The DEIS is a programmatic EIS that evaluates impacts from implementation of the Comprehensive Strategy. Because the Comprehensive Strategy includes specific cleanup alternatives, the DEIS also includes an evaluation of specific impacts associated with these actions. Six different alternatives were developed to address critical sediment cleanup sites in the bay, and integrate habitat restoration and land use considerations with the cleanup. These alternatives were designed by the Pilot Team to cover the spectrum of cleanup options:

- Alternative 1, No-Action: No near-term remedial action.

- Alternative 2, Removal and Capping To Achieve Authorized Channel Depths (Confined Aquatic Disposal). The purpose of this alternative is to maintain existing navigation channels, minimize dredging and disposal of contaminated sediment, and maximize the areal extent and diversity of aquatic intertidal habitat through capping.

- Alternative 3, Removal and Capping to Achieve Authorized Channel Depths (Upland Disposal). The purpose of Alternative 3 is to maintain existing navigation channels, minimize the amount of dredging, and dispose of contaminated sediment in upland locations.

- Alternative 4, Full Removal From Navigation Areas (Confined Aquatic Disposal): The purpose of Alternative 4 is complete elimination of contaminated sediments from the navigation channels, maximum future provision of navigation channel depth without further sediment cleanup, and (secondarily) enhancement/creation of low intertidal, high sub-tidal habitat.

- Alternative 5, Full Removal From Navigation Areas and Partial Removal From the G-P ASB and Starr Rock Areas (Upland Disposal): The purpose of this alternative is to perform full removal from the navigation areas, and the GP ASB where partial removal is proposed. Dredge material would be disposed in upland locations.

- Alternative 6, Full Removal From Public Lands (Upland Disposal): The purpose of Alternative 6 is to completely remove all contaminated sediment from Bellingham Bay, and totally avoid disposal in the aquatic environment.

A decision on the cleanup and sediment disposal actions in Bellingham Bay is expected by the end of 1999. Construction is anticipated during 2002 to 2004.

4.3 Multi-user Disposal Sites

As part of the 1987, Puget Sound Management Plan, the Puget Sound Water Quality Authority identified the importance of having a multi-user disposal site (MUDS) for contaminated sediments in the region. In response, Ecology prepared a series of fact finding reports supporting the need for MUDS. The 1994 Puget Sound Management Plan called for an interagency group to conduct a feasibility study and in 1995, COE prepared a Reconnaissance Study Report showing there is a federal interest in the feasibility of building a MUDS. In 1996, the Washington State Legislature approved matching funds to work with COE on a study that compares the merits of several alternatives for disposing of contaminated sediments. In 1997, COE, EPA, Ecology, Washington State Department of Natural Resources, and the Puget Sound Water Quality Action Team, began a three year study to explore three options for disposal of contaminated sediment including confined aquatic disposal (CAD), nearshore confined disposal and upland disposal. The study includes a programmatic environmental impact statement (PEIS) addressing disposal alternatives, siting decision process and siting criteria as well as facility ownership and site selection. The draft PEIS was released for public comment in early 1999. Pending conclusions of the final PEIS and public and peer review comments, the cooperating agencies may prepare a site-specific EIS.[30]

5.0 ASSESSMENT OF CONTAMINATED SEDIMENT SITES

In 1985, the Puget Sound Estuary Program developed a toxics control strategy to provide a consistent, comprehensive, long-term approach to managing contaminated sediments. Known as the "urban bay approach", this strategy built on the data analysis, problem identification and site prioritization scheme used in the Commencement Bay remediation program and added the elements of multi-agency coordination and public involvement used in Metro's water quality control programs.[31] The urban bay approach set the stage for current sediment management activities in the Puget Sound area as well as describing methodologies for site evaluation and cleanup.

Site remediation activities identified in the urban bay approach and used to conduct many cleanup projects in Puget Sound include:

- Defining the type and extent of contamination at a site ;

[30] Babcock 1998.
[31] PTI 1989 pages 3-30.

- Identifying potential sources of contamination;
- Identifying remediation alternatives;
- Evaluating ecological and human health risks;
- Identifying potential for recontamination; and
- Selecting cleanup alternatives.

The following describes each element of the urban bay approach remediation process and provides examples of how the approach has been applied in Puget Sound.

5.1 Defining the Type and Extent of Contamination at a Site

Defining the type and extent of contamination at a site begins with a characterization of the study area. Available current and historical data is compiled as part of a site study.[32] Site-specific information routinely collected as part of a site study includes:

- A description of the site boundary (within which contamination occurs);
- Known physical processes such as sediment depositional patterns, bathymetry, and wave actions; and
- Current and ongoing sources of sediment contamination.

After compiling general and historical site information, the next step in defining the type and extent of contamination is to select appropriate parameters to measure contamination and appropriate standards or guidelines against which to evaluate the level of contamination (results of the measurement parameters). Multiple indicators are used to confirm that the contaminants do indeed pose a health or environmental threat. The selected indicators are compared to environmental quality, health or regulatory levels established for each indicator being measured. When more than one indicator exceeds established regulatory or acceptable levels the site is then considered for cleanup activities. Where sites are highly contaminated, a single indicator, such as sediment chemistry may be all that is needed to require cleanup.

Indicators

Indicators used to identify (or confirm) contaminated sites include:

- Sediment chemistry – direct measure of chemical concentrations found at the site;

- Biological effects – an indirect measure of the impact of chemicals found in sediments on various biological organisms; and

- Bioaccumulation – measures contaminant concentrations in organisms (usually in close proximity to the site).

The results of these measures are consolidated into an evaluation matrix and compared to the limits or regulatory levels established previously. If more than one measure is found above these levels, the site is considered contaminated and is further evaluated for cleanup actions.

[32] A site study is required by WAC 173-204.

Sediment Chemistry Standards

In 1991, the State of Washington adopted a set of regulatory standards for designating sediments that have acute or chronic adverse effects on aquatic organisms. Three sets of standards were established: sediment quality standards, sediment cleanup standards and source control standards.

Sediment quality standards (SQS) were developed to identify sediments that have no adverse effects on biological resources.[33] They include sediment chemistry concentration thresholds for 47 chemicals used to make an initial determination if sediments are contaminated.[34] If sediment chemistry concentrations exceed SQS levels, the sediments being evaluated are designated as having adverse effects on biological resources and fail the SQS. Sediments failing the SQS may be reevaluated using confirmatory biological tests described in WAC 173-204-315 to confirm or refute the original designation.

If sediments are determined to exceed the SQS for any one of the 47 listed chemicals, they are subject to sediment cleanup standards set in WAC 173-204-520. The sediment cleanup standards establish chemical concentrations and biological effects criteria that determine if contaminated sediments require cleanup. Cleanup screening levels (CSL) set the maximum degree of contamination on a site before cleanup is required. Likewise, minimum cleanup levels (MCUL) establishing the maximum degree of contamination to be allowed on a site after cleanup and to be used in the evaluation of cleanup alternatives are specified in the SQS. MCULs are set at the same level as CSLs.

A third set of sediment chemistry standards, designed to eliminate or minimize the impacts from potential sources of sediment contamination, are set in WAC 173-204-420. Source control standards define the maximum level of sediment contamination allowed in sediments impacted by ongoing discharges. WAC 173-204-500 and 173-204-510 give Ecology the ability to designate a zone (sediment impact zones) in which contamination above cleanup screening levels is allowed provided appropriate source control and remedial activities have occurred.[35]

[33] Ecology is in the process of developing human health criterion to satisfy WAC 173-204-310(2)(b).
[34] WAC 173-204-310(1)
[35] Sediment impact zones are authorized by the Ecology through stormwater or wastewater discharge permits or formal administrative actions.

Biological Effects Standards

A number of parameters are used to measure different biological effects:

- Sediment toxicity - Common measures used to evaluate biologic effects are bioassays including: acute mortality of amphipods, abnormalities in oyster larvae, bacterial luminescence.

- Surveys of benthic organisms – The number of different of organisms and the number of the same type of organisms at a site are evaluated and compared to a reference (or non-contaminated) site. If the number of different organisms is less than the reference site, the site may be considered contaminated.

- Biomarkers – A metabolic function of an organism is measured in response to a chemical contaminant (i.e., induction of specific liver enzymes that are induced in response to the presence of a specific chemical).

- Histopathology in fish – A measure of cancerous or tumorous growths in fish (i.e., liver lesions in English sole).

Sediment Toxicity and Surveys of Benthic Organisms

The State of Washington has developed tests for determining biological effects caused by sediment contamination as part of the State Sediment Management Standards. Five tests for determining sediment toxicity are described in WAC 173-204-315. One of the tests is a survey for benthic organism abundance. The five tests are:

- Acute Toxicity:
  - Amphipod ten-day mortality sediment bioassay
  - Larval mortality/abnormality sediment bioassays for: Pacific Oyster, Blue mussel, purple sea urchin, green sea urchin or sand dollar

- Chronic Toxicity
  - Abundance of major benthic organisms (Class Crustacea, Class Polychaeta, and Phylum Mollusca)
  - Juvenile polycheate: twenty-day growth rate of the juvenile polycheate
  - Microtox saline extract

Two acute toxicity and one chronic toxicity tests are required to confirm the designation of sediment that has either passed or failed any SQS.[36]

Contaminated sediments from the site being evaluated (reference) are compared to control sediments collected from a distant site known to be uncontaminated in comparison to the site in question. Performance standards for biological test results for amphipod, larval and benthic abundance tests, from reference and control sediments, are set in WAC 173-204-315(2).

[36] WAC 173-204-310(2)(a)

Biomarkers and Histopathology

Biomarkers are biochemical, physiological or pathological responses measured in individual organisms that provide information concerning exposures to environmental contaminants and/or sublethal exposures arising from such exposures.[37] Histopathological responses are structural alterations to cells, tissues and organs. To date, standards have not been developed for the use of biomarkers or histopathological parameters. This may change in the future as more information is collected.

Biomarkers however, can be useful in hazard assessments. In a number of cases, biomarkers, particularly those associated with mechanisms of action, can provide the most sensitive measures of exposure and response achievable for many contaminants.[38] For example, the induction of enzymes that might lead to the development of a tumor or cancer usually occurs in a relatively short time, whereas development of the cancer itself can take years. Thus, biomarkers can be used as early warning signals of ecological degradation. Some biochemical, physiological and histopathological indices, recording potential effects of contaminants on fish and mammals have developed and are being used in site specific studies.

Examples of biomarkers used in Puget Sound to evaluate the biological effects of contaminated sediments include:

- Potential effects of maternal transfer of PCBs to quillback rockfish larva, and the effect on reproductive health of male rockfish;[39]
- Induction of cytochrome P450 in benthic fish inhabiting areas of Puget Sound contaminated with PAH;[40]
- Imposition of male characters on female snails as a bioindicator of tributyltin contamination;[41] and
- Measures of hepatic cyctochrome P-450 system and alterations in immune system function in juvenile chinook salmon.[42]

Histopathological evaluations of bottom-dwelling fish have been conducted since the late 1980s.[43] Liver lesions in English sole were monitored in the Duwamish River, Eagle Harbor, Elliott Bay, and Commencement Bay.

[37]Benson, W.H., and R.T. Di Giulo 1992, page 241.
[38]Ibid.
[39]Puget Sound Water Quality Action Team 1998, page 47.
[40]Benson, W.H., and R.T. Di Giulo 1992, page 242.
[41]Ellis, D.V, and M.M Saavedra Alvarez 1991, page 449.
[42]Varanashi, U. et al. 1998, page 2.
[43]The PSAMP was established to monitor the health of Puget Sound.

Standards for Bioaccumulation

No standards or thresholds currently exist for measuring bioaccumulation in benthic organisms or bottom-dwelling fish. However, a number of approaches have been taken to measure bioaccumulation of sediment contaminants. These include:

- Direct measurement of contaminants of concern in fish or shellfish tissue;
- Indirect measurement of contaminants of concern via laboratory testing;
- Utilization of a bioaccumulation factor (BAF);
- Equilibrium partitioning bioaccumulation model; and
- Kinetic Models.

Direct measurement of tissue concentration of bottom dwelling or bottom feeding organisms is the most straightforward way to measure bioaccumulation of contaminants associated with sediments. These measurements can then be used in a risk characterization. Some Puget sound studies examining bioaccumulation include:

- *Organic and Inorganic Toxicants in Sediment and Marine Birds from Puget Sound;*[44]
- *The Commencement Bay Nearshore/Tideflats Remedial Investigation;*[45]
- *The National Benthic Surveillance Project*;[46] and
- The long-term *comprehensive Puget Sound Monitoring Program* (PSMP).[47]

The Commencement Bay Nearshore/Tideflats Remedial Investigation demonstrated elevated levels of lead in crab tissue associated with high lead concentrations in sediments. This study similarly correlated chlorinated compounds found in English sole tissue with contamination of sediments in the Hybelos Waterway. High concentrations of PCBs and copper, presumably from contaminated sediments, were measured in a variety of birds from Elliott and Commencement Bay as part of a larger study by NOAA in 1983. This same study demonstrated biomagnification of PCBs from off-bottom fish to marine birds and from seawater to birds in areas with contaminated sediments.

Over a four-year period, from 1984 to1989, NOAA investigated metal contamination in pacific coast sediments and bioaccumulation of metals in fish. The study found elevated concentrations of several metals (i.e., copper, mercury, selenium and silver) in fish stomachs and liver tissue associated with sediment concentrations.

Tissue concentrations of PCB and mercury in quillback rockfish; PCBs and PAHs in English sole; PCBs, pesticides, and metals in mussels; and PAHs, PCBs, pesticides, and metals in Littleneck clams have been monitored in Puget Sound by the Puget Sound Ambient Monitoring Program over a number of years. The substances found in these organisms have been associated with sediment concentrations.

[44]NOAA 1983.
[45]Tetra Tech 1985, pages 4.1 – 4.53.
[46]NOAA 1994.
[47]Puget Sound Water Quality Authority 1988.

A number of models estimating bioaccumulation are being used or developed. For a review of these models see "Models, Muddles, and Mud: Predicting Bioaccumulation of Sediment-Associated Pollutants."[48]

5.2 Identifying Potential Sources of Contamination

Sediment remedial actions will not be effective unless major ongoing sources of contaminants are controlled. Therefore, prior to selecting a cleanup alternative, an evaluation of the status of sources, source controls currently in place, and source loadings are usually undertaken. Two approaches are used to control sources of CSO and storm drain discharge contaminants. One is to reduce the overall volume of CSO discharged. The other is to reduce the amount of contaminant in the discharge.

King County has been conducting CSO control projects since the 1960s and first formalized its control program in 1979. Many projects have been implemented since that time resulting in significant decreases in CSO volumes being discharged. King County CSO discharges to Lake Washington have been eliminated and over a ten-year period, annual CSO volumes have been reduced up to 80 percent.[49] Further reductions will be achieved through the implementation of the Regional Wastewater Services Plan.

Reducing the amount or concentration of toxic substances released during CSO events has also been accomplished by implementing various storage or treatment methods to reduce the loading to a level that avoids sediment recontamination. In addition, King County implements an industrial pretreatment program to control industrial sources of wastewater contaminants

At times, it is also necessary to identify individual sources, past and present, contributing toxic substances to CSOs. The following is information useful in identifying these sources:

- Permitted commercial and industrial facilities discharging to the sewage treatment plant;
- Stormwater entering the CSO during overflow events;
- Direct stormwater discharges; and
- Direct industrial discharges.

Lists of these sources can be found in site-specific cleanup studies or reports. Industrial and commercial dischargers located in proximity to King County CSOs can be found through NPDES Permits, NPDES Stormwater Permits, King County Industrial Waste Discharge Permits, Toxics Release Inventory, and a number of other information sources.[50] Stormwater can be evaluated through a basin drainage study.[51]

[48] Lee II, H. 1992.
[49] Annual CSO volumes vary with rainfall. Therefore, CSO volume reduction varied from 80% in 1994/95 to 0.08% in 1996/97. However, despite record rainfall in 1995 through 1997, CSO volume was still lower than baseline values in 1988/89. King County Department of Natural Resources Wastewater Treatment Division, 1998 Figure 2.2.
[50] See results of Sediment Management Plan Task 6 report which is a compilation of contaminated sites and sources near seven King County CSOs and where information regarding these sites and sources are located.
[51] See Kennedy/Jenks/Chilton 1987 for a case study.

5.3 Identifying Remediation Alternatives

Once the type and extent of sediment contamination has been identified, a site-specific list of remediation alternatives is developed. Each alternative is further evaluated to determine its technical and economic feasibility as well as its potential environmental risk. A number of alternatives have been used at various sites in Puget Sound. In addition, new technologies are being developed in British Columbia and as part of the Great Lakes cleanup activities. The following summarizes current remediation technologies, where they have been utilized, and their drawbacks and effectiveness.

There are three general types of remediation alternatives that are considered in evaluating sediment remediation options:

- No action/natural recovery;
- In-situ remediation; and
- Removal.

No Action/Natural Recovery

The no action remediation alternative leaves sediments untouched allowing natural processes to reduce contaminant concentrations. It is dependent on sediment degradation processes such as microbial or chemical breakdown of toxics or burial of contaminated areas through normal sedimentation. This alternative is used as a baseline alternative to which other alternatives are compared.

Similar to the no action alternative, the natural recovery option requires no cleanup activities. However, unlike the no action alternative, studies are required to determine whether, over time, sediment contamination would be reduced to levels below the Sediment Quality Standards (SQS).

A number of parameters need to be evaluated when developing these alternatives as a baseline alternative as well as when considering these options for remediation. Factors to be considered include: location of the contaminant within the sediment (i.e., top layers, middle), how long the chemical will stay within the ecosystem, the capacity of the sediments to assimilate the contaminant and then release it, the ability of the sediment to biodegrade the contaminant, and the risk of recontamination.

Studies on natural recovery have been conducted in Eagle Harbor and Elliott Bay.[52] At Eagle Harbor, natural recovery was deemed possible for surface sediment PAHs at some sites because sediment resuspension rates allowed a portion of the suspended sediments to be moved out of the basin and biodegradation activity was present in some areas. In addition, the major source of PAH at Eagle Harbor, activity from a wood treating operation, was suspended in the 1940s.

In Elliott Bay natural recovery of PAH was not considered viable. Although sediment resuspension rates were similar to those measured in Eagle Harbor, no active industrial sources were identified. It was postulated that PAHs from diffuse sources would present a continuous risk of recontamination.

[52]Patmont, C.R. and E.A. Crecelius 1991, pages 255-254.

This coupled with little evidence of biodegradation activity, natural recovery was not considered for the Elliott Bay sites examined.

Natural recovery was evaluated as a remediation alternative at the Norfolk CSO,[53] and the Duwamish/Diagonal CSO[54] sites but was not selected due to regulatory constraints and type of contamination at these sites. At both sites organic contaminants of concern (e.g., PCBs) are strongly adsorbed to sediments and either will not biodegrade may not do so under anaerobic conditions, or may biodegrade very slowly. Because rates of recovery are uncertain, it was believed that combined processes of sedimentation and biodegradation would take a long time to meet sediment quality standards.

In-Situ Remediation

In Situ technologies involve remediating contaminated sediments in place. Three types of in-situ technologies are currently used around the country:

- Capping
- Treatment
- Containment

Capping is the placement of a covering or cap over an area of contaminated sediment used to isolate or reduce the amount of contaminants in surface sediments.[55] The cap may be constructed of clean sediments, sand or gravel or it may consist of geotextile materials. Determining if capping is a viable alternative is dependent on a number of factors such as existing and future uses of the waterway and erosive forces present at the site. For example, capping may not be the best option in or near active navigation channels because it raises the bottom sediment level or adds to a slope. Scouring by passing vessels or wave action can remove portions of a cap and cause the release of contaminants into the water column.

Two types of capping have been implemented in Puget Sound: thin-layer and thick-layer capping. Thin-layer capping entails placing a thin-layer (0.5 to 1 ft) of clean sediment over contaminated sediment. Known also as enhanced natural recovery, thin-layer capping initially isolates the underlying contaminated sediment. Over time, the cap sediment is recolonized by organisms that survived below the cap and have burrowed to the surface. The community reestablishes itself at the sediment-water interface. Thin-layer capping may not be effective in areas of high sediment erosion. However, preventative measures can mitigate sediment migration by covering the cap with a protective armor of rocks and riprap. Thin-layer capping has been effectively implemented to isolate sediment contamination in and around Elliott Bay. Thin-layer caps have been placed in 1989 at the Ferry Terminal Expansion at Coleman Dock, in 1992 on a portion of the Pier 53-55 cap site, and in 1994 at the Seattle Waterfront at Bell Street to isolate underlying contaminated sediments.[56] This option is being evaluated for use at some areas near the Denny Way CSO.

[53]King County Water Pollution Control Division 1996, pages 5-18.
[54]King County Department of Natural Resources 1997, pages 5-21.
[55]Surface sediments are the top 10 cm of the sediment) which corresponds to the biologically active zone as defined in the state Sediment Management Standards.
[56]Romberg, P.1998, personal communication.

In thick-layer capping, a layer of clean sediment, thicker than one foot, is placed over contaminated sediment to isolate the contaminants from the biologically active zone. This process smothers the underlying biological communities and unlike thin-layer capping, recoloniziation proceeds from the surface. In Puget Sound, thick-layer caps have been employed at the Simpson Paper Company in Commencement Bay and at Wyckoff/Eagle Harbor. Three-foot thick caps have been used for several projects including the Denny Way Sediment Cap Project in 1990. A thick layer cap of 4 to 20 feet of clean sand in the Saint Paul Waterway was completed in 1991. In 1992 an area near downtown Seattle, Pier 53/55, was capped to isolate nearshore contaminated sediments and allow natural recovery along certain areas of the cap. In the past two years, thick-layer caps have been placed at the ASARCO, Eagle Harbor West sites and at the Schnitzer Steel site in the Hylebos Waterway.

Inverted capping is an option that involves excavating contaminated surface sediments and the underlying clean sediments. The contaminated sediments are placed at the bottom of the excavated area then covered with clean sediments. This option has generally not been used in Puget Sound due to the difficulty in permitting and logistics due to the need to stockpile and rehandle sediment at the site. However, in 1987, an inverted cap was placed at the One Tree Island Marina, a marine site in south Puget Sound[57].

In-situ treatment is used to treat or manage sediments in place. These technologies can be applied to sediments in place or applied to sediments that have been dredged and placed in a disposal area. There are three general types of in-situ treatment technologies currently available:

- Chemical
- Biological
- Immobilization

Chemical treatment involves mixing reagents into sediments to chemically alter the contaminants. This has been used to release phosphorous and control eutrophication in Wisconsin. Injection of nutrients to stimulate the biodegradation of organics and injection of stabilization agents to reduce contaminant mobility are being investigated as part of the Lower Fox River Cleanup Project.[58]

Biological treatment involves seeding sediments with microorganisms to stimulate natural populations, which ingest or breakdown contaminants. This is being tested for remediation of PCB contaminated sediments in Wisconsin.

Immobilization alters the sediment’s physical and/or chemical characteristics with cement, thermoplastics and other binders to prevent contaminant release. This is not commonly used and is still in the experimental stages.

In-situ containment is the complete isolation of the sediment from a portion of the waterway. Physical barriers such as sheetpile, cofferdams, stone or earthen dikes are used to as barriers. Containment is not a commonly used in-situ technology.

[57]Sumeri, A. 1989, page 5.
[58]Wisconsin Department of Natural Resources 1998.

Removal

Sediment removal or dredging involves digging up contaminated sediments and moving them to another site for further treatment and/or disposal. Often, dredged sediments are de-watered and sent to a solid waste landfill or to hazardous waste facility for further treatment and final disposal. Dredged sediments can also be disposed of at an in-water “confined disposal facility”.

Two types of dredging technologies are currently being utilized to remediate contaminated soils: mechanical and hydraulic dredging. Mechanical dredging has been proven effective at removing contaminants to a depth of eight feet. Sediments are picked up in a large, specially designed clamshell bucket and moved to a barge or on land. Minimal amounts of water are picked up in the process. This alternative was selected for the Norfolk project and is being considered for a portion of the remediation area at the Denny Way CSO.

Hydraulic dredges are also effective at removing sediments to the depth of observed contamination eight feet below the mudline. However, hydraulic dredges use a cutterhead to dig the sediment and large pumps to create a suction to remove sediment in a sediment-water slurry, thus requiring more de-watering than mechanical dredging. Because hydraulic dredges capture more water than mechanical dredges, they need a large pond area to settle out the contaminated sediment and may need to treat the water before it is discharged back to the waterbody.

Containment, Treatment and Disposal of Dredged Sediments

Once sediments have been dredged, they are moved away from the contaminated site. Sediments can be moved to in-water sites for confined disposal. Confined aquatic disposal or CAD entails excavation of the contaminated sediment and in-water disposal at a designated CAD site, and then capping the contaminated sediment with clean sediment. This technology is effective in shallow water areas with minimal current, however due to navigational constraints around many sites in Puget Sound, this method for sediment remediation is not often used. In addition, it is not cost effective at small sites.

Nearshore confined disposal requires the construction of a confined disposal facility (CDF) in a nearshore area. Typically, a wall or berm is constructed on the water side of the CDF with land providing containment on the opposite side. Once contaminated sediment is placed within the CDF, it is capped with clean sediment to the desired elevation. This method has been used at a number of sites in the Northwest. The Wyckoff/Eagle Harbor West Harbor site cleanup project included disposing of dredged contaminated sediments in an on-site near-shore CDF. Contaminated sediments (not requiring Superfund cleanup) dredged from the Sitcum and Blair Waterways in Commencement Bay during maintenance dredging operations were used to fill the nearby Milwaukee Waterway. In 1998, The City of Tacoma, proposed to the EPA, to dredge contaminated sediments in the Thea Foss Waterway and possibly sediments from the Middle Waterway in Commencement Bay to be placed on a 14-acre site in the Saint Paul Waterway. The Saint Paul CDF would then be capped.

If sediments will not be contained in a CAD or CDF, they will be treated, in a manner similar to that used for treating contaminated soils. Three types of treatment options have been examined at Puget Sound sites:

- Bioremediation
- Mechanical treatment (soil washing)
- Thermal treatment

Bioremediation relies on living organisms, typically bacteria, to process and degrade organic contaminants. It requires contaminated sediments to be excavated, treated off site and then reworked at a handling facility. Although this technology is effective for a range of organic contaminants, it is ineffective in remediating contaminants such as PCBs and heavy metals.

Mechanical treatment involves washing excavated sediments to remove organic and inorganic contaminants. This method may work well for sediments containing large amounts of sand where the contaminants, which are typically bound to fine-grained particles can be effectively washed away. Again, this treatment would require off site treatment, reworking and rehandling. It is currently unproven and expensive to implement.

Thermal treatment involves the placement of non-hazardous sediments in a rotary or cement kiln designed to heat the sediment to over 2000^{o} F. In the process, organic contaminants are either destroyed or converted to less toxic constituents which can be safely managed, and heavy metals are immobilized. The residue is combined with gypsum to produce cement. Thermal treatment is one of the options proposed to treat contaminated sediments from the Norfolk CSO and the Denny Way CSO.

Other thermal treatment technologies include portable thermal plants and lightweight aggregate from dredged sediments (LADS). Portable thermal plants can be used to treat dredged materials and are effective for most organic contaminants, but do not immobilize heavy metals. LADS is basically a mobile rotary kiln that is located on a barge or near the site. Sediments are treated and then replaced after they are 'cleaned'. These two technologies are currently unproven and are not cost effective.

Thermal incineration is based on the same principles as the rotary kiln process and has been proven effective at removing contaminants. Excavated sediments are removed from the site and treated in an incinerator. However, there are no plants in the northwest, and the costs of transporting sediments to an incineration facility would be prohibitive.

Disposal options for treated contaminated sediments are limited. Non-toxic sediments can be disposed in solid waste landfills (Subtitle D), or used as municipal landfill closure material. Sediments classified as hazardous waste must be disposed at a hazardous waste landfill (Subtitle C).

Sediments from the Norfolk site, not treated in a rotary kiln, are proposed to be disposed off-site either as non-hazardous waste or as a hazardous substance. Non-hazardous waste will go to a cement kiln for treatment or to a solid waste (Subtitle D) landfill. Sediment with PCB concentrations classifying it as a toxic substance will be transported to a hazardous waste landfill (Subtitle C) in eastern Oregon).

5.4 Evaluating Ecological and Human Health Risks

The accumulation of toxics in sediments and subsequent bioaccumulation of these chemicals in fish and shellfish can pose a health risk to animals and humans ingesting them. To determine potential risks to humans, a baseline health risk assessment based on bioaccumulation studies is conducted. This usually establishes potential risk levels to humans from ingesting fish or shellfish. Cancer and non-cancer risks are calculated in parallel. Additional analyses are conducted when evaluating potential cleanup alternatives. A human risk assessment is required as part of the sediment cleanup study under WAC 173-204-560(e).

Early risk assessments of contaminated sediments in Puget Sound focused primarily on human risks. In 1985, Ecology and EPA completed a remedial investigation of Commencement Bay.[59] They evaluated potential cancer and non-cancer risk from ingesting English sole and crab containing priority pollutants and/or EPA designated carcinogens. They found that for individuals eating more than one pound of fish or crab per day, the lifetime risks would exceed $1 \text{ X } 10^{-6}$ for six carcinogens:

- PCBs
- Arsenic
- Hexachlorobenzene
- Hexachlorobutadiene
- Bis (2-ehtylhexyl) phthalate
- Phthalate
- Tetrachloroethylene

The initial assessment by the Elliott Bay Toxics Action Program also evaluated risk to humans from consuming English sole and crab. In addition, they evaluated risk from sablefish, Pacific cod, and butter clam.[60] Both cancer and non-cancer risks were evaluated for a variety of chemicals. They found that PCBs and arsenic were problem chemicals from regular consumption (one meal per week) of seafood from Elliott Bay or the Duwamish River. They found mean concentrations of PCBs in muscle of English sole, sablefish, Pacific cod, and crab from 6 to 54 times the guideline concentrations.[61] PCB levels in Elliott Bay samples were elevated about 12-33 times above reference levels in English sole.

Potential human health risks were evaluated at the Duwamish/Diagonal CSO.[62] Data collected on English sole tissue concentrations of chemicals of potential concern were evaluated for human cancer and non-cancer risks from fish consumption. The assessment found cancer risks from PCBs, DDT and arsenic. However, the risks from PCBs and DDT were less than risks estimated for regional Puget Sound seafood ingestion studies. The risks from arsenic were greater than risks estimated for regional Puget Sound seafood ingestion studies.

The Southwest Harbor Cleanup and Redevelopment project conducted both human health and marine life risk assessments.[63] Although the Southwest Harbor site is an industrial site with little

[59]Tetra Tech 1985, pages 49-52.
[60]Tetra Tech 1986 Appendix G, pages 137 – 181.
[61]Tetra Tech calculated guideline concentrations for carcinogens and non-carcinogenic priority pollutants based on risk assessment procedures described by the EPA in 1980 through 1985. Ibid. page 147.
[62]King County Department of Natural Resources and Ecochem Inc. 1997.
[63]COE et al. 1994.

and no fishing or swimming, a human risk assessment was conducted to develop a baseline against which to evaluate cleanup alternatives. Both cancer and non-cancer risks were evaluated. The major cancer risk to humans was from consumption of shellfish. Arsenic and copper contributed to the majority of estimated non-cancer health risks from this pathway. A marine life risk assessment was also conducted to evaluate the potential for chemicals in sediments or water to adversely effect fish or clams. A screening level analysis was conducted for the same chemicals that were evaluated in the human risk assessment. This evaluation indicates a potential for risk to marine life from exposure to arsenic, copper and lead.

A recent study by King County, the Combined Sewer Overflow Water Quality Assessment (WQA) examined potential risk to aquatic organisms, wildlife, and humans from overall environmental conditions surrounding CSOs and from CSO outfalls alone.[64] Risk from contaminants of potential concern in marine sediments were evaluated as part of this study. Bioassays, benthic surveys and previous monitoring results were used to establish baseline conditions that were compared to sediment hazard quotients developed from SQS values and other parameters. Results from the study demonstrate that risks to aquatic organisms from nickel, TBT, 1,4-dichlorbenzene, bis(2-ehtylhexyl)phthalate, and PCBs exceeded guideline values in both the Duwamish River and Elliott Bay. Similarly, wildlife hazard quotients were developed for spotted sandpipers, river otters, bald eagle, and great blue herons from studies of surrogate species and existing data. Chemical exposure pathways from food ingestion, sediment ingestion and combined pathways were all evaluated. Risks were predicted to sandpipers from lead, copper, PCBs, and zinc in their food. In addition, lead posed a low risk to bald eagles and otters. Human cancer and non-cancer risk assessments from fish and shellfish ingestion were also conducted. PCBs and arsenic in fish posed health risks for humans consuming seafood about two times per month[65].

5.5 Identifying Potential for Recontamination

As part of a site study, an evaluation is conducted to assess the likelihood of recontamination after clean up. This is an important aspect of a site evaluation because at two sites, Denny Way and Pier 53-55, there is evidence that recontamination is occurring on the existing caps. Information on sources and contaminants currently contributing to sediment contamination is collected and documented. At the same time information on past contamination, non-source contaminants, sediment accumulation rate, sediment resuspension, and advection of toxicants from other sites is identified. Once this basic information is collected a computer model or series of models is run to predict the potential for recontamination.

Analytical models evaluating the potential for recontamination at a contaminated site have been used in Puget Sound since 1987. SEDCAM was used to evaluate the relationship between source loading and sediment accumulation in Commencement Bay.[66] The model uses sediment accumulation, contaminant loading, sediment mixing and chemical loss to biodegradation, chemical degradation, and diffusion. METSED 1.0, a similar model, combines SEDCAM and another model to address time varying bulk sediment loading or contaminant loading not addressed in SEDCAM.

[64] King County Department of Natural Resources 1998.
[65] King County Department of Natural Resources 1998, Appendix E.
[66] SEDCAM was developed by Tetra Tech and PTI for Ecology and EPA, King County Department of Metropolitan Services 1994, page 5-6.

A third model in use for evaluating potential recontamination, Officer and Lynch, describes the diffusion of toxicants through sediment layers. This model allows for a detailed input of resuspension and bioturbation in estimating sediment dynamics. Use of both the METSED 1.0 and Officer and Lynch models was proposed for the Duwamish/Diagonal cleanup project in the cleanup study workplan.[67] METSED 1.0 was used for the final evaluation.

The recontamination potential at Norfolk was evaluated using a modified SEDCAM/METSED model that uses hydrographic data based on 10 measurements for 19 years. However, this model is still viewed as a screening level model that is very conservative because it does not include some large factors such as tidal change and resuspension of sediment in the river.[68] The Elliott Bay Waterfront Recontamination Study did not use these models. The study evaluated potential recontamination of the Seattle Waterfront by incorporating the results of core samples and sediment trap data into sediment accumulation rates.[69] In addition, sediment resuspension rates were calculated based on erosion rates and bed shear stresses. Propeller wash resuspension was calculated based on measured propeller generated currents and by metering of passenger ferries. A conceptual model of the site was developed from the collected information.

5.6 Selecting Cleanup Alternatives

A number of strategies have been developed to evaluate and select appropriate remediation technologies for remediating contaminated sediments. Various approaches have been employed by the EPA Superfund program, Army Corps of Engineers/EPA Dredged Material Management Program, the Great Lakes Assessment and Remediation of Contaminated Sediments Program (ARCS),[70] and King County. Despite their differences, they all contain similar elements: an initial identification of potential remediation and disposal options followed by a detailed screening of these options. In the Superfund and King County approaches, an alternative matrix is developed and cleanup options are evaluated in parallel. The Army Corp of Engineers/EPA approach evaluates options in order of increasing complexity. ARCS incorporates elements of both approaches[71].

Initially, suitable remediation options must answer the following question: Will the remediation technology and process options be able to cleanup the site and achieve cleanup goals? Contaminant distribution, contaminant concentrations, site and sediment characteristics are all taken into consideration. If a technology is determined to be ineffective, it is immediately eliminated from further consideration.

Additional analysis and screening of the alternatives is conducted. The remaining cleanup technologies are assembled into a set of cleanup alternatives. In developing cleanup alternatives, there may be some instances, where more than one 'site unit' requires remediation. This is dependent on the distribution and concentration of contaminants of concern and is reflected in the assembly of cleanup alternatives.

Cleanup alternatives are further evaluated according to the following or similar criteria:

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[67] King County Department of Metropolitan Services 1994, page 5-7.
[68] Romberg, 1998 personal communication.
[69] Aura Nova Consultants, Inc. 1995 pages 55-72.
[70] USEPA Great Lakes National Program Office 1998.
[71] Ibid.

- Implementability - Can the remediation technology and process option be both implemented on site and permitted by regulatory authorities? Will the technology be logistically difficult to implement at the site? Will the remedial technology and process option conflict with regulatory or land-use requirements and based on policy, be difficult to obtain permits?

- Cost Effectiveness - What are the costs of each technology and process option relative to their implementability and efficacy? Remedial technologies having a high relative cost in relation to the benefit received are eliminated from further consideration.

- Adverse Impacts – Will natural resources, historic sites, existing land uses, and aesthetic values be adversely impacted? Technologies that may cause adverse impacts that can not be easily or effectively mitigated will be eliminated from further consideration.

A good review of decisionmaking strategies can be found in "Assessment and Remediation of Contaminated Sediments (ARCS) Program".[72]

The Washington State Sediment Management Standards require that cleanup alternatives be evaluated according to eight criteria:

- Protection of human health and the environment
- Compliance with cleanup standards and applicable laws
- Short term effectiveness of the proposed action
- Long-term effectiveness of the proposed action
- Implementability
- Cost
- Community concerns
- Recycling, reuse and waste management

6.0 SUMMARY

In the early 1980's, Puget Sound was identified as an estuary exhibiting major environmental problems. Declining water quality, due to permitted and unpermitted industrial discharges of toxics, CSO discharges, stormwater runoff, and past practices of disposing toxics into the marine environment was impairing wildlife and aquatic organisms. In addition, habitat loss from development, changing land use patterns and dredging was occurring at an alarming rate. The results of these activities led to much of the sediment contamination found today.

Numerous studies have been conducted in Puget Sound on sediment chemistry and the effects of sediment toxicity to aquatic organisms. The body of literature reviewed indicates that toxics found in sediments can be bioaccumulated in invertebrates as well as mammals. Histopathological effects have been correlated with higher than normal (reference) tissue concentrations of chemicals in fish and birds. Consumption of seafood containing high level of contaminants can increase the risk of cancer and non-cancer diseases to humans.

[72] Ibid.

A number of activities have taken place over the past 15 years to address sediment contamination in Puget Sound. In 1985, the Puget Sound Water Quality Authority was established by the Washington State Legislature to develop and oversee the implementation of a comprehensive management plan for Puget Sound. A plan was adopted in1986 directing the Ecology to develop Sediment Management Standards that were completed in 1991. In 1991, the plan was amended to include a long-term monitoring program designed to measure the health of Puget Sound.

During this same time period, Puget Sound was designated as an estuary of national significance and became part of the National Estuary Program, and the State Model Toxics Control Act was passed. In addition, a Natural Resource Damage Assessment lawsuit initiated by NOAA (*United States et. al. v. City of Seattle and the Municipality of Metropolitan Seattle*, Case 90-395) was filed to recover damages for injury to resources caused by contaminants in storm drains and CSOs. A Consent Decree was agreed to by the City of Seattle and King County (as Metro) which allocates funds to cleanup CSO sites identified by a designated group, the Elliott Bay/Duwamish Restoration Program (EBDRP).

The EBDRP identified four sites for remediation: Norfolk CSO, Seattle Waterfront, Pier 53/55 Sediment Capping Project, and Duwamish Pump Station CSO/Diagonal Way CSO/Storm Drain. Cleanup studies and work plans were developed for all four sites. In 1992, the Pier 53/55 Sediment Capping Project was completed and a monitoring program is underway. A recontamination study has been completed for the Seattle Waterfront Project and a site assessment has been started. The Norfolk project has been initiated and is scheduled for completion in 1999. Cleanup investigations are underway at the Duwamish/Diagonal site and a site assessment was completed in 1997.

King County’s Sediment Baseline Monitoring Plan identified Lander and King Streets as requiring cleanup and will be evaluating alternatives in the near future. Other sites in Puget Sound have been cleaned up or are targeted for sediment remediation. They include four Superfund sites: Commencement Bay, Wyckoff/ Eagle Harbor, Bellingham Bay, and Bremerton Harbor.

In 1996, Ecology published its Sediment Management Standards Contaminated Sediment Site List. Seven sites associated with King County CSO outfalls were identified as requiring cleanup evaluations: Denny Way, King, Lander, Hanford #2, Duwamish/Diagonal, Chelan, and Brandon. The Denny Way CSO site is undergoing cleanup investigations. The Duwamish/Diagonal is being remediated by EBDRP. The other five sites plus a portion of the Denny site will be evaluated in the Sediment Management Plan to determine if further actions are necessary.

As continued monitoring of Puget Sound takes place, it is likely that more areas of sediment contamination will be identified, additional cleanup activities will be proposed, and individual sites will be remediated. However, the long-term and cumulative impact of these activities on the environment and the effectiveness of cleanup technologies currently being employed are unknown. The effects of removing contaminated sediments through dredging increases water concentrations of toxicants, at least locally, and destroys the habitat of marine invertebrates. Similarly, capping an area to isolate sediment contaminants alters the ecology of the site. And even when an appropriate technology is implemented and contaminated sediments are isolated from clean sediments, it is not clear that there is any way to prevent recontamination from existing or future sources such as the case at Denny Way and Pier 53-55.

It is clear that site remediation alone will not correct past or future environmental problems associated with sediment contamination. Continued source reduction efforts should be encouraged and emphasized as part of a comprehensive sediment management program to remedy sediment contamination in Puget Sound.

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