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

PRELIMINARY REVIEW OF SEDIMENT REMEDIATION ALTERNATIVES

Task 1000
Draft Technical Memorandum

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EXECUTIVE SUMMARY

This technical memorandum presents a draft compilation of sediment remediation technologies for King County's consideration, based on a review of information and projects located primarily within the Puget Sound region. Sediment remedial technologies considered in this document include source control/natural recovery, containment, removal, disposal, and treatment.

Natural recovery is a process that may occur in sediments once the contaminant sources have been controlled. The containment technologies focus on placement of a thin- or thick-layer cap to prevent the release and mobilization of contaminants. Removal technologies involve the removal of sediments via hydraulic or mechanical dredging. Disposal technologies include both aquatic and upland disposal. Aquatic disposal can occur in either a nearshore fill or confined disposal site; upland disposal generally occurs at a lined landfill facility. Treatment technologies include chemical, physical and/or biological treatment of the sediments.

Each remediation technology is evaluated relative to technical feasibility, implementability, and cost. Technical feasibility involves the ability of that technology to be implemented, given site-specific conditions and the requirements necessary to implement that technology. Implementability includes the administrative and regulatory feasibility and availability of goods and services that would be required to implement a given technology. Cost includes direct and indirect costs associated with engineering, administrative, and foreseeable costs to implement a given technology. For each category, these technologies are evaluated relative to each other.

Additionally, each technology is discussed relative to the different process options that are available and have previously been used in Puget Sound. The information contained within this document, as generally summarized in the attached matrix (Table 1), will be used to develop preliminary (programmatic) remedial alternatives for seven identified King County CSO sediment cleanup sites.

Table 1 - Sediment Remediation Technology Matrix

Remedial Technology	Typical Process Option	Technical Feasibility: Established Design Criteria	Technical Feasibility: Most Frequently Encountered Design Constraint	Technical Feasibility: Primary Site Constraints (Technical)	Technical Feasibility: Constructability Concerns	Technical Feasibility: Long-term Monitoring Requirements	Technical Feasibility: Proven Applications (Field Scale) (see below)	Implementability: Land Use/ Navigation Impacts	Implementability: Habitat and Sensitive Species Impacts	Implementability: Short-Term Water Quality Impacts	Implementability: Other Environmental Impacts	Implementability: Habitat Enhancement/ Restoration Opportunities	Implementability: MTCA Preference for Permanent Solutions	Cost: Construction & O/M Costs	Cost: Potential Landowner Encumbrances/ Easements
Source Control / Natural Recovery															
	- Upland controls - Burial & biodegradation (OK) - Resuspension & dispersion - (marginal) - 10-year recovery periods allowed under SMS but not favored	- Sediment Management Standards (WAC 173-204) define data needs and modeling requirements for proper evaluation - Accepted models include SEDCAM, Officer and Lynch, and WASP	- Estimation of net sedimentation rates - Modeling of source control and dispersion processes require sophisticated mathematical techniques - Biological isolation	- Sufficient control of ongoing sources - Navigational requirements potentially requiring future dredging - Insufficient sedimentation rates to "drive" natural recovery	None	- Typically, detailed surface chemistry (and/or biological testing) data need to be collected over a period of up to 10 years to document the success of natural recovery	- Bellingham Bay (n) - Sitcum Waterway (j) - Los Angeles Bight (p) - Eagle Harbor (g/h) - Seattle Waterfront (c/d) - Puget Sound (deep)	- No impacts - However, may not be appropriate in prospective dredging areas or where landowners identify significant encumbrances related to subsurface contaminants	At some locations, sediment contamination can result in habitat impairment continuing through the recovery period	At some locations, ongoing sediment resuspension can result in minor impairment of water quality	- Environmental risks associated with sediment contaminants would be reduced over a period of time, until recovery is complete	None	This technology provides the least permament solution under MTCA	$0.1 to $2 per square yard (long-term monitoring)	Some land owners and managers (e.g., Washington State DNR) have identified potentially significant encumbrances related to subsurface contaminants, that may not be addressed by natural recovery
Containment Technologies															
Enhanced Natural Recovery/Thin-Layer Capping	- Windrows - Hydraulic placement - Clamshell bucket - Split hull barge - Flat barge wash	- Natural recovery assessment guidelines may also apply to this technology (see above) - Various Corps of Engineers and EPA documents provide design criteria (Palermo 1998a,b,c)	- Modeling of windrow dispersion processes can require sophisticated mathematical techniques - Cap integrity (erosion resistance) - Chemical isolation - Biological isolation	- Potential ongoing sources - Navigational requirements potentially requiring future dredging - Erosive forces (currents, prop wash, waves, anchors, etc.)	- Adequate lateral and vertical coverage	- Long-term monitoring intensity is typically intermediate between natural recovery (above) and thick capping (below) - Periodic monitoring of surface sediments (bathymetry, chemistry, recolonization)	- Pier 51(b) - Pier 53(c) - Pier 64 (d) - Eagle Harbor (h)	- Appropriate in areas currently having suitable navigational depth or after shallow dredging - Cap surface needs to be at least two feet below navigational depth - Possible encumbrances associated with subsurface contaminants	- Placement of a thin-layer cap commonly results in relatively minor short-term impacts to existing benthos (reduced impact relative to thick capping)	- Some "clean" turbidity associated with capping material - Minimal resuspension possible with cap material placement disturbing sediments	- Possible short-term navigation impacts during construction	- Some opportunities to enhance existing habitat by improving slopes, elevations, and grain size characteristics	This technology provides a relatively low preference solution under MTCA	$3 to $15 per square yard (construction and long-term monitoring) (considering the range of cap material sources) Open Water $25 to $60 per square yard (construction and long-term monitoring) (considering the range of cap material sources) Under Pier	Some land owners and managers (e.g., Washington State DNR) have identified potentially significant encumbrances related to subsurface contaminants, that may not be addressed by capping
Thick-Layer Capping	- Hydraulic placement - Clamshell bucket - Split hull barge - Flat barge wash	- Corps (Palermo 1998a) present guidance for design of caps - EPA (Palermo 1998b) presents guidance for design of caps - Corps (Palermo 1998c) present design recommendations for capping and CDFs in Puget Sound	- Cap integrity (erosion resistance) - Chemical isolation - Biological isolation	- Potential ongoing sources - Navigational requirements potentially requiring future dredging - Erosive forces (currents, prop wash, waves, anchors, etc.)	- Adequate lateral and vertical coverage - Potential mixing of capping material with sediments during placement	- Periodic monitoring (typically accomplished at years 1, 3, and 8 following capping) - Monitoring of surface sediments (bathymetry, chemistry, recolonization)	- Denny Way (a) - Pier 53 (c) - Eagle Harbor (g/h) - Simpson Tacoma Kraft (l)	- Appropriate in areas currently having suitable navigational depth or after shallow dredging - Cap surface needs to be at least two feet below navigational depth - Possible encumbrances associated with subsurface contaminants	- Placement of a thick cap results in temporary loss of existing benthic populations, with subsequent recovery	- Some turbidity associated with capping material - Minimal resuspension possible with cap material placement disturbing sediments	- Possible short-term navigation impacts during construction	- Some opportunities to enhance existing habitat by improving slopes, elevations, and grain size characteristics	This technology provides a relatively low preference solution under MTCA	$10 to $45 per square yard (construction and long-term monitoring) (considering the range of cap material sources) Open Water $75 to $180 per square yard (construction and long-term monitoring) (considering the range of cap material sources) Under Pier	Some land owners and managers (e.g., Washington State DNR) have identified potentially significant encumbrances related to subsurface contaminants, that may not be addressed by capping
Removal Technologies															
Hydraulic Dredging	- Suction - Cutterhead - Horizontal auger - Hand held	- Standard of practice - Corps/EPA have some guidance on turbidity	- Short-term water quality impacts - Residuals	- Potential ongoing sources - Disposal site can limit hydraulic dredging (e.g., typically not suitable for upland or CAD disposal) - Sediment characteristics can control effectiveness	- Water quality at point of dredging - Return water quality - Residual sediments - Debris impacts on process	Not applicable	- Sitcum (j)	Not applicable	- By deepening mudline depths, dredging can result in degradation of local habitat	- Moderate at point of dredging - Moderate to significant at point of discharge	- Possible short-term navigation impacts during construction	Not applicable	Not applicable	$4 to $40 per cubic yard (removal only) Open Water $100 to $250 per cubic yard (removal only) Under Pier	None
Mechanical Dredging	- Backhoe - Clamshell bucket - Environmental bucket	- Standard of practice - Corps/EPA have some guidance on turbidity	- Short-term water quality impacts - Residuals	- Potential ongoing sources - Confined areas (e.g., underpier or around piling) can limit access - Sediment characteristics can control effectiveness	- Water quality at point of dredging - Residual sediments - Debris impacts on process	Not applicable	- Terminal 91, Port of Seattle (e) - West Waterway CAD (f) - Eagle Harbor (h) - Simpson Tacoma Kraft (l) - Slip 3, Port of Tacoma (k) - One Tree Island Marina (m)	Not applicable	- By deepening mudline depths, dredging can result in degradation of local habitat	- Moderate at point of dredging - Moderate at point of discharge	- Possible short-term navigation impacts during construction	Not applicable	Not applicable	$4 to $70 per cubic yard (removal only) Open Water	None
Disposal Technologies															
Confined Aquatic Disposal	- Subtidal depression/ pit - Nearshore intertidal	- Ecology (1990) presents general guidance on design aspects of CADs - WES (1998) present design recommendations for capping and CDFs in Puget Sound	- Cap integrity - Short-term water quality impacts during disposal - Long-term water quality impacts - Seismic stability	- Navigational requirements - Erosive forces (currents, prop wash, waves, anchors, etc.)	- Temporary side slope stability (if required) - Underwater berm construction (if required) - Contaminated sediment placement control - Capping disposed soft sediments	- Periodic monitoring for 10 to 30 years following construction - Monitoring of surface sediments (bathymetry, chemistry, recolonization) - Monitoring of water quality as practicable	- West Waterway CAD (f) - One Tree Island Marina (m) - Los Angeles Shallow Water Habitat Site (u) - Ross Island Sand and Gravel Pit (o) - Boston Harbor Navigation & Improvement Project (q) - Port Authority of New York/New Jersey Newark Bay CAD (r)	- Cap surface needs to be at least two feet below navigational depth - Possible encumbrances associated with subsurface contaminants	- Construction of a CAD facility results in temporary loss of existing benthic populations, with subsequent recovery	- Moderate during disposal - Function of currents, water depth, material type, and disposal site design	- Possible short-term navigation impacts during construction	- Significant opportunities to use the dredged material beneficially for restoration or enhancement of mudlflats, eelgrass meadows, etc.	- Site-specific "permanence" determination; Placement of contaminated sediment in some CAD environments can significantly restrict contaminant mobility	$25 to $70 per cubic yard (removal, facility construction, disposal, long-term monitoring) (high confinement volume to low confinement volume)	Some land owners and managers (e.g., Washington State DNR) have identified potentially significant encumbrances related to subsurface contaminants that may be associated with CADs
Nearshore Fill		- Corps (1987) presents guidance for CDF sizing and design - Ecology (1990) presents general guidance on design aspects of nearshore fills - WES (1998) present design recommendations for capping and CDFs in Puget Sound	- Habitat impacts - Short-term water quality impacts during disposal - Long-term water quality impacts - Seismic stability	- Site capacity and geometry - Hydrogeologic conditions	- Berm stability - Return water quality - Capping disposed soft sediments	- Periodic monitoring for 10 to 30 years following construction - Monitoring of water quality in berm typically required - Sediment and habitat monitoring site-specific	- Terminal 91, Port of Seattle (e) - Eagle Harbor (h) - Sitcum Waterway (j) - Slip 3, Port of Tacoma (k) - Stage 1 Marine Terminal Improvements, Port of Everett (v)	- Area has to be abandoned for navigational use - Landowner has to accept abandonment of water uses	- Construction of a nearshore fill results in permanent loss of aquatic habitat, potentially requiring extensive mitigation	- Moderate to significant during disposal - Function of CDF geometry and sediment characteristics	- Possible short-term navigation impacts during construction	- Some opportunities to improve habitat quality on or near the face of the containment berm	- Site-specific "permanence" determination; Placement of contaminated sediment in some nearshore fills can significantly restrict contaminant mobility	$25 to $120 per cubic yard (removal, facility construction, disposal, long-term monitoring) (high confinement volume to low confinement volume)	Some land owners and managers have identified potentially significant encumbrances related to subsurface contaminants that may be associated with nearshore fills
Upland/Landfilling	- Municipal landfill - Monofill	- Corps (1987) presents guidance for CDF sizing and design - Ecology (1990) presents general guidance on design aspects of upland disposal - WES (1998) present design recommendations for capping and CDFs in Puget Sound	- Sediment handling - Short-term water quality impacts during disposal - Long-term water quality impacts	- Site capacity for monofills - Offloading facility	- Dewatering sediments - Double handling sediments - Transporting sediments	- Periodic monitoring for 10 to 30 years following construction - Monitoring of groundwater quality required - O&M components	- Eagle Harbor (h) - Bremerton Shipyard (i)	Not applicable	- Construction of an upland disposal facility results in displacement and/or modification of existing upland habitat	- Moderate to significant - Function of dewatering system and sediment characteristics	- Increased community/worker exposure during transportation	- Typically, few habitat enhancement or restoration opportunities exist with upland disposal options	- Site-specific "permanence" determination; Placement of contaminated sediment in some upland landfills can significantly restrict contaminant mobility	$60 to $100 per cubic yard (removal and disposal at regional landfill) $50 to $120 per cubic yard (monofill; removal, facility construction, long-term monitoring; no property acquistion costs)	Some land owners and managers have identified potentially significant encumbrances related to subsurface contaminants that may be associated with upland landfills
Treatment Technologies															
Physical Treatment/Dewatering	- Belt Presses - Additives - Hydrocyclones - Grizzly	- EPA (1994) present general guidance for selecting equipment	- Large volumes and low contaminant concentrations	- Appropriate sediment grain size for process - Contaminant segregation among sediment grain sizes	- Double handling sediments - Residual contaminants/products	None	- Bayou Bonfouca Sediment Remediation (s) - Marathon Battery Superfund (t)	Not applicable	Not applicable	- Waste water from treatment stream may require further controls	- Possible local air quality and noise impacts	None	- Material segregation can provide some degree of "permanence" under MTCA	$15 to $200 per cubic yard (dewatering) (USEPA 1994) $0.5 to $100 per cubic yard (physical separation)	None
Chemical Treatment	- Thermal Treatment - Stabilization - Solvent extraction - Low Temperature Thermal Desorption - Hazleton Maxi-Clone/Maximstrip Air Stripping - Slurry Aeration/Oxidation	- EPA (1994) present general guidance for selecting equipment - Vendors can prepare specific designs	- Large volumes and low contaminant concentrations	- Appropriate contaminant types and levels	- Potential need to dewater sediments - Double handling sediments - Area for treatment train - Potential residual contaminants/products	None	- Bayou Bonfouca Sediment Remediation (s) - Marathon Battery Superfund (t) - Eagle Harbor (h) (~50cy to remove RCRA characteristics prior to landfilling)	Not applicable	Not applicable	- Waste water from treatment stream may require further controls	- Possible local air quality and noise impacts	None	- Provides a permanent solution to the extent that quantitative segregation and/or destruction of hazardous substances occurs	$100 to $400 per cubic yard (treatment only) (USEPA 1994)	None
Biological Treatment	- Bioslurry treatment - Land treatment (including pytoremediation)	- EPA (1994) present general guidance for selecting equipment - Vendors can prepare specific designs	- Large volumes and low contaminant concentrations	- Appropriate contaminant types and levels	- Potential need to dewater sediments - Double handling sediments - Area for treatment train	None		Not applicable	Not applicable	- Waste water from treatment stream may require further controls	- Possible local air quality and noise impacts	None	- Provides a permanent solution to the extent that quantitative destruction of hazardous substances occurs	$20 to $270 per cubic yard (treatment only) (USEPA 1994)	None

Proven Applications:

a) Denny Way CSO, Seattle (Sumeri, 1996; Metro, 1993))
b) Pier 51 WSDOT Ferry Terminal Expansion, Seattle (Sumeri, 1996)
c) Pier 53 CSO, Seattle (Sumeri, 1996; King County, 1998)
d) Pier 64, Seattle (Sumeri, 1996)
e) Port of Seattle, Terminal 91 Nearshore Fill (Hotchkiss and Boatman, 1994)
f) West Waterway CAD, Seattle (Sumeri, 1996)
g) Eagle Harbor - East Harbor Operable Unit, Bainbridge Island (Sumeri, 1996)
h) Eagle Harbor - West Harbor Operable Unit, Bainbridge Island (Verduin, et. al., 1998)
i) Bremerton Shipyard
j) Port of Tacoma, Sitcum Waterway (Port of Tacoma, 1992; Verduin, et. al., 1994)
k) Port of Tacoma, Slip 3 Nearshore Fill
l) Simpson Tacoma Kraft Co., Tacoma (Sumeri, 1996)
m) One Tree Island Marina (Sumeri, 1996)
n) Bellingham Bay, Washington
o) Ross Island Sand and Gravel Pit
p) Los Angeles Bight
q) Boston Harbor Navigation and Improvement Project (Murray, et. al. 1998)
r) Port Authority of New York/New Jersey Newark Bay CAD (Knoesel, et. al. 1998)
s) Bayou Bonfouca Sediment Remediation, Slidell, LA (PIANC, 1997)
t) Marathon Battery Superfund Dredging and Disposal, Cold Spring, NY (PIANC, 1997)
u) Los Angeles Shallow Water Habitat Site (Messa, 1995)
v) Stage 1 Marine Terminal Improvements, Port of Everett

INTRODUCTION

King County recently contracted with Brown & Caldwell and its subconsultants (Herrera Environmental Consultants and Anchor Environmental) to develop a Sediment Management Plan (SMP) Program for King County's Combined Sewer Overflow (CSO) Program. One of the initial tasks (Task 1000) of this effort is to review, evaluate, and summarize commonly available sediment remediation technologies that may be relevant for consideration within the SMP project area. This technical memorandum presents a draft compilation of sediment remediation technologies for King County's consideration, based on a review of information and projects located primarily within the Puget Sound region. The information contained within this document will be used to develop preliminary (programmatic) remedial alternatives for each of the seven identified King County CSO sediment cleanup sites.

SEDIMENT REMEDIAL TECHNOLOGIES

Many sediment remediation options have been developed and evaluated for application within Puget Sound and others regions of the world containing contaminated sediments. USEPA (1994) presents a guidance document discussing most of these options. The purpose of this document is to provide an initial review of sediment remediation options, particularly these technologies and process options that have been successfully demonstrated as practical and cost-effective.

Sediment remedial technologies considered in this document can be divided into five main categories:

- Source control/natural recovery
- Containment technologies
- Removal technologies
- Disposal technologies
- Treatment technologies

Each of these technologies is discussed below including descriptions of different process options used in Puget Sound.

Table 1 summarizes an evaluation of the different technologies. Evaluation criteria used in Table 1 include the following:

- **Technical Feasibility**
  - **Established Design Criteria**. Are there established design criteria and procedures for the technology?
  - **Most Frequently Encountered Design Constraint**. What is the most commonly encountered design aspect of the technology?
  - **Primary Site Constraints (Technical).** What primary site constraints can have the most significant impact on design and implementation?
  - **Constructability Concerns.** What are typically the critical issues associated with this technology during construction?

  - **Long-term Monitoring Requirements**. What long-term monitoring programs are the regulatory agencies commonly requiring to confirm the success of the remedial technology?

  - **Proven Applications (Field Scale).** Where has this technology been implemented, and how successful was the project?

- **Implementability**

  - **Land Use/Navigation Impacts**. What impact could this technology have on existing or future land use or navigation in the area of the remediation?

  - **Habitat and Sensitive Species Impacts**. Does the technology have potential habitat or sensitive species impacts?

  - **Short-term Water Quality Impacts**. Are there water quality impacts associated with implementation of the technology?

  - **Other Environmental Impacts**. Are there other significant environmental impacts possible with this remedial technology?

  - **Habitat Enhancement/Restoration Opportunities**. Is there a significant opportunity to enhance or restore habitat as part of this remedial technology?

  - **MTCA Preference for Permanent Solutions**. Does the remedial technology satisfy or partially satisfy the preference for use of permanent solutions to the maximum extent practicable as set forth in the Model Toxics Control Act (MTCA) Cleanup Standards Regulation and other regulatory programs?

- **Cost**

  - **Construction & O/M Costs**. What have been the observed unit costs for implementing and maintaining this technology? Because costs are very sensitive to site conditions as well as quantity of material remediated, a range of unit costs is presented in this analysis.

  - **Potential Landowner Encumbrances/Easements**. What other costs could be expected from existing landowners for easements or mitigation for encumbrances potentially resulting from the implementation of the remedial technology?

SOURCE CONTROL/ NATURAL RECOVERY

Natural recovery of contaminated sediment may occur over time through a combination of several processes including chemical degradation, diffusion from the sediment matrix into the water column, burial of contaminated sediment under newly deposited clean material, and mixing of the contaminated sediment with clean sediments above and below through bioturbation. Since the deposition of overlying clean sediment plays a role in the process of natural recovery, this process can be enhanced by actively providing a layer of clean sediment to the target area. This is often referred to as "enhanced" natural recovery or thin-layer capping, and generally consists of placing approximately 15 to 30 centimeters (6 to 12 inches) of clean sediment over the existing contaminated sediments. Thin-layer capping is discussed in Section 4.1.

Figure 1 presents a general schematic of the natural recovery process.

Source control and natural recovery have been demonstrated as an effective process, and subsequently approved as a major element of sediment cleanup plans at the following projects/locations:

- **Commencement Bay Nearshore/Tideflats Superfund Site** (Sitcum Waterway; Hylebos Waterway; and Thea Foss Waterway) (EPA, 1989)
- **Eagle Harbor Superfund Site – West Harbor Operable Unit (WHOU)** (EPA, 1995)
- **Bellingham Bay MTCA Site** (Anchor, 1998)
- **Seattle Waterfront – North Colman Dock** (Hart Crowser, 1997; informal approval only)

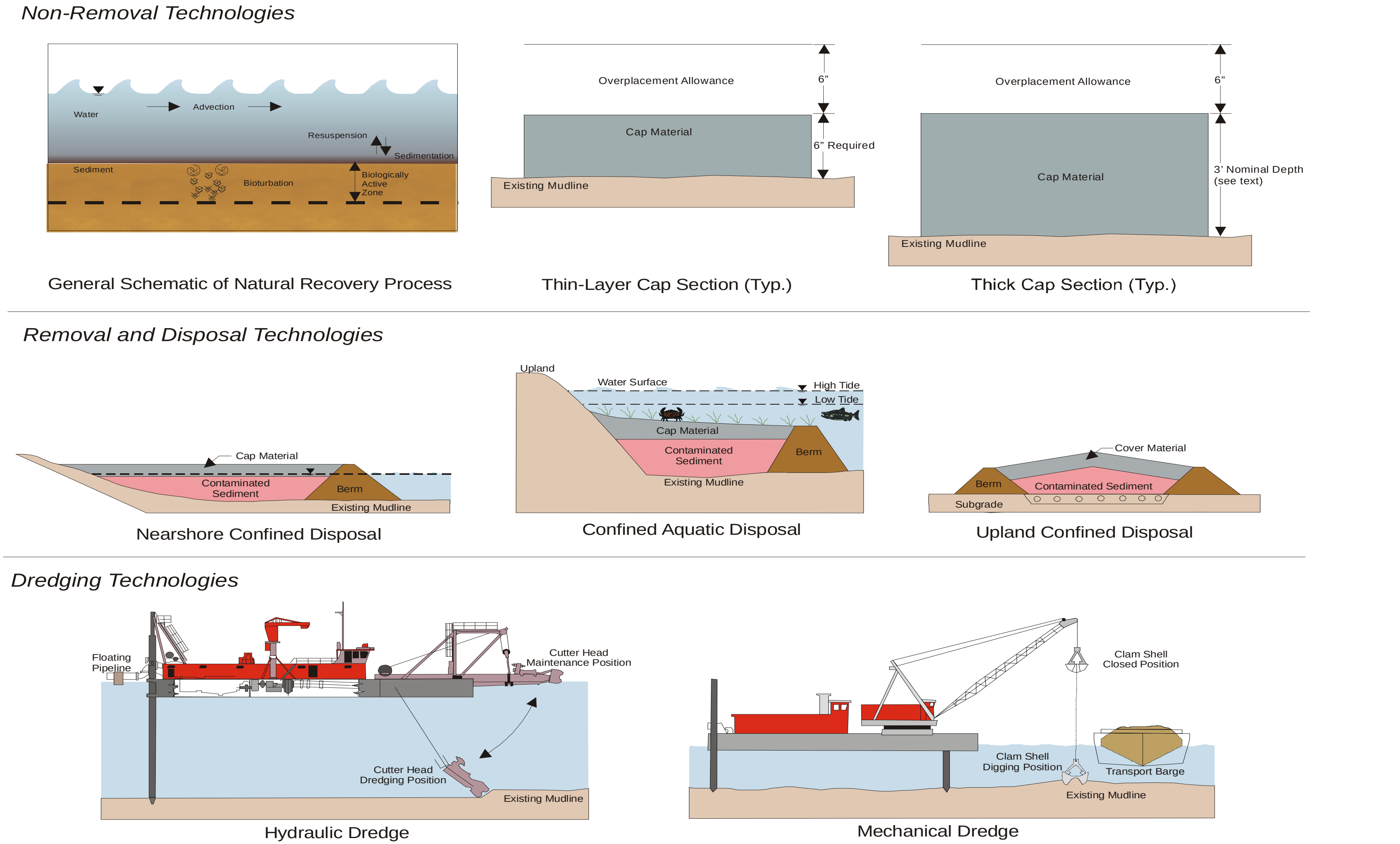

Figure 1. Sediment Remediation Technologies

IN SITU CONTAINMENT TECHNOLOGIES

In situ containment technologies are typically the most cost effective active remediation approach addressing contaminated sediments. They offer a means to remediating impacted sediments without having to deal with the costs, environmental impacts, and permitting associated with removal and disposal. Two *in situ* containment technologies are available: thin layer capping and thick layer capping.

Enhanced Natural Recovery/Thin-Layer Capping

Enhanced natural recovery (ENR)/thin-layer capping is a technology that enhances the natural recovery process already occurring at a site by accelerating the sedimentation process. This enhancement is the introduction of clean material to the impacted area.

Placement of a thin cap can be implemented by a number of common methods including:

- **Windrows.** Capping material is placed in mounded rows perpendicular to the predominant current direction. The current action evenly distributes the material over the impacted area. This method has been used on beach nourishment projects.

- **Clam Shell Bucket**. Capping material is placed by clamshell bucket over the target area. This approach needs moderate water depth (greater than 10 feet) and is typically used in areas without large unobstructed open water areas.

- **Split Hull Barge**. Capping material is placed by slowly moving an opening bottom dump barge full of capping material over the target area. This approach needs deeper water (greater than 16 to 20 feet) without in-water structures (such as dolphins or piers) in the target area.

- **Wash off Flat Barge**. Capping material is placed by washing material off of a flat haul barge over the target area. This approach needs moderate water depth (greater than 10 feet) without in-water structures (such as dolphins or piers) in the target area and over soft sediments.

- **Hydraulic**. Capping material is hydraulically dredged from an *in situ* source or off of a haul barge, piped to the disposal site, and placed using a diffuser which sprinkles the material over the sediments. This approach is often used for capping under piers or other structures, capping soft sediments, or in areas located close to a capping material source.

Materials used for capping can be comprised of either:

- **Clean Sediment Material**. Sediment dredged for navigational purposes can be beneficially reused as capping material. For instance, Corps maintenance dredged material has been successfully reused for capping at the Eagle Harbor - EHOU and Seattle Waterfront locations. Alternatively, if a nearby source of clean material is available, this can be another source of clean sediment. One drawback with this source of material is that the grain size distribution of the material is likely limited. A royalty fee may be required to the Department of Natural Resources for the material. Typical navigational dredge material sources in the Puget Sound are from the Duwamish River Turning Basin and the Snohomish River Settling Basin. The Duwamish River requires between 30,000 to 50,000 CY of dredging every two years beginning in 1999 (Sumeri, 1998). The Snohomish River requires between 200,000 to 300,000 CY of dredging every two to three years with the next dredging event in 2000. Table 2 summarizes the potentially available navigational dredge capping material.

- **Upland Materials**. Capping material can be purchased from an upland quarry and hauled to the site. Although this source is generally more expensive than using clean sediments, more flexibility with grain size distribution is available.

Figure 1 presents a typical cap section for a thin-layer cap.

ENR and thin layer capping has been implemented at the following projects:

- **Pier 51 Washington Department of Transportation (WSDOT) Ferry Terminal Expansion, Seattle** (Sumeri, 1996). Implemented in 1989.

- **Pier 53 CSO, Seattle** (Sumeri, 1996; Metro, 1993). Implemented in 1992.

- **Pier 64, Seattle** (Sumeri, 1996). Implemented in 1994.

- **Eagle Harbor – WHOU, Bainbridge Island** (Verduin, et. al., 1998). Implemented in 1997.

Thick-Layer Capping

The thick-layer cap technology is similar to the ENR/thin-layer cap technology except a thicker cap section, generally twice as thick, is placed. The intent of the thick cap is to provide additional resistance to erosive forces or to provide additional isolation if necessary. In Puget Sound, a minimum of 3 feet is typically used for thick layer capping.

A thick cap would be constructed with similar process options described in Section 4.1 for a thin-layer cap. The windrow placement technique may not be appropriate however for a thick cap.

Figure 1 presents a typical cap section for a thick-layer cap.

Thick layer capping has been implemented at the following projects:

- **Simpson Tacoma Kraft Co., Tacoma** (Sumeri, 1996). Implemented in 1988.
- **Denny Way CSO, Seattle** (Sumeri, 1996: Metro, 1993). Implemented in 1990.
- **Pier 53 CSO, Seattle** (Sumeri, 1996; King County, 1998). Implemented in 1992.
- **Eagle Harbor – East Harbor Operable Unit (EHOU), Bainbridge Island** (Sumeri, 1996). Implemented in 1993.
- **Eagle Harbor – WHOU, Bainbridge Island** (Verduin, et. al., 1998). Implemented in 1997.

Table 2. Capping Material Sources and Availability[1]

Year	Source	Available Volume (in 1000 cubic yards)
1999	Duwamish Turning Basin	30 to 50
2000	Snohomish Settling Basin	200 to 300
2001	Duwamish Turning Basin	30 to 50
2002-3	Snohomish Settling Basin	200 to 300
2003	Duwamish Turning Basin	30 to 50
2004-6	Snohomish Settling Basin	200 to 300
2005	Duwamish Turning Basin	30 to 50
2006-9	Snohomish Settling Basin	200 to 300
2007	Duwamish Turning Basin	30 to 50
2009	Duwamish Turning Basin	30 to 50

[1] Sumeri, 1998

REMOVAL TECHNOLOGIES

Contaminated sediments can be removed via two methods: hydraulic and mechanical dredging. Each is unique, providing distinct benefits and disadvantages.

Hydraulic Dredging

Hydraulic dredges remove and transport in the form of a slurry. Hydraulic dredges provide an economical means of removing large quantities of contaminated sediments.

Typical process options for hydraulic dredges include the following:

- **Suction Head.** This type of hydraulic dredge does not employ the use of a cutterhead to loosen material. This type of dredge would likely be limited to a small volume of very soft sediments located in a confined area. Stiffer sediments would likely not flow as efficiently towards a plain suction dredge therefore lowering the efficiency of the system.

- **Cutterhead.** This type of hydraulic dredge is the most common hydraulic dredge in the United States. The cutterhead rotates around the suction pipe loosening the material being dredged and directing it towards the pipe. This type of dredge makes “zig zag” arcs back forth as it dredges. Cutterhead dredges in the Pacific Northwest range in size from 16 to 26 inches.

- **Horizontal Auger.** This type of hydraulic dredge employs a level horizontal auger, which cuts and directs the sediment toward the center where the suction pipe is located. This type of dredge moves in a forward direction making parallel cuts with each pass.

- **Hand Held.** A hand held type hydraulic dredge is typically used to remove sediments in confined or very shallow inaccessible areas. These dredges can be 4- to 8-inch diameter lines usually operated by a diver or wader in shallow water.

Sediment is most economically transported from a hydraulic dredge to a disposal site via a pipeline. At the disposal site, the dredge slurry is allowed to settle before the effluent is discharged.

Figure 1 illustrates a typical cutterhead hydraulic dredge.

Environmental hydraulic dredging in the Pacific Northwest has only occurred on one main project. The Port of Tacoma completed the Sitcum Waterway Remediation Project in 1994 (Port of Tacoma, 1992; Verduin, et. al., 1994) using hydraulic dredging.

Mechanical Dredging

Mechanical dredging removes bottom sediment through the direct application of mechanical force to dislodge and excavate the material. The material is then hoisted to the surface at near *in situ* densities and typically placed on a barge for shipment.

Typical process options for mechanical dredges include the following:

- **Backhoe.** Backhoe dredging equipment usually consists of a standard upland backhoe working off of a barge. A backhoe is limited to its reach depth.

- **Clamshell Bucket.** The clamshell bucket dredge is likely the most common type of mechanical dredge in the area. The dredge simply consists of a crane on a spud barge. Buckets range in size from 3 to 50 CY in size with the 4 to 10 CY capacity the most common.

- **Environmental Bucket.** A variation of the clamshell bucket is the environmental or closed bucket. This bucket is closed at the top, which limits spillage and leakage from the bucket and also protects the sediments within the bucket from disturbance. The Cable Arm bucket is a type of environmental bucket that a few northwest contractors have. Because of the cabling mechanisms this bucket can provide a level cut after dredging. The Cable Arm bucket is lighter weight and is therefore commonly limited to maintenance material or other soft sediments.

Sediments are most economically transported from a mechanical dredge to a disposal site via either a bottom-dump or flat barge.

Figure 1 illustrates a typical mechanical dredge.

Mechanical dredging has been implemented at the following projects:

- **West Waterway CAD, Seattle** (Sumeri, 1996). Implemented in 1984.

- **One Tree Island Marina, Olympia** (Sumeri, 1996). Implemented in 1987.

- **Port of Seattle, Terminal 91** (Hotchkiss and Boatman, 1994). Implemented in 1988.

- **Port of Tacoma, Slip 2**. Implemented in 1988.

- **Bremerton Shipyard, Pier D.** Implemented in 1994.

- **Stage 1 Marine Terminal Improvements, Port of Everett.** Implemented in 1997.

- **Eagle Harbor – WHOU, Bainbridge Island** (Verduin, et. al., 1998). Implemented in 1997.

Disposal Technologies

There are generally three types of confined disposal facilities (CDFs) available for the disposal of contaminated sediments:

- Confined aquatic disposal (CAD);
- Nearshore confined disposal; and
- Upland.

Confined Aquatic Disposal

This type of CDF entails confining the contaminated sediment below water in either a natural depression, pit or bermed area.

Typical variations of CAD facilities include:

- **Pit CAD.** Either a natural depression or excavated pit is filled with contaminated sediment and then capped to create a pit-type CAD.
- **Nearshore CAD.** A toe berm is constructed offshore along a shoreline. Contaminated sediment is placed behind the berm and then a cap is placed to confine the sediments. The surface of the CAD can be constructed to convert deeper water substrate into shallower water (e.g., intertidal and shallow subtidal) habitat.

Figure 1 illustrates a nearshore CAD facility.

CADs have been utilized at the following projects:

- **West Waterway CAD, Seattle** (Sumeri, 1996). Implemented in 1984.
- **One Tree Island Marina, Olympia** (Sumeri, 1996). Implemented in 1987.
- **Los Angeles Shallow Water Habitat Site** (Mesa, 1995). Implemented in 1995.
- **Boston Harbor Navigation and Improvement Project** (Murray, et. al. 1998; IDR, 1998). Implemented in 1997.
- **Port Authority of New York/New Jersey Newark Bay CAD** (Knoesel, et. al. 1998). Ongoing
- **Ross Island Sand and Gravel Pit, Portland, OR.** Ongoing

In addition, CADs have been evaluated through the preliminary design stage at Southwest Harbor (Port of Seattle, 1994), Thea Foss Waterway (City of Tacoma, 1998) and Hylebos Waterway (HCC, 1998).

Nearshore Fill

A nearshore CDF is a type of fill constructed underwater along the shoreline. A berm is constructed of clean material near the shoreline. The lower layer of the area between the berm and the shoreline is then filled with contaminated sediment delivered by barge or by a hydraulic dredge. The upper layer of the area is covered with clean sediment or fill material until it is above tidal level. Nearshore fills create new land that can be used for public shoreline access or for businesses that depend on being near water. Nearshore CDFs constructed in Puget Sound have often been integrated with upland redevelopment, and can also be sited on existing contaminated sediment areas to provide further efficiencies.

Figure 1 illustrates a nearshore CDF.

Five nearshore CDF have been completed in the Puget Sound region:

- **Port of Seattle, Terminal 91** (Hotchkiss and Boatman, 1994). Implemented in 1988.
- **Port of Tacoma, Slip 2**. Implemented in 1988.
- **Sitcum Waterway Remediation Project (Milwaukee Waterway Fill)** (Port of Tacoma, 1992; Verduin, et. al., 1994). Implemented in 1994.
- **Stage 1 Marine Terminal Improvements, Port of Everett.** Implemented in 1997.
- **Eagle Harbor – WHOU, Bainbridge Island** (Verduin, et. al., 1998). Implemented in 1997.

Upland/Landfilling

With this option, contaminated sediments are dredged and placed in a landfill that is on dry land, away from the aquatic environment. The landfill would include liners and a special water collection system so that leachate draining through the landfill does not escape and contaminate groundwater.

There are typically two types of landfilling options:

- **Monofill.** Under this option a project specific landfill is created to contain all the sediments. The landfill would need to be designed to meet the State's minimum functional standards for a landfill.

- **Municipal Landfill.** Sediments would be transferred to an existing RCRA Subtitle C or D disposal facility.

Figure 1 illustrates a nearshore CDF.

The following Puget Sound projects have utilized upland disposal:

- **Bremerton Shipyard, Pier D.** Implemented in 1994.

- **Eagle Harbor – WHOU, Bainbridge Island** (Verduin, et. al., 1998). Implemented in 1997.

TREATMENT TECHNOLOGIES

Treatment technologies are generally the least cost-effective means to remediating contaminated sediments. This is because sediment remediation generally involves large volumes of sediment with relatively low contaminant levels. Treatment technologies can become more cost-effective for remediating sites of relatively low volume and/or high contaminant levels. Treatment technologies can be classified into three broad categories: physical; chemical; and biological.

Physical Treatment

Physical treatment technologies primarily focus on dewatering sediment to improve handling and separation to minimize contaminants.

Dewatering process options include:

- **Belt Press.** Belt presses are generally considered the most economical type of mechanical dewatering technology. The sediment is run through a conveyor system that squeezes the water out.

- **Additives.** Additives such as fly ash or cement can be added to the sediment to absorb the free water. These additives increase the strength of the sediment, but can also increase the unit weight.

Physical separation technologies can be used if contaminants are common to one grain size. For instance, if the contaminant is associated with the silt and clay sized fraction of the mass, then a separation process that can break off this fraction could be used. Physical process options include:

- **Hydrocyclones.** Hydrocyclones are typically cone-shaped vessel with a cylindrical section containing a tangential feed entry port and axial overflow port on top and an open apex at the bottom. They can fairly accurately separate sediments into coarse- and fine-grained portions (USEPA, 1994). Hydrocyclones have been used on pilot-scale demonstration projects in the Great Lakes (USEPA, 1994).

- **Grizzly, Vibrating Screen.** Debris and other larger sized materials can be screened out by running the sediment through screens or grizzlies. These type of separators have been used on small pilot-scale demonstration projects in the Great Lakes (USEPA, 1994).

Physical separation/dewatering treatment have not been used in the Puget Sound region but have been completed full scale on a few projects around the United States:

- **Bayou Bonfouca Sediment Remediation, Slidell, LA** (PIANC, 1997)

- **Marathon Battery Superfund Dredging and Disposal, Cold Spring, NY** (PIANC, 1997) Implemented 1995.

Chemical Treatment

Chemical treatment technologies primarily focus on stabilizing the contaminant in the sediment matrix. Chemical process options include:

- **Thermal Treatment (Cement Plant).** A local cement plant may be able to use the dredged material as raw material to create cement with its rotary kiln process, thereby recycling it. The process to produce cement raises the raw feed stock (i.e., sediment, soil, sand and contaminants) to very high temperatures. This causes the material to become semi-molten, forming the cement. During the process, organics are destroyed and heavy metals are immobilized in the clinker at the bottom of the kiln, making them unavailable to leaching. This clinker is ground and combined with gypsum to make cement. Holnam is a local manufacturer located on the Duwamish River in Seattle who has been approached about this process. This option may be limited to fresh water sediments, as marine sediments may lower the cement's strengths.

- **Stabilization.** The sediments would be run through a pug mill and a stabilizing agent would be added to the sediments. Agents can include fly ash, lime, and Portland cement. The mixture would control how the sediment placed and cured. A flowable type mix would be poured into its disposal site or temporary holding area and allowed to cure. A dry mix would be spread as soil and compacted with earth moving equipment. Either scenario would produce a material significantly stronger than the raw sediment and less leachable.

- **Solvent Extraction.** Similar to soil washing, but uses a solvent rather than water-based wash solution.

- **Low Temperature Thermal Desorption.** Commercially available technology that heats sediment to 200 to 600ºF to volatilize water and organic compounds. Typically a vacuum system collects the off-gas and the off-gas is oxidized.

- **Hazleton Maxi-Clone/Maximstrip Air Stripping.** Hydraulically dredged material is screened to ½ inch then passed through a series of Maxi-Clones. Volatiles are stripped from the slurry and sediment in each Maxi-Clone. Treatment may be enhanced by the addition of oxidizing agents such as ozone or peroxide.

- **Slurry Aeration/Oxidation.** Dredged sediment is placed in aeration tanks at about 10 to 20 percent solids and treated in batch, semi-continuous, or continuous mode. Treatment may be enhanced by the addition of oxidizing agents such as ozone or peroxide. Ambient air is injected to strip VOCs and a mixer is used to keep solids in suspension. Vapors are collected and treated.

Chemical treatment has been completed full scale on one project in the Puget Sound region and on a few projects around the United States:

- **Eagle Harbor – WHOU, Bainbridge Island** (Verduin, et. al., 1998). Implemented in 1997.

- **Bayou Bonfouca Sediment Remediation, Slidell, LA** (PIANC, 1997).

- **Marathon Battery Superfund Dredging and Disposal, Cold Spring, NY** (PIANC, 1997) Implemented 1995

Biological Treatment

Biological treatment technologies are a managed or spontaneous process in which microbiological processes are used to degrade or transform contaminants to less toxic or nontoxic forms. Because of high costs and uncertain effectiveness, this technology has not been applied to sediment cleanup projects with the Pacific Northwest. Biological process options include:

- **Bioslurry Treatment.** Anaerobic or aerobic activated sludge processes.

- **Land Treatment (including pytoremediation).** Sediment is mixed with amendments and placed on a treatment area that typically includes leachate collection. The soil and amendments are mixed using a windrow composter, conventional tilling equipment, or other means to provide aeration. Moisture, heat nutrients, oxygen, and pH can be controlled to enhance biodegradation. Other organic amendments such as wood chips, potato waste, or alfalfa are added to composting systems.

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