*L*ower *D*uwamish *W*aterway *G*roup

Port of Seattle / City of Seattle / King County / The Boeing Company

Lower Duwamish Waterway Remedial Investigation/Feasibility Study:

IDENTIFICATION OF CANDIDATE CLEANUP TECHNOLOGIES FOR THE LOWER DUWAMISH WATERWAY SUPERFUND SITE

FINAL

Prepared for

The U.S. Environmental Protection Agency
Region 10
Seattle, WA

The Washington State Department of Ecology
Northwest Regional Office
Bellevue, WA

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List of Acronyms

°F	degrees Fahrenheit
°C	degrees Celsius
AOC	Administrative Order on Consent
ARAR	applicable or relevant and appropriate requirement
ARCS	Assessment and Remediation of Contaminated Sediments
ASTM	American Society for Testing and Materials
CDF	confined disposal facility
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
cfs	cubic feet per second
CLU-IN	Hazardous Waste Clean-Up Information
COC	chemical of concern
COPC	chemical of potential concern
CSO	combined sewer overflow
CTF	confined treatment facility
CTM	Candidate Technologies Memorandum
cy	cubic yard
cy/hr	cubic yards per hour
DMMP	Dredged Material Management Program
DNR	Washington State Department of Natural Resources
DOER	Dredging Operations and Environmental Research
EAA	Early Action Area
Ecology	Washington State Department of Ecology
EE/CA	engineering evaluation/cost analysis
EIS	environmental impact statement
ENR	enhanced natural recovery
EPA	Environmental Protection Agency
FS	feasibility study
GLNPO	Great Lakes National Program Office
GRA	general response action
HDPE	high-density polyethylene
HTTD	high-temperature thermal desorption
ISC	*in situ* capping
kg	kilogram
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
LTTD	low-temperature thermal desorption
m^3/s	cubic meters per second
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MNR	monitored natural recovery
MTCA	Model Toxics Control Act
MUDS	Multi-User Disposal Site
NCP	National Contingency Plan
NPDES	National Pollutant Discharge Elimination System

List of Acronyms

OSWER	Office of Solid Waste and Emergency Response
OU	operable unit
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
ppm	parts per million
RAO	remedial action objective
RCRA	Resource Conservation and Recovery Act
RETEC	The RETEC Group, Inc.
RI	remedial investigation
ROD	Record of Decision
SITE	Superfund Innovative Technology Evaluation
SL	screening level
TBT	tributyltin
TSCA	Toxic Substances Control Act
TSS	total suspended solids
USACE	United States Army Corps of Engineers
uv	ultraviolet
v/v	volume-to-volume
w/w	weight-to-weight
w/v	weight-to-volume
WAC	Washington Administrative Code
WDNR	Wisconsin Department of Natural Resources

1 Introduction

This Candidate Cleanup Technologies Memorandum (CTM) identifies and screens candidate remedial (cleanup) technologies that may be applicable to the Lower Duwamish Waterway (LDW) Superfund site in Seattle, Washington. The CTM is a required deliverable under a joint Administrative Order on Consent (AOC) to conduct a Remedial Investigation and Feasibility Study (RI/FS) under the federal Comprehensive Environmental Response Compensation and Liability Act (CERCLA) and Washington State's Model Toxics Control Act (MTCA) (see Section 1.1). This memorandum is the first step in the development of remedial alternatives in the Feasibility Study (FS) for the LDW.

An evaluation of the candidate remedial technologies is a required step in the FS process described in the EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies* (EPA 1988) and is consistent with the state's cleanup study requirements (Washington Administrative Code [WAC] 173-204-560(4)(k) and MTCA FS requirements (WAC) 173-340-350(8)). The CTM presents a preliminary list of processes and equipment associated with each candidate technology[1] that could be incorporated into the remedial alternatives and applied to the physical conditions and the chemicals of potential concern (COPCs[2]) within the LDW sediments. From the identified candidate technologies, alternatives are assembled and screened using the criteria of effectiveness, implementability, and cost in a preliminary screening of alternatives. A short-list of representative alternatives are subject to a detailed analysis in the FS using the nine CERCLA evaluation criteria listed below, which include consideration of public concern and acceptance of an alternative(s). The FS process for the LDW is described in the *Remedial Investigation/Feasibility Study Integration Memorandum for the Lower Duwamish Waterway* (Appendix A).

The nine CERCLA evaluation criteria include:

- Long-Term Effectiveness and Performance
- Implementability
- Cost
- Overall Protection of Human Health and the Environment
- Compliance with ARARs
- Reduction of Toxicity, Mobility, and Volume through Treatment
- Short-Term Effectiveness
- State Acceptance
- Community Acceptance

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[1] As an example, dredging is one possible process for implementation of the removal technology, and mechanical dredging using an open clamshell bucket is one possible equipment configuration.

[2] The COPCs discussed in this document are based on those identified in the Phase 1 remedial investigation (see Section 2.3). The final FS for the LDW will be based on the actual chemicals of concern (COCs) identified in the Phase 2 remedial investigation and the associated human health and ecological risk assessments.

The development of remedial alternatives, which will occur as part of the FS, also needs to consider the complete site investigations being conducted during the remedial investigation (RI) and the human health and ecological risk assessments. Furthermore, the investigations and cleanup alternatives developed for full or partial cleanup actions at the Early Action Areas (EAAs) will inform the content of the FS. These EAAs include:

- Slip 4 and Terminal 117 CERCLA Non Time-Critical Removal Actions
- Diagonal/Duwamish removal conducted as part of the Elliott Bay/Duwamish Restoration Program
- Boeing Plant 2 sediment remediation undertaken as a Resource Conservation and Recovery Act (RCRA) Corrective Action
- The limited sediment removal undertaken by Boeing under the MTCA Voluntary Cleanup Program near their stormwater outfall at the Developmental Center, downstream of the Norfolk CSO.

In addition, overall site cleanup goals (called remedial action objectives, or RAOs) and all applicable or relevant and appropriate federal and Washington State requirements (yet to be determined) need to be considered in the development of remedial alternatives.

The purpose of this CTM is to identify and screen those remedial technologies that are effective for managing the COPCs in the LDW and that can be implemented given overall site conditions. Although focused on river-wide remedial actions, the information presented in this document may be further evaluated on a site-specific basis during the development of removal alternatives for the EAAs.

1.1 Background

In December 2000, the City of Seattle, King County, the Port of Seattle, and the Boeing Company (collectively, the Lower Duwamish Waterway Group [LDWG]) signed a joint AOC with the United States Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) to conduct an RI/FS for the LDW.

The RI, which is currently under way, will include characterization of the LDW; specifically, the nature and extent of chemical contamination, a sediment transport study, human health and ecological risk assessments, and evaluation of potential sources of COPCs to the LDW.

As specified in the AOC, the FS will be conducted in accordance with CERCLA, the associated National Contingency Plan (NCP), and MTCA. The FS will develop, screen, and evaluate in detail a suite of potential remedial actions (Washington Administrative Code [WAC] 173-340-350 [8]). Factors considered will include the findings of the RI and the potential performance and cost of the screened candidate technologies. The

AOC also requires that any potential remedial actions identified in the FS must comply with both federal and state laws. EPA and Ecology will evaluate the FS, and select a preferred cleanup alternative. The agencies will then solicit public comments on a proposed cleanup plan for the site and document their final decision after consideration of public comments in a Record of Decision (ROD).

In addition, the AOC identifies a series of deliverables (documents) that are required as part of the FS process. This CTM is one such document and was identified as a pre-work plan deliverable in the *Remedial Investigation/Feasibility Study Integration Memorandum* (Integration Memorandum) submitted to EPA and Ecology (RETEC 2005) (Appendix A).

In accordance with EPA Superfund guidance (EPA 1988), the Integration Memorandum identified activities that would be undertaken concurrent with the RI[3] and technical memoranda that would be completed as part of that process. The rationale for conducting these activities is to ensure (1) that data needed to complete the FS are collected during the RI to the extent possible, and (2) that the FS is completed within the schedule established for the LDW RI/FS. The purpose of completing the technical memoranda early is to provide a useful forum for the exchange of ideas among LDWG, EPA, and Ecology. It is acknowledged that decisions reached in early technical memoranda may need to be modified as new information becomes available through the RI/FS process. Key deliverables, interactions with the RI, and a general representation of how the FS schedule interacts with the RI were also presented in the Integration Memorandum (Figure 1-1).

1.2 Guidance for the Feasibility Study

This CTM and the LDW FS will address the LDW as a whole, i.e., on a river-wide basis. Remedial technologies and remedial alternatives evaluated in the FS will be based on the general range of LDW sediment characteristics, physical conditions, and the chemicals of concern (COCs) that will be identified in the Phase 2 RI (LDWG 2003). Potential remedial technologies considered in the LDW FS must also be evaluated in accordance with requirements of CERCLA, the NCP, and MTCA. The specific documents that guide the FS include:

- The AOC for the LDW
- The Clarification of Feasibility Study Requirements (a clarification letter from LDWG to EPA and Ecology, December 4, 2003) (LDWG 2003)

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[3] "Alternatives are typically developed concurrently with the RI site characterization, with the results of one influencing the other in an iterative fashion (i.e., RI site characterization data are used to develop alternatives and screen technologies, whereas the range of alternatives developed guides subsequent site characterization or treatability studies)." (EPA 1988)

- *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA 1988)
- MTCA criteria for the selection of cleanup actions and content of an FS (WAC 173-340-350 through 360)
- Sediment Management Standards guidance and criteria for the conduct of a Cleanup Study (WAC 173-204-560, 570, and 580)
- *A Guide for Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents* (EPA 1999)
- *A Guide for Developing and Documenting Cost Estimates During the Feasibility Study* (EPA 2000a).

Additional documents relevant to how the FS is conducted and to the evaluation of potential remedial technologies in the FS include:

- *A Risk-Management Strategy for PCB-Contaminated Sediments* (NRC 2001)
- *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (EPA 2002a)
- *Draft Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (OSWER 2005)
- *Standards for Confined Disposal of Contaminated Sediments Development* (Ecology 1990)
- *Multi-User Sites for the Confined Disposal of Contaminated Sediments from Puget Sound* (Ecology 1991a)
- *Multi-User Disposal Sites (MUDS) for Contaminated Sediments from Puget Sound – Subaqueous Capping and Confined Disposal Alternatives* (USACE 1997)
- *Puget Sound Confined Disposal Site Study Programmatic NEPA/SEPA Environmental Impact Statement* (USACE et al. 1999)
- *Multi-User Disposal Site Investigation* (Ecology 2001a)
- *Puget Sound Confined Disposal Site Study, Washington* (USACE 2003).

1.3 Definitions

Candidate technologies in this memorandum are taken to mean all potentially applicable sediment natural recovery, removal, isolation or containment, treatment, and disposal equipment and processes that could be applied for sediment management in the LDW. In developing specific remedial alternatives, there is a hierarchy of relevant terms, as defined below:

- **General Response Actions (GRAs)** describe in broad terms the kinds of remedial measures that could be applied to manage COPCs in the sediments. GRAs range from no action to complete removal with treatment or disposal, encompassing all the possible remedial actions that could be used to achieve the remedial action objectives. Identifying GRAs appropriate to contaminated sediments reduces and focuses the list of technologies to be screened.

- **Technology Types** are the general technologies that describe a means for achieving the GRAs; examples of technology types include capping, dredging, dry excavation, and chemical treatment. For instance, removal is a GRA that can be achieved using excavation or dredging technologies, while treatment is a GRA that can be achieved using physical, biological, or chemical technologies.

- **Process Options** are specific processes within each technology type. For example, chemical treatment, which is a technology type, includes such process options as solvent extraction and slurry oxidation. Process options are selected based on the characteristics of the medium (for instance, sediment) and the technologies available to address the medium.

- **Components** are the specific individual pieces of equipment that collectively comprise a system. For example, components of a dredge system could include:

    - Point-of-dredging components such as the cutterhead, auger screw, dustpan, and matchbox, as well as various mechanical means, such as clamshell or backhoe excavator bucket.

    - Support components such as the support barge or pontoon, jack-up platforms, and amphibious systems.

    - Discharge components such as pumps, pipelines, barges, and trucking.

- **Systems** represent the detailed engineering design that combines the selected process options and components to implement an overall remedial action. As shown in Figure 1-2, combinations of process options and components are coupled to build a system for managing contaminated sediments until their placement in a final containment or disposal facility. For example, a system for hydraulic dredging with physical separation followed by mechanical dewatering, treatment of the removed (decant) water, and disposal would involve numerous individual components such as type of dredge, size of slurry lines, pumps matched to support the separation and dewatering and water treatment plants, disposal location, and transport systems for disposal, right down to the number of railcar/truck trips per day.

Finally, an *alternative* is a combination of all the above, from GRAs through specific representative systems. For the FS, the components and systems are *representative* in that assumptions are made about the equipment to be used under each alternative in order to develop cost estimates for the cleanup. CERCLA guidance requires that the cost estimate for the representative system be accurate within +50 to -30 percent. The actual remedial system will be designed, bid, and implemented after EPA and Ecology select a remedy in the ROD and during the remedial design phase.

1.4 Screening Criteria for Candidate Technologies

This section presents the criteria used to screen the candidate remedial technologies for the LDW. Both EPA guidance (1988) and Washington State's MTCA rule (WAC 173-340) for conducting an FS require that the initial screening of potential remedial technologies be based on effectiveness, implementability, and cost. Evaluation of the additional criteria listed in Table 1-1, including community concerns and acceptance of alternatives, occurs later in the FS process.

This CTM bases the initial screening of a technology on effectiveness and implementability following EPA guidance. Costs will be considered later in the FS process. The effectiveness screening considers how proven and reliable the process technology is with respect to the contaminants at the site. Implementability screening is based upon whether the technology can be applied to site-specific conditions, and is commercially available. Site-specific means that the technology is applicable to the conditions on the LDW, but may be applied either river-wide or locally. While no one option may be applicable to all removal activities anywhere in the river, any specific option may be applicable at local, smaller scales. For a technology to be considered commercially available, it must be available in North America and have been demonstrated for use at a project with similar conditions and scale as the LDW.

Some technologies have been shown in laboratory or pilot-scale testing to be effective for treating contaminated sediments, but have not been applied for cleanup of a large site such as the LDW. EPA guidance (EPA 1988) suggests that innovative technologies be retained, but only when full-scale testing that will result in data on which effectiveness or cost can be fully evaluated is under way. For the CTM, innovative technologies will be retained if they are known to be entering the full-scale phase and if data from the testing are expected to be available before alternatives are assembled and subjected to detailed evaluation in the LDW FS (Figure 1-1). Innovative technologies that develop pilot-scale data may also be reconsidered later in the development of the FS.

Four key factors were considered when evaluating the effectiveness and implementability of the candidate technologies:

1) Are the technologies effective for the contaminants in the LDW?
2) Are the technologies implementable under specific site conditions in the LDW?
3) Are the technologies commercially available in North America and have they been successfully applied to similar projects?
4) Is an innovative technology under development with full-scale testing data expected within the time frame of the LDW FS?

1.5 Document Objectives and Organization

The objective of this CTM is to identify a preliminary list of technology types and process options that are potentially applicable for the management of contaminated sediments in the LDW. Where applicable, the CTM also addresses how those technologies are evaluated relative to site conditions, including physical, biological, and chemical properties, and to site uses (for example, shipping, navigational dredging, fishing). No single technology will be applicable throughout the entire LDW. Site conditions vary, particularly between intertidal and subtidal areas of the LDW. Therefore, different technologies may be more or less appropriate at specific areas of the site and will be evaluated in the LDW FS and any engineering evaluation/cost analysis (EE/CA) documents that may be prepared for the Early Action Areas (EAAs).

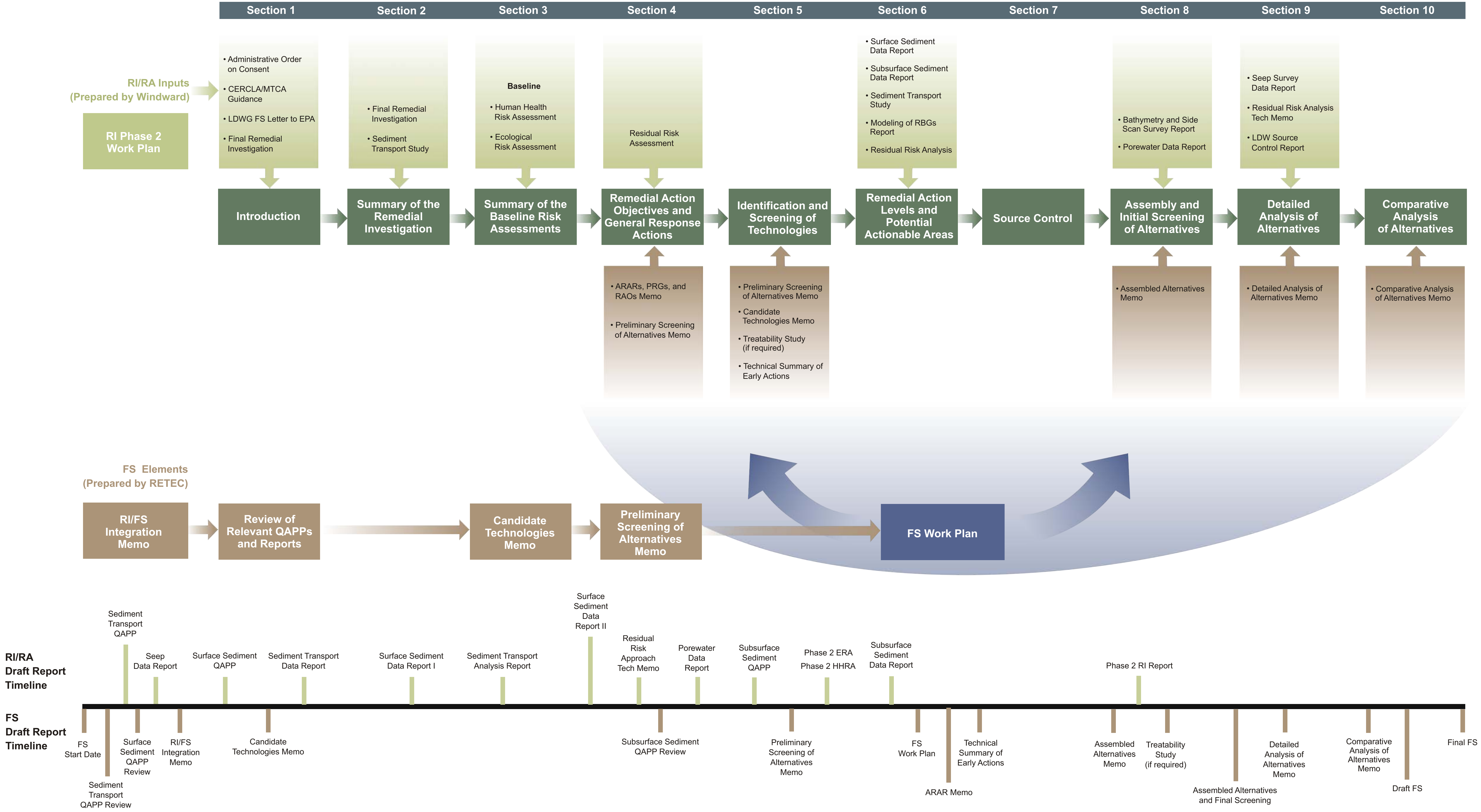
In addition to evaluating remedial technologies for their implementability and effectiveness, this memorandum identifies the COPCs and general site conditions in the LDW to which a given technology may be applicable. Finally, relative cost information is presented, although cost is not used in the screening of technologies. Cost considerations include the specific physical site conditions, the volumes of material to be managed, the technologies selected and the other equipment paired with those technologies, and the manner and location for disposing of contaminated sediments removed from the LDW. However, specific and detailed cost information is reserved for development in later documents.

This CTM is the first of several steps that will be taken in preparing the LDW FS (Figure 1-1). Results from the CTM will be incorporated into the *Preliminary Screening of Alternatives Memorandum*, which will use the sediment chemistry data collected during the RI to further screen remedial technologies and assemble combinations of those technologies into remedial alternatives. The preliminary screening of alternatives memorandum will serve as an initial filter of technologies and alternatives to carry forward into the later evaluations when all sediment data are available. The preliminary screening will evaluate the applicability of technologies and alternatives based on the CERCLA and MTCA screening criteria of effectiveness, implementability, and cost. Site conditions, including the general physical, biological, and chemical properties, as well their applicability to site uses (for example, shipping, navigational dredging, fishing) will also be considered. The preliminary screening memorandum will acknowledge that site conditions vary, particularly between intertidal and subtidal areas, and that different technologies or alternatives may be more or less appropriate at specific areas of the site.

The remainder of this CTM is organized as follows:

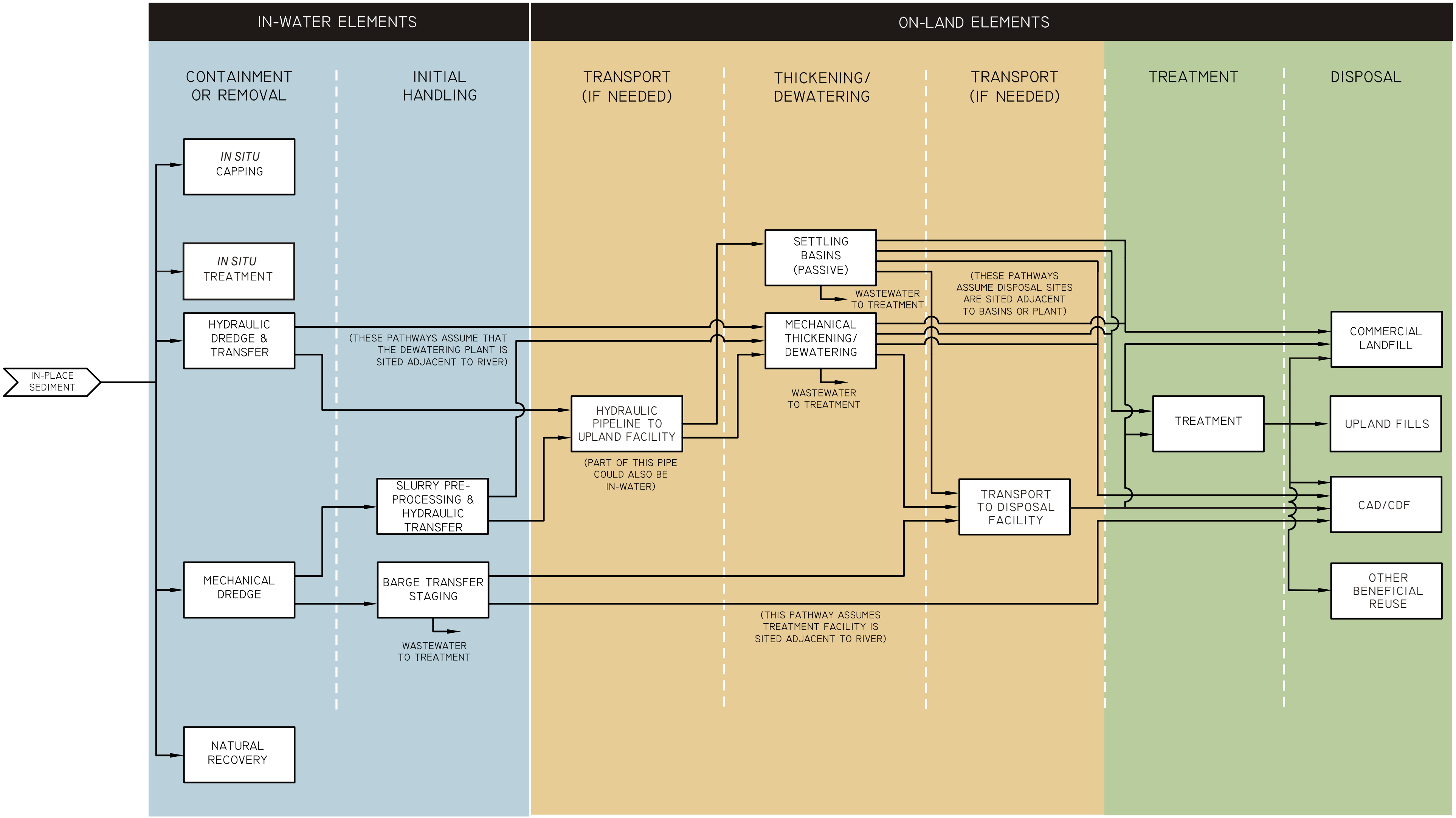
- **Section 2** describes the general physical conditions of the LDW that could impact the selection of process options and the COPCs driving the design of the remedial actions.
- **Section 3** defines the GRAs for the LDW on the basis of general conditions and COPCs.
- **Section 4** identifies the available information sources (for example, reports, studies, databases, and engineering evaluations) that describe the state of practice for sediment management in North America. On the basis of that information, a preliminary list of technology types and process options applicable to the LDW GRAs is developed.
- **Sections 5 through 8** present and evaluate the subset of technologies and process options for four of the GRAs: No Action and institutional controls, monitored and enhanced natural recovery, containment, and removal. Technologies and process options are initially screened against the criteria presented above (Section 1.4), and the site-specific factors (such as operational constraints) that will influence implementability or effectiveness are identified.
- **Section 9** presents ancillary technologies necessary for implementing specific management options for the LDW. An example of an ancillary technology is the transport mechanism (for instance, railcar or truck) selected to move dredged sediment from the site to its place of disposal. Ancillary technologies do not necessarily require screening.
- **Sections 10 and 11** present and evaluate the subset of technologies and process options for two of the GRAs: treatment and disposal. Technologies and process options are initially screened against the criteria presented above (Section 1.4), and the site-specific factors (such as operational constraints) that will influence implementability or effectiveness are identified.
- **Section 12** presents the results of the technology screening and briefly describes the primary factors that influenced the decision to retain or eliminate a particular technology.
- **Section 13** provides the references cited in this document.

Figure 1-1 Feasibility Study Outline, Scope of Work, and Schedule



Schedule is currently under discussion among LDWG, EPA and Ecology

Figure 1-2 Example of Candidate Remediation Technologies in System Sequences Potentially Feasible for Lower Duwamish Waterway



2 Site Characteristics

The Phase 1 RI (Windward 2003) summarizes the LDW site and chemical conditions through an evaluation of historical physical, chemical, and biological data. This section summarizes information presented in the Phase 1 RI report regarding general physical characteristics of the site, waterway uses, and the COPCs, which are relevant to the identification and evaluation of remedial technologies potentially applicable to the LDW.

The Phase 2 work plan (Windward 2004) outlines additional data that will be collected during the Phase 2 RI to support the FS. Phase 2 data collection and analysis are currently under way. Copies of the Phase 1 RI and Phase 2 work plan, as well as planning documents (e.g. quality assurance project plans for Phase 2 field studies), can be found at http://www.ldwg.org.

2.1 Physical Site Characteristics

2.1.1 Physiography

The LDW is located at the downstream end of the Green/Duwamish watershed (the name refers to the Green and Duwamish rivers), which includes parts of the cities of Seattle, Tukwila, SeaTac, Renton, Kent, Federal Way, Auburn, Black Diamond, and Enumclaw, as well as forested areas in unincorporated southeastern King County. From Harbor Island to just south of the upper turning basin, the LDW is about 8 km (5 mi) in length (Figure 2-1). The highly developed LDW shoreline consists primarily of piers, riprap, constructed seawalls, and bulkheads for industrial and commercial use. The maximum depth of the LDW varies from approximately 17 m (56 ft) at mean lower low water (MLLW) near the mouth to 3.0 m (10 ft) at MLLW near the head of the navigation channel. The navigation channel is maintained at a depth of approximately 9.1 m (30 ft) up to the First Avenue Bridge, a depth of approximately 6 m (20 ft) from the First Avenue Bridge to Slip 4, and a depth of approximately 4.6 m (15 ft) between Slip 4 and the upper turning basin. The average width of the LDW is 134 m (440 ft), although it is wider downstream of the First Avenue Bridge.

2.1.2 Hydrology

The Green River, which is the main source of water to the LDW, originates at the crest of the Cascade Mountains near Stampede Pass and flows past the Howard Hanson Dam and the Tacoma Headworks Dam. Multiple tributaries as well as some small flows from the Black River also contribute to the Green/Duwamish river system. The LDW is a highly regulated river, in the sense that a portion of its flow is controlled by the Howard Hanson Dam on the upper Green River. Streamflow is also influenced by water diversions, particularly from the Tacoma Headworks Dam, which diverts water for municipal use. In addition, historical flows to the watershed have been reduced substantially through the diversion of water from the White River to the Puyallup and from the Cedar River to Lake Washington.

Flow rates are highest in the winter because of seasonal precipitation, and flows are lowest throughout the late summer dry season. Streamflow can be increased by surface water sources within the LDW area, such as storm drains, combined sewer overflows (CSOs), industrial effluents, and nonpoint inputs, although these sources of flow are expected to be less than 1 percent of total discharge, even during peak flow events. However, these influences are small relative to the influence of upstream dams in controlling river flow. The Howard Hanson Dam effectively decreased peak flows, which now do not exceed 340 m^3/s (12,000 cfs), but increased moderate flows from 85 to 140 m^3/s (3,920 to 6,460 cfs) as a result of the metered release of floodwaters stored behind the dam. Eighty percent of the water flows out of the LDW through the West Waterway because of the presence of a sill at the head of the East Waterway.

In its lower portions, the LDW is a stratified, salt-wedge-type estuary influenced by river flow and tidal effects; the relative influence of each is highly seasonally dependent. Fresh water moving downstream overlies the tidally driven saltwater wedge. Typical of salt-wedge estuaries, the LDW has a sharp interface between the freshwater outflow at the surface and saltwater inflow at depth. The diurnal tides can range up to 16 ft over a tidal cycle.

2.1.3 Sediment Characteristics

The composition of sediment varies throughout the LDW, ranging from sand to mud depending on the sediment source and current speed. The sediment typically consists of slightly sandy silt with varying amounts of organic detritus. Coarser sediments are present in nearshore areas adjacent to CSOs and storm drain discharges. Finer-grained sediments are typically located in remnant mudflats, along channel side slopes, and within portions of the navigation channel. Main channel sediments near the upper turning basin are predominately sands, whereas sediments toward the mouth are predominately fine-grained silts. Sediments in the river upstream of the upper turning basin are generally coarser than in the remaining downstream portion of the LDW.

The Phase 1 RI reports that the LDW system has been a net sink for sediments (that is, it is a depositional environment). From 1960 to 1980, the LDW retained, on average, approximately 90 percent of the total incoming sediment load. Sediments deposited within the LDW have either contributed to steady accretion of the bed or have been removed from the system (disposed off site) through routine dredging for channel maintenance, primarily in the upper turning basin and in the channel upstream of the South Park Bridge (also known as the 16th Avenue South Bridge). Sediment transport was identified as a data gap for further study in the Phase 2 RI. Likely areas of deposition and episodic erosion will be characterized by the sediment transport analyses, which will influence the selection of alternatives in the FS.

2.2 Site Use

The LDW is primarily an industrial-use waterway. Land use, zoning, and land ownership within the LDW corridor are consistent with an active industrial waterway. The LDW provides a critical navigational corridor for the movement of material associated with these facilities. Most of the industrial and commercial facilities on the LDW operate year-round vessel schedules; these facilities include shipping companies that move container-laden barges, cement companies that move raw materials, and shipyards that move boats in and out of service and repair areas.

Traditional and recreational uses of the LDW are also important. Uses of the LDW by Native Americans include treaty-reserved fishing rights, as well as subsistence, ceremonial, and commercial harvest of resources. Recreational uses of the LDW include a number of public access points that allow the public to enter the LDW for boating, fishing, and shoreline/riverbank activities. These access points include marinas, motorboat launches, hand boat launches, and shoreline public access sites.

Two mixed residential/commercial neighborhoods, South Park and Georgetown, are near the LDW. The South Park neighborhood is at the southern edge of the Seattle city limits and borders the west bank of the LDW. The Georgetown neighborhood is east of the LDW and East Marginal Way South. Georgetown is separated from the LDW by several commercial facilities between the LDW and East Marginal Way South, although it is possible to access the LDW by foot from this neighborhood.

2.3 Habitat and Biological Characteristics

There are many important habitats and species that use the LDW. Intertidal flats and marine riparian vegetation are the dominant natural nearshore habitat types present. Man-made structures such as pilings also provide habitat for fish and for encrusting invertebrates, such as barnacles and mussels. Benthic invertebrate species are important components of the LDW ecosystem because they serve as a major food resource for fish and wildlife species. The benthic invertebrate community is dominated by annelid worms, mollusks, and arthropods. Larger invertebrates include Dungeness crabs, slender crabs, clams, mussels, echinoderms, and various other crustaceans.

Numerous anadromous and resident fish species have been found in the LDW. All species of Pacific salmon (coho, Chinook, chum, sockeye and pink) as well as bull trout and summer steelhead have been found in the LDW. These anadromous fish use the estuary for rearing and as a migration corridor for adults and juveniles. Non-salmonid fish include shiner surfperch, English sole, Pacific staghorn sculpin, starry flounder, snake prickleback, and longfin smelt. The habitats in the LDW also support a diversity of wildlife, including numerous species of birds as well as harbor seals and river otters.

2.4 Chemicals Considered for the CTM

In order to evaluate candidate technologies relative to the first screening criteria – are the technologies effective for the contaminants in the LDW – it is first necessary to understand the nature (types and concentrations) of contaminants and the extent to which they are distributed throughout the LDW. The Phase 1 RI reviewed data from approximately 1,200 surface sediment samples, 230 subsurface sediment samples, and 225 fish and invertebrate tissue samples collected from the LDW and analyzed for metals and organic compounds since 1990. These data showed that chemicals in the sediment are not uniformly distributed throughout the LDW and may vary widely throughout the site. Elevated chemical concentrations generally occur in discrete, well-defined locations that are separated by sections of the LDW in which chemical concentrations are low. For example, over the entire LDW the spatially weighted mean concentration of total polychlorinated biphenyls (PCBs) presented in the Phase 1 RI (0.36 mg/kg dry weight) was much lower than the maximum total PCB concentrations at the candidate EAAs, which are typically 10 mg/kg dry weight, or greater.

Based on the Phase 1 ecological risk assessment, metals, semivolatile organic compounds, PCBs, polycyclic aromatic hydrocarbons (PAHs), pesticides, and tributyltin (TBT) were identified as COPCs for ecological receptors. The Phase 1 human health risk assessment identified arsenic, mercury, TBT, carcinogenic PAHs, and PCBs as COPCs for human receptors. Arsenic, carcinogenic PAHs, and PCBs were found to pose cancer risks greater than one in 1,000,000, while arsenic, PCBs, TBT, and mercury posed unacceptable noncancer risks. The exposure pathway of greatest concern for human health was the ingestion of seafood from the LDW.

On the basis of this information from the Phase 1 ecological and human health risk assessments, the preliminary and representative list of COPCs for consideration in the CTM consists of metals (arsenic, copper, lead, and mercury), semivolatile organic compounds (specifically PAHs and phthalates), TBT, pesticides (e.g., DDT), and total PCBs. It is acknowledged that this list may need to be revisited and modified after consideration of the Phase 2 data collection and after completion of the human health and ecological risk assessments. For example, additional data are being collected to address both pesticides and dioxin/furan concentrations and distributions. Candidate technologies suitable for cleanup of PCBs are equivalent to those that would be used for pesticides and dioxins/furans.

Finally, Washington's Sediment Management Standards (WAC 173-204) contain biological standards, which may form the basis for a cleanup action. Where toxicity standards may influence the selection of specific cleanup technologies is noted in the CTM.

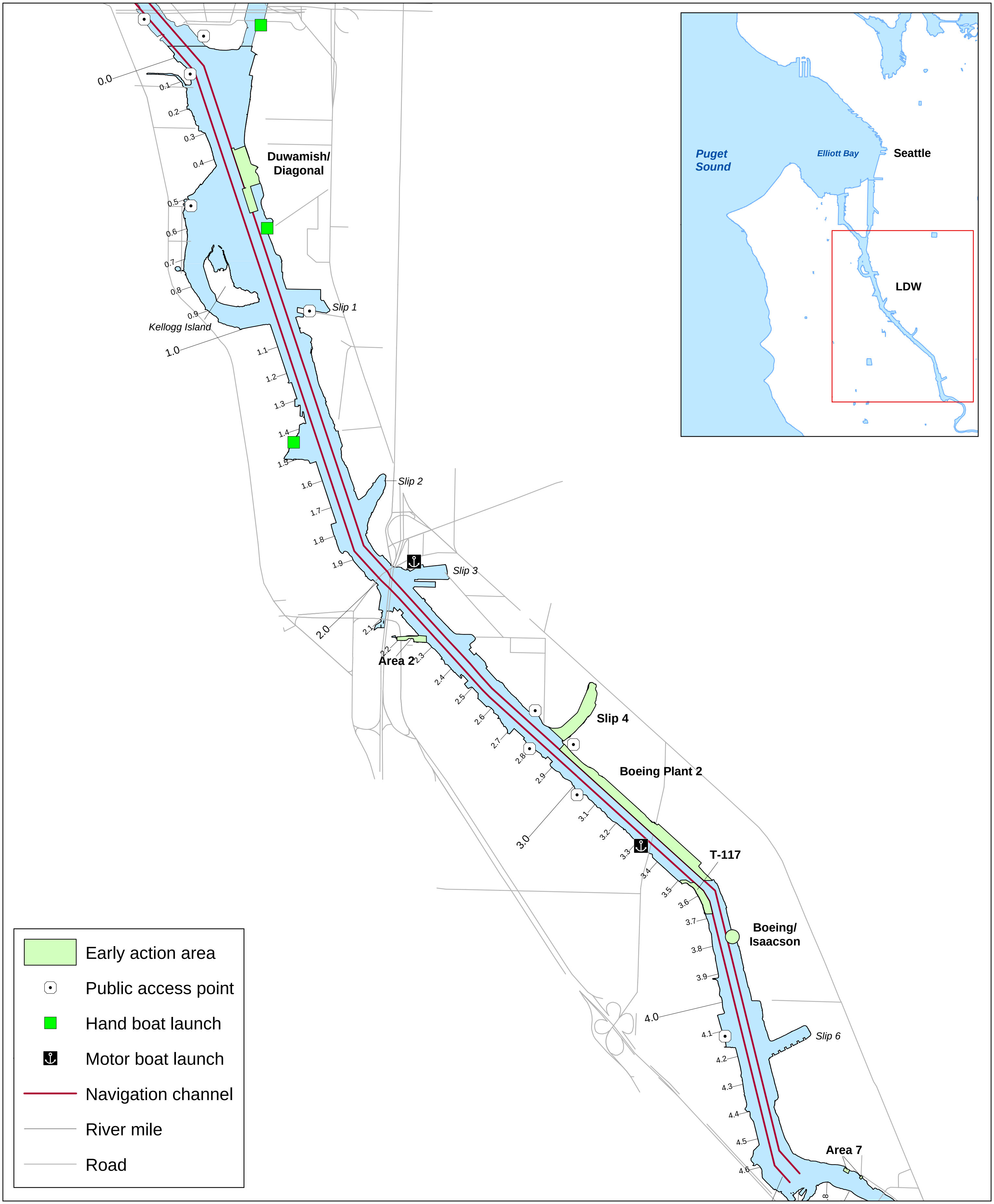


Figure 2-1. Lower Duwamish Remedial Investigation and Feasibility Study Area

Windward environmental LLC

Prepared by STS 07/15/05 Map 1917

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3 General Response Actions

General response actions are broad categories of possible remedial actions, such as treatment, containment, and disposal, and their various combinations. GRAs are typically identified only after the RI and risk assessments are completed and the RAOs have been identified. For the purposes of this CTM, however, the GRAs are the categories identified in the Draft *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (OSWER 2005):

- No Action
- Institutional controls
- Monitored natural recovery
- Enhanced natural recovery
- Containment
- Removal
- *In situ* treatment
- *Ex situ* treatment
- Disposal
- Combined actions.

Each of these is briefly described below and discussed in more detail in Sections 5 through 8, 10, and 11.

3.1 No Action

The NCP at § 300.430(e)(6) requires consideration of a No Action alternative as part of the FS process. Under the No Action alternative, site conditions as defined in an RI, and human health and ecological risks as identified in a baseline risk assessment, would remain in place, because no remedial action would be undertaken.

The No Action alternative may become a No Further Action alternative if a baseline risk assessment demonstrates that there are no adverse effects to human health or the environment or if remedial actions already undertaken at the site have achieved the risk-based RAOs (OSWER 2005). The No Further Action alternative does not include treatment, engineering, or institutional controls, but can include long-term monitoring to verify that the site continues to pose no unacceptable risks to human health or the environment.

3.2 Institutional Controls

Institutional controls are legal or administrative measures that restrict human use or access of the site, thereby preventing or reducing exposure to contaminants (OSWER 2005). Fish consumption advisories, restrictions on use of the waterway, deed restrictions, and access restrictions are examples of institutional controls. When developing institutional controls, consideration must be given to the nature and use of the LDW. For example, a moratorium on dredging may not be appropriate for an active, commercial waterway with a federally authorized navigation channel, such as the LDW. Access restrictions that conflict with Native American usual and accustomed harvest areas will also be avoided to the extent possible.

3.3 Monitored Natural Recovery

Natural recovery is the reduction of COPC concentrations in contaminated sediments over time as a result of natural processes such as biodegradation, burial, or dilution[4] (OSWER 2005). Monitored natural recovery (MNR) relies on the same natural processes, but also includes regular monitoring, such as the periodic collection and analysis of sediment samples, to ensure that human health and ecological risks are reduced to expected levels within a specified time frame.

MNR is different from No Action. No Action can be selected only when baseline risks are at acceptable levels, and monitoring may be a component to ensure that those conditions do not change. With MNR, low-level risks may be present, but over time the low-level risks are expected to decrease to an acceptable level as a result of natural processes. Monitoring is performed to confirm that natural recovery is occurring as anticipated.

3.4 Enhanced Natural Recovery

Enhanced natural recovery (ENR) involves the application of thin layers of clean material over areas where natural recovery processes are already occurring, yet at a rate that is insufficient to reduce risks within an acceptable time frame (OSWER 2005). By applying thin layers of clean sediments over an area and allowing natural resorting or bioturbation[5] to mix the contaminated and clean sediment layers, the natural recovery process is accelerated and results in a surface layer with chemical concentrations within acceptable levels. ENR is also sometimes used post-removal to effectively manage low levels of residual contaminants after the cleanup is complete. Additional long-term monitoring would be required in conjunction with ENR.

3.5 Containment

Containment in this document refers to the in-place physical isolation or immobilization of contaminants in sediment through *in situ* capping. Although other sediment remediation guidance documents (Averett et al. 1990; USACE 1998a) include contained aquatic disposal and confined disposal facilities in this category, these are discussed as disposal alternatives in this memorandum.

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[4] Biodegradation is the breakdown of contaminants through biological processes; burial is the deposit of clean sediments on top of the contaminated sediments through natural forces, other forces such as ship scour, or the action of organisms that live in the sediments; dilution is the reduction of chemical concentrations through the mixing in of clean, naturally deposited materials.

[5] Bioturbation is the mixing of sediment layers through the action of benthic organisms that live in the sediment.

With containment, no sediment treatment occurs other than by natural processes under the cap surface. Assuming effective cap placement, the bioavailability[6] and mobility of contaminants present in the sediments would be immediately limited because the underlying chemicals are thereby isolated from biota.

3.6 Removal

Removal refers to the physical dredging or excavation of contaminated sediments. Following removal, the material is usually relocated to a treatment or a disposal facility. Excavation refers to removal of sediments in the dry, while dredging often requires consideration of other process options, such as in-water controls to minimize contaminant resuspension during removal, dewatering to reduce sediment moisture content, treatment of dredge water before discharge, transport of dredged sediment, and disposal or treatment of dredged material.

3.7 *In Situ* Treatment

In situ treatment involves the in-place application of chemical or biological methods for reducing contaminant concentrations or bioavailability. The sediment is not removed from the site.

3.8 *Ex Situ* Treatment

Ex situ treatment involves the out-of-water application of treatment technologies to transform, destroy, or immobilize COPCs following removal of the contaminated sediments. Treatment processes have the ability to reduce sediment contaminant concentrations, mobility, or sediment toxicity by contaminant destruction or detoxification, extraction of contaminants from sediment, reduction of sediment volume, or sediment solidification/stabilization (OSWER 2005). Examples of *ex situ* treatment include stabilization, separation, solidification, thermal destruction, and vitrification. After treatment, the residual materials are disposed of in a landfill or, where permitted, used for other beneficial purposes (for example, industrial fill or landfill cover).

3.9 Disposal

Disposal is the permanent placement of material into a permitted and/or appropriate structure or facility. Examples of disposal alternatives include in- or near-water facilities such as contained aquatic disposal cells or confined disposal facilities, upland and off-site landfills, and the placement of permitted and/or treated materials into an upland fill or other potential beneficial use application. Disposal facilities located within the LDW CERCLA site boundary would be required to meet all of the substantive permit requirements, but would be exempt from actually obtaining those permits. Any off-site disposal facility must be permitted and in compliance with the CERCLA Off-site policy (i.e., the facility must also be in compliance with all substantive permit requirements).

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[6] Bioavailability is the degree or rate at which a substance is absorbed into a biological organism.

3.10 Combined Actions

As GRAs, combined actions are defined as the use of two or more response actions within a single operable unit or site. For example, partial dredging may be combined with capping or in-water containment facilities to achieve site RAOs, or MNR may be paired with removal and containment alternatives (OSWER 2005).

4 Identification of Candidate Remedial Technologies

This section describes the documents and processes through which candidate remedial technologies were identified and concludes by listing and describing the candidate remedial technologies (Table 4-1).

Contaminated sediment management is a rapidly developing and maturing field of environmental engineering, with an expansive set of publicly available documents in the scientific and engineering literature. Management of contaminated sediments has been the subject of multiple review documents (OSWER 2005; NRC 1997, 2001; Demars et al. 1997; Cushing 1999; Cura et al. 1998; Cleland 1997, 2000; Sediment Management Work Group 1999; Sediment Priority Action Committee 1997; SEDTEC 1997; DOD 1994; EPA 1994a 1994b; Averett et al. 1990; Sierra Club 2001). Numerous federal, regional, Washington State, and international documents and databases provide detailed information on removal, containment, treatment, and disposal.

For the CTM, an extensive and comprehensive body of literature was assembled, including databases, websites, engineering sediment design studies, documents and presentations on ongoing federal sediment treatment programs, sediment remedial bid documentation and as-built reports completed for other sites, and FS documents from other CERCLA contaminated sediment sites. These engineering and scientific resource documents were reviewed, cross-referenced against similar documents, and in several cases updated through interviews with nationally and internationally recognized scientists and engineers in the field of sediment remediation. Information extracted from these sources included descriptions of potential candidate technologies; the state of technology development (bench-scale, pilot-scale, full-scale demonstrations; commercial availability); the COPCs to which a technology has been applied; the physical site conditions appropriate to a technology; information on short- and long-term effectiveness; and cost information, as available.

The major programs and documents on which the CTM relies are discussed below. Other technology-specific documents and resources are cited in the relevant technology sections. The candidate remedial technologies are then presented in Section 4.5.

4.1 Federal Guidance/Source Documents for Management of Contaminated Sediments

The EPA, along with the United States Army Corps of Engineers (USACE), has been actively involved in the development of remedial technologies for the management of contaminated sediments. Two important documents guiding the selection of appropriate candidate technologies are the CERCLA RI/FS guidance (EPA 1988) and the recent Draft *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (OSWER 2005). OSWER (2005) provides a general overview of technical and policy guidance issues relevant to remedial response or non-time-critical removal actions under CERCLA.

The EPA's Great Lakes National Program Office (GLNPO) coordinated a number of important studies and relevant guidance documents relative to the management of contaminated sediments, collectively referred to as the Assessment and Remediation of Contaminated Sediments (ARCS) program. The ARCS program considered removal, capping, and bench- and pilot-scale treatment studies, as well as case studies for several contaminated Great Lakes sites. Although several of these documents are cited in this CTM, the key summary document is Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes (Averett et al. 1990). The ARCS website can be accessed at http://www.epa.gov/glnpo/arcs/index.html.

The USACE has also produced important technical resource documents for dredging, capping, treatment, and confined aquatic disposal and containment facilities. The USACE maintains an active research role in sediment management, in part through its Dredging Operations and Environmental Research (DOER) program. These resources consist largely of focused technology transfer documents and are cited here in the relevant technology sections. The DOER website and most of these technical resource documents can be accessed at http://el.erdc.usace.army.mil/dots/doer/. The USACE also maintains the Environmental Effects of Dredging and Disposal (E2-D2) literature database at http://el.erdc.usace.army.mil/e2d2/.

4.2 Puget Sound Multi-User Disposal Site Study

In the mid-1990s, the resource agencies in Washington State with responsibility for contaminated sediment management in the Puget Sound area initiated a study to develop a concerted strategy for managing contaminated marine sediments (USACE 2003). Collectively, these agencies[7] initiated the Puget Sound Confined Disposal Site Study, also known as the Multi-User Disposal Site (MUDS) program. A series of carefully constructed programs and studies evaluated options for the disposal and treatment of contaminated marine sediment.

The objective of the MUDS program was to determine the feasibility of establishing one or more multi-user/multi-source facilities for the disposal or treatment of contaminated sediments (USACE 2003). A programmatic environmental impact statement (EIS) completed in October 1999 demonstrated a need to remove a large volume of moderately contaminated sediment from the greater Puget Sound and transfer it to one or more appropriate locations for disposal or treatment. A number of treatment and disposal options were evaluated for implementation, effectiveness, and cost (DNR 2001; Ecology 2001a, 2001b; USACE 2003). The MUDS program and its findings are discussed in more detail in Sections 10 and 11.

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[7] U.S. Army Corps of Engineers, Seattle District; U.S. Environmental Protection Agency, Region 10; Washington State Department of Ecology; Washington State Department of Natural Resources; and Puget Sound Water Quality Action Team.

4.3 CERCLA Sediment Feasibility Studies and Review Documents

Evaluation of remedial technology alternatives is a required component of all CERCLA feasibility studies (EPA 1988). Two recently completed FSs for contaminated sediments at CERCLA sites – the Lower Fox River in Wisconsin (RETEC 2003) and the Hudson River in New York (EPA and USACE 2000, EPA 2004a) – have evaluated a comprehensive range of process options. At both sites, removal, containment, treatment, upland and in-water disposal facilities, and associated ancillary technologies were examined in detail. The two projects are relevant to the LDW because (1) the FSs evaluated remedial technologies relevant to river-wide systems with a complex suite of chemicals, and (2) the projects have proceeded to remedial design and/or implementation. Both projects are discussed below.

4.3.1 Lower Fox River, Wisconsin – Feasibility Study and Detailed Evaluation of Alternatives Study

The Wisconsin Department of Natural Resources, along with EPA Region 5, completed an RI/FS, a Record of Decision (ROD), and a detailed evaluation of alternatives for the 39 miles of contaminated sediments in the Lower Fox River and 100 linear miles of Green Bay (RETEC 2002a, 2002b; WDNR and EPA 2002, 2003; RETEC 2004b). PCBs were identified as the principal COCs at the site; other COCs included arsenic, mercury, PAHs, and pesticides.[8]

As part of the RI/FS process, the agencies and their contractors undertook several elements that have relevance to the LDW. These included:

- Two pilot hydraulic dredging programs (Deposit N and SMU 56/57) to evaluate removal methods, mechanical dewatering, water treatment, and residual contaminant issues
- A comprehensive compilation and evaluation of all known bench-, pilot-, or full-scale treatment technologies that would be applicable to treatment of contaminated sediments and treatment pilot programs in the FS
- Demonstration of vitrification of PCB-contaminated sediments through the EPA's Superfund Innovative Technology Evaluation (SITE) program

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[8] Although the overall evaluations of remedial technologies from the Lower Fox River and the Hudson River are germane to those for the LDW, it should be noted that concentrations of PCBs at both of those sites, and of mercury at the Lower Fox River, were much higher than those in the LDW. Fish consumption advisories and/or commercial fishing bans based on PCBs are in effect for both of those sites.

- Evaluation of potential ecological effects from resuspension of sediments during dredging
- Development of a monitored natural recovery alternative to be used alone and in conjunction with dredging
- Preparation of a design-basis requirements document for placement of an *in situ* cap within the river.

The Fox River FS also included an evaluation of case studies of environmental remediation using dredging to determine the effectiveness of dredging at achieving short-term target goals (immediately after dredging) and long-term remedial objectives (such as reduced fish tissue concentrations) for each project.

The joint ROD (WDNR and EPA 2002, 2003) determined that the selected alternative was removal with landfill disposal, combined with a period of MNR for three of the four operable units (OUs) in the Lower Fox River (OUs 1, 3, and 4), and MNR for OU 2 and all of Green Bay. The ROD also identified both vitrification and capping as potential remedies if either could be demonstrated to be implemented safely and at a lower cost than the dredging and landfill-disposal remedy. The ROD also found that the *ex situ* treatment process could be cost-effective for a remediation program of that size[9] and could potentially be combined with the disposal remedy, provided that a commercial vendor would fund construction and operation (to achieve unit costs similar to that of upland disposal). Administrative difficulties were also identified for a locally sited thermal treatment facility.

Since the ROD was signed, EPA and WDNR have entered into a Consent Decree for remedial design/remedial action in the most upstream operable unit (OU) 1, as well as an Administrative Order on Consent for the remedial design on OUs 2 through 5 (Shaw and Anchor Environmental 2004). Detailed engineering analyses have been completed to assess different transportation and disposal options, as well as the contingent capping remedy. The remedial engineering evaluation has also included detailed evaluation of dredging residuals. To date, no treatment technologies, other than potential separation of sands with beneficial use, have been added to the site remedial design.

4.3.2 Hudson River, New York – PCBs Reassessment, RI/FS, Feasibility Study, and Remedial Engineering Evaluations

EPA Region 2 and the USACE completed a comprehensive RI/FS for the upper Hudson River PCB-contaminated sediment site in New York State (EPA and USACE 2000). The Hudson River PCBs Site is a 40-mile stretch of the Hudson River between Mechanicville and Fort Edward, New York. An estimated 1.1 million pounds of PCBs had been discharged into this stretch of river. The State identified 40 "hot spots,"

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[9] The Records of Decision for the Lower Fox River estimated a total removal volume of 7.25 million cubic yards.

defined as sediments contaminated with greater than 50 parts per million (ppm) of PCBs. Also included in the site are five "remnant" areas, which are river sediments exposed when the level of the river was lowered as a result of removal of the Fort Edward Dam.

The Hudson FS evaluated a comprehensive range of potentially applicable remedial technologies or process options for addressing the PCB-contaminated sediments. The GRAs evaluated for the Hudson River are the same as those anticipated for the LDW. Potentially applicable remedial technologies and process options in the Hudson River FS were evaluated using a two-phased process. First, the FS identified applicable technologies under the GRAs and then screened those technologies based on the CERCLA remedy criteria of effectiveness and site-specific technical implementability. Second, the retained technologies were then further evaluated based on effectiveness, implementability, and cost.

The Hudson River FS provided an analysis of the potentially applicable removal, treatment, and disposal alternatives, with detailed supporting evaluations and vendor costs. Of the technologies considered in the initial screening, *ex situ* bioremediation, *in situ* treatment technologies, and aquatic disposal were not retained for further analysis. *Ex situ* bioremediation was not retained because the available scientific literature demonstrated that dechlorination of PCBs could not meet remedial objectives within a reasonable time frame. *In situ* treatment technologies were not found to be implementable or effective, and aquatic disposal sites in the upper Hudson River were not practicable or implementable.

Process options for treatment and disposal that were retained included near-river treatment, off-site disposal, and beneficial use of dredged materials. Treatment technologies, such as thermal desorption, were determined to be technically feasible but were not retained because of their high cost, and a locally sited thermal treatment facility was not expected to be administratively feasible.

The remedy selected in the ROD requires targeted removal of PCB-contaminated sediments, transport by barge or pipeline to a land-based facility, dewatering, and transport to an off-site landfill (EPA 2002b). Other than stabilization, and potentially separation, the ROD found that treatment would not be economically feasible. However, the ROD also committed EPA to re-evaluate during the design phase any new treatment options or beneficial uses for the dredged sediment that would improve the cost-effectiveness of the remedy.

Since the ROD was signed, EPA has been actively engaged in engineering analyses of appropriate technologies applicable to the Hudson River. These analyses include an evaluation of dredging equipment, transportation, and disposal options, along with controls for resuspension and production standards (EPA 2004a). The remedial engineering evaluation also includes detailed consideration of multiple dredging case studies. To date, no treatment technologies, other than potential separation of sands with beneficial use, have been added to the site remedial design (GE 2004).

4.4 Other Review Documents

Other documents that provide relevant reviews of technologies include *Advances in Dredging Contaminated Sediment* (Cleland 1997), *Results of Contaminated Sediment Cleanups Relevant to the Hudson River* (Cleland 2000), *Healthy Harbors, Restored Rivers* (Sierra Club 2001), and *Analysis of Sediment Management Technologies Effectiveness* (BBL 1999). Other relevant websites accessed for information include Environment Canada's Contaminated Sediment Remediation website (http://www.nwri.ca/research/contaminatedsediment-e.html), the Great Lakes Dredging Team website (http://www.glc.org/dredging/index.html), the Sediment Management Work Group website (http://www.smwg.org), General Electric's Major Contaminated Sediment Sites Database (http://www.hudsoninformation.com/mcss/index.htm), and the "SedWeb" website operated by Georgia Tech and the Hazardous Substance Research Center (http://maven.gtri.gatech.edu/sediments). Finally, relevant and emerging technologies in Europe, Asia, and elsewhere were reviewed using the *Remediation and Beneficial Reuse of Contaminated Sediments* (Hinchee et al, 2002), and the recent Third International Conference on Remediation of Contaminated Sediments (Battelle 2005). While a number of innovative and potentially applicable international technologies were cited in these documents/conferences, only those available in North America were considered in the CTM.

4.5 Candidate Remedial Technologies

The first step in determining candidate remedial technologies for the LDW was to identify technologies potentially applicable to the LDW sediments. From the citations listed above, only technologies that were potentially applicable to conditions in the LDW, that would be effective for the listed COPCs, that were demonstrated ready for full-scale operations, or were considered an innovative technology, were compiled and further evaluated. Technologies unworkable in the context of sediment remediation were eliminated from further consideration and are not discussed in the CTM. Those candidate technologies are listed in Table 4-1, along with the GRAs that they address and descriptions of the process options for their implementation.

The candidate technologies listed in Table 4-1 are evaluated in detail against the screening criteria (Section 1.4) in subsequent Sections 5 through 8, 10, and 11.

Table 4-1 Candidate Remedial Technologies

GRA	Technology Type	Process Option	Brief Description
No Action	None	Not Applicable	No active remedy
Institutional Controls	Physical, Engineering, or Legislative Restrictions	Consumption Advisories	Advisories to indicate that consumption of fish and shellfish in the area may present a health risk.
		Access Restrictions	Constraints, such as fencing and signs, placed on property access.
		Waterway Use Restrictions	Regulatory constraints on uses such as vessel wakes, anchoring, and dredging.
Monitored Natural Recovery	Physical Transport	Combination	Desorption, dispersion, diffusion, dilution, volatilization, resuspension, and transport.
	Chemical and Biological Degradation	Dechlorination (aerobic and anaerobic), biodegradation	Chlorine atoms are removed from PCB molecules by bacteria; however, toxicity reduction is not directly correlated to the degree of dechlorination. PAHs may be partially or completely degraded.
	Physical-Burial Processes	Sedimentation	Contaminated sediments are buried (by naturally occurring sediment deposition) to deeper intervals that are less biologically available.
Enhanced Natural Recovery	Enhanced Physical Burial	Thin-layer placement to augment natural sedimentation	Application of a thin layer of clean sediments and natural resorting, sedimentation, or bioturbation to mix the contaminated and clean sediments, resulting in acceptable chemical concentrations.
Containment	Capping	Conventional Sand Cap	Placement of clean sand over existing contaminated bottom to physically isolate contaminants.
		Conventional Sediment/Clay Cap	Use of dredged fine-grained sediments or commercially obtained clay materials to achieve contaminant isolation.
		Armored Cap	Cobbles, pebbles, or larger material are incorporated into the cap to prevent erosion in high-energy environments or to prevent cap breaching by bioturbators (example: membrane gabions).
		Composite Cap	Soil, media, and geotextile cap placed over contaminated material to inhibit migration of contaminated pore water and/or inhibit bioturbators.
		Reactive Cap	Incorporation of materials such as granular activated carbon or iron filings to provide chemical binding or destruction of contaminants migrating in pore water.
Removal	Dredging	Hydraulic Dredging	Hydraulic dredges cut and vacuum sediments and the material is transported through a pipeline to a selected land-based dewatering facility.
		Mechanical Dredging	A barge-mounted floating crane maneuvers a dredging bucket. The bucket is lowered into the sediment; when the bucket is withdrawn, the jaws of the bucket are closed, retaining the dredged material.
	Dry Excavation	Excavator	This removal option includes erecting sheet pile walls or a cofferdam around the contaminated sediments to dewater. Removal then involves conventional excavation (backhoe) equipment. Removal during low tides may not require sheet pile walls or cofferdams.
In Situ Treatment	Biological	*In-situ* Slurry Biodegradation	Anaerobic, aerobic, or sequential anaerobic/aerobic degradation of organic compounds with indigenous or exogenous microorganisms. Oxygen, nutrients, and pH are controlled to enhance degradation. Requires sheet piling around entire area and slurry treatment performed using aerators and possibly mixers.
		In-situ Aerobic Biodegradation	Aerobic degradation of sediment *in situ* with the injection of aerobic biphenyl enrichments or other co-metabolites. Oxygen, nutrients, and pH are controlled to enhance degradation.
		In-situ Anaerobic Biodegradation	Anaerobic degradation *in situ* with the injection of a methanogenic culture, anaerobic mineral medium, and routine supplements of glucose to maintain methanogenic activity. Nutrients and pH are controlled to enhance degradation.
		Imbiber Beads™	A “cover blanket” of Imbiber Beads™ placed over contaminated sediments to enhance anaerobic microbial degradation processes and allow exchange of gases between sediments and surface water. The beads are spherical plastic particles that would absorb PCB vapors generated.
	Chemical	*In-situ* Slurry Oxidation	Oxidation of organics using oxidizing agents such as ozone, peroxide, or Fenton’s reagent.
		Aqua MecTool™ Oxidation	A caisson (18’ by 18’) is driven into the sediment and a rotary blade is used to mix sediment and add oxidizing agents such as ozone, peroxide, or Fenton’s reagent. A bladder is placed in the caisson to reduce total suspended solids (TSS) and the vapors may be collected at the surface and treated.
	Physical-Extractive Processes	*In-situ* Oxidation	An array of injection wells is used to introduce oxidizing agents such as ozone to degrade organics.
		Sediment Flushing	Water or other aqueous solution is circulated through contaminated sediment. An injection or infiltration process introduces the solution to the contaminated area and the solution is later extracted along with dissolved contaminants. Extraction fluid must be treated and is often recycled.
	Physical-Immobilization	Aqua MecTool™ Stabilization	A caisson (18' by 18') is driven into the sediment and a rotary blade is used to mix sediment and add stabilizing agents. A bladder is placed in the caisson to reduce TSS and the vapors may be collected at the surface and treated.
		Electro-chemical Oxidation	Proprietary technology in which an array of single steel piles is installed and low current is applied to stimulate oxidation of organics.
		Vitrification	Uses an electric current *in situ* to melt sediment or other earthen materials at extremely high temperatures (2,900-3,650 °F). Inorganic compounds are incorporated into the vitrified glass and crystalline mass and organic pollutants are destroyed by pyrolysis. *In-situ* applications use graphite electrodes to heat sediment.
		Granulated Activated Carbon (GAC) Addition	Granulated activated carbon (GAC) is worked into surface sediments. Organics and some metals become preferentially bound to the GAC and are thus are no longer biologically available.
		Ground Freezing	An array of pipes is placed *in situ* and brine at a temperature of -20 to -40 °C is circulated to freeze soil. Recommended only for short-duration applications and to assist with excavation.
Ex Situ Treatment	Biological	Landfarming/ Composting	Sediment is mixed with amendments and placed on a treatment area that typically includes leachate collection. The soil and amendments are mixed using 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.
		Biopiles	Excavated sediments are mixed with amendments and placed in aboveground enclosures. This is an aerated static pile composting process in which compost is formed into piles and aerated with blowers or vacuum pumps. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation.

Table 4-1 Candidate Remedial Technologies

GRA	Technology Type	Process Option	Brief Description
Ex Situ Treatment (continued)	Biological (continued)	Fungal Biodegradation	Fungal biodegradation refers to the degradation of a wide variety of organopollutants by using fungal lignin-degrading or wood-rotting enzyme systems (example: white rot fungus).
		Slurry-phase Biological Treatment	An aqueous slurry is created by combining sediment with water and other additives. The slurry is mixed to keep solids suspended and microorganisms in contact with the contaminants. Upon completion of the process, the slurry is dewatered and the treated sediment is removed for disposal (example: sequential anaerobic/aerobic slurry-phase bioreactors).
		Enhanced Biodegradation	Addition of nutrients (oxygen, minerals, etc.) to the sediment to improve the rate of natural biodegradation. Use of heat to break carbon-halogen bonds and to volatilize light organic compounds (example: D-Plus [Sinre/DRAT]).
	Chemical	Acid Extraction	Contaminated sediment and acid extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.
		Solvent Extraction	Contaminated sediment and solvent extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use (example: B.E.S.T.™ and propane extraction process).
	Chemical/ Physical	Slurry Oxidation	The same as slurry-phase biological treatment with the exception that oxidizing agents are added to decompose organics. Oxidizing agents may include ozone, hydrogen peroxide, and Fenton’s reagent.
		Reduction/ Oxidation	Reduction/oxidation chemically converts hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are hypochlorites, chlorine, and chlorine dioxide.
		Dehalogenation	Dehalogenation process in which sediment is screened, processed with a crusher and pug mill, and mixed with sodium bicarbonate (base catalyzed decomposition) or potassium polyethylene glycol. The mixture is heated to above 630 °F in a rotary reactor to decompose and volatilize contaminants. Process produces biphenyls, olefins, and sodium chloride.
		Sediment Washing	Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.
		Radiolytic Dechlorination	Sediment is placed in alkaline isopropanol solution and gamma irradiated. Products of this dechlorination process are biphenyl, acetone, and inorganic chloride. Process must be carried out under inert atmosphere.
	Physical	Separation	Contaminated fractions of solids are concentrated through gravity, magnetic, or sieving separation processes.
		Solar Detoxification	Through photochemical and thermal reactions, the ultraviolet energy in sunlight destroys contaminants.
		Solidification	The mobility of constituents in a “solid” medium is reduced through addition of immobilization additives.
	Thermal	Incineration	Temperatures greater than 1,400 °F are used to volatilize and combust organic chemicals. Commercial incinerator designs are rotary kilns equipped with an afterburner, a quench, and an air pollution control system.
		High-temperature Thermal Desorption (HTTD)	Temperatures in the range of 600-1,200 °F are used to volatilize organic chemicals. These thermal units are typically equipped with an afterburner and baghouse for destruction of air emissions.
		Low-temperature Thermal Desorption (LTTD)	Temperatures in the range of 200-600 °F are used to volatilize and combust organic chemicals. These thermal units are typically equipped with an afterburner and baghouse for treatment of air emissions.
		Pyrolysis	Chemical decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash.
		Thermal Desorption	Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system (examples: X*TRAX™, DAVES, Tacuik Process, and Holoflite™ Dryer).
		Vitrification	Current technology uses oxy-fuels to melt soil or sediment materials at extremely high temperatures (2,900-3,650 °F).
		High-pressure Oxidation	High temperature and pressure are used to break down organic compounds. Operating temperatures range from 150-600 °C and pressures range from 2,000-22,300 MPa (examples: wet air oxidation and supercritical water oxidation).
Disposal	On-site Disposal	Level-bottom Cap	Relocation of contaminated sediment to discrete area and capping with a layer of clean sediments. Provides similar protection as capping, but requires substantially more sediment handling that may cause increased releases to surface water.
		Contained Aquatic Disposal (CAD)	Untreated sediment is placed within a lateral containment structure (i.e., bottom depression or subaqueous berm) and capped with clean sediment.
		Confined Disposal Facility (CDF)	Untreated sediment is placed in a nearshore confined disposal facility that is separated from the river by an earthen berm or other physical barrier and capped to prevent contact. A CDF may be designed for habitat purposes.
	Off-site Disposal	Subtitle D Landfill	Off-site disposal at a licensed commercial facility that can accept nonhazardous sediment. Regional landfills can accept both dewatered and wet sediments.
		Subtitle C Landfill	Off-site disposal at a licensed commercial facility that can accept hazardous dewatered sediment removed from dredging or excavation. Depends on analytical data from dredged sediment. Dewatering required to reduce water content for transportation.
		TSCA-licensed Landfill	Off-site disposal at a licensed commercial facility that can accept TSCA sediment. Dewatering required to reduce water content for transportation.
		Dredged Material Management Program (DMMP) Open-water Disposal	Treated or separated sediment is placed at the Elliott Bay DMMP disposal site. Requires that the placed sediment be at, or below, Puget Sound Dredged Disposal Analysis (PSDDA) disposal criteria for priority pollutants and potentially bioaccumulative chemicals.
		Upland MTCA Confined Fill (Commercial/ Industrial – Beneficial Use)	Treated or untreated sediment is placed at an off-site location. Requires that sediment be at, or treated to, MTCA cleanup levels at an off-site location and meet non-degradation standards. Location may require cap or other containment devices based on analytical data.
		Upland MTCA Fill (Residential/ Clean – Beneficial Use)	Treated or untreated sediment is placed at an off-site location. Requires that sediment be at, or treated to, a concentration at or below MTCA cleanup levels for unrestricted land use and meet non-degradation standards.
		Dredged Material Management Program (DMMP) Open-water Disposal	Treated or separated sediment is placed at the Elliott Bay DMMP disposal site. Requires that the placed sediment be at, or below, Puget Sound Dredged Disposal Analysis (PSDDA) disposal guidelines for priority pollutants and potentially bioaccumulative chemicals.
		In-Water Beneficial Use	Sediments treated to below PSDDA guidelines may be beneficially reused for habitat creation, capping, or residual management.

5 No Action and Institutional Controls

This section presents the GRAs of No Action and institutional controls. Although these are not contemplated for implementation as sole remedial technologies, it is a requirement that these two actions be considered, either on their own or in combination with other actions (i.e., in assembling an alternative). Therefore, both GRAs are described in this section, as well as the technology screening, which discusses how effective they might be, how they might be implemented in the LDW and their relative costs.

5.1 No Action

The NCP requires that No Action be used as a baseline comparison against other technologies. The No Action alternative requires no human intervention for cleanup, such as treatment, engineering, or institutional controls, but can include long-term monitoring to ensure that site conditions do not result in unacceptable risks to human health or the environment (EPA 1988).

The No Action alternative may be selected by EPA/Ecology if a baseline risk assessment demonstrates that there are no unacceptable risks to human health or the environment. A "No Further Action" alternative may be selected if cleanup actions already undertaken at a site have achieved risk-based RAOs (OSWER 2005).

5.2 Institutional Controls

Institutional controls are non-engineering GRAs intended to affect human activities in such a way as to prevent or reduce exposure to hazardous situations. Institutional controls are typically administrative actions that limit site or resource use. Both CERCLA and MTCA incorporate the expectation that institutional controls would not be the primary cleanup alternative for a contaminated sediment site, unless active measures such as removal or capping are not practicable (EPA 1997, WAC 173-340-360(2)(e)). Institutional controls are most often used in conjunction with cleanup alternatives that manage contaminated sediments in place or in circumstances where concentrations of contaminants in fish or shellfish are expected to pose risks to human health for some time in the future (EPA 1997).

Institutional controls can range from informational tools (for instance, informing the public about site restrictions) to easements, covenants or deed restrictions, state or local use restrictions, and advisories (EPA 2000d). The process options for institutional controls (Table 5-1) are:

- Fish consumption advisories and restrictions
- Access and property use restrictions
- Waterway use restrictions.

Fish consumption advisories and fishing bans are used to protect the general public from risks posed by eating contaminated fish or shellfish caught in affected areas.

These types of controls are applicable for contaminants that can be taken up from sediments into fish or shellfish at levels that can cause unacceptable cancer risks or other deleterious human health effects. Most commonly, consumption advisories or fishing bans have been issued in North America in areas with elevated concentrations of PCBs, mercury, or arsenic.

Fish consumption advisories are communicated to the public through posted signs, the distribution of educational material, and other forms of information transfer to the potentially affected communities to support the goal of self-limited fish consumption. Fishing bans are generally placed on commercial fishing interests for specific fish or shellfish. Currently, there is a formal fish consumption advisory in place for PCBs in fish and shellfish collected in the LDW (http://www.doh.wa.gov/ehp/oehas/fact%20sheets%20pdf/Duwamish_FS_7-28-05.pdf). The Washington State Department of Health (DOH) public health assessment for the LDW recommends that no consumption of resident fish (e.g. English sole, starry flounder, perch, etc.), shellfish or crab from the Duwamish River. No consumption limits are proposed for salmon caught in the LDW because PCB concentrations in those salmon are lower than in those found in resident fish.

Access restrictions are principally applied to upland or nearshore properties to control human access to contaminated areas. Deed restrictions would potentially preclude, or place restrictions on, future in-water activities, including utilities such as underwater pipelines and electrical or telephone cables, marinas, boat ramps, piers, or other construction that would require disturbance of the contaminated sediments.

Waterway restrictions are administrative controls on such activities as boating, anchoring, dredging, or other water-dependent uses. These controls can be implemented to protect both human health and ecological health by restricting processes that could disturb sediments (e.g., restricting wakes or anchoring). These controls may be used in conjunction with an alternative that leaves residual contaminants in place. Monitored natural recovery, capping, or in-water disposal (i.e., confined aquatic disposal) are examples of alternatives that may require long-term waterway restrictions (OSWER 2005). Boating restrictions could include establishing no-access, no-anchoring, or no-wake zones. However, enforcement of these restrictions may be difficult in a large, public, commercial waterway. Restrictions on dredging, such as dredging moratoriums, are designed to preclude sediment disturbance or removal in contaminated areas, thereby reducing short-term direct contact and sediment resuspension risks. For an active waterway with a federally authorized navigation channel, such as the LDW, dredging moratoriums are not applicable to the site as a whole, but may be applicable to specific areas as part of a specific alternative (e.g., in-water containment).

Institutional controls may be effective at limiting human activities, and while they cannot limit activities of ecological receptors, certain controls may be effective at providing protection for ecological receptors. For example, an institutional control that prevents anchoring or construction through a sediment isolation cap can be effective at protecting ecological receptors from the isolated contaminants.

Implementation of institutional controls for the LDW would require the cooperation of the implementing agencies and local Native American tribes, as well as public acceptance. Institutional controls that restrict access to resources in Tribal usual and accustomed harvest areas may not be considered appropriate long-term solutions. Enforcement of these restrictions and public acceptance may therefore be difficult to achieve. While institutional controls may be effective at limiting human exposures, they are generally less effective at providing protection to ecological receptors in areas where impacts are ongoing.

Costs for institutional controls are primarily related to the legal and administrative aspects of implementation. In general, institutional controls are a low-cost approach to managing the risks posed by contaminated media. The costs of institutional controls are substantially less than the costs of technology-based cleanup options that involve containment, removal, treatment, or disposal.

5.3 Retained Technologies

As shown in Table 5-1, both No Action and institutional controls are applicable to the site conditions and COPCs; in the case of No Action, the finding of applicability is a statutory requirement. Both No Action and institutional controls may be applied to chemical or specific cleanup goals. Institutional controls have also been used at other sites on a scale similar to the LDW. Neither No Action nor institutional controls qualifies as an innovative technology.

Table 5-2 expands on the rationale for these findings and presents the screening decision, which is that No Action and institutional controls are both retained for further evaluation in the FS. No Action is retained because it is required by the NCP. Institutional controls are retained for possible use in conjunction with more active technologies, such as in-water containment. The screening of No Action and institutional controls is discussed in detail below.

5.3.1 Effectiveness

No Action must be considered, but would not expected to be effective at managing the risks associated with site contaminants unless a baseline risk assessment demonstrated that there were no unacceptable risks to human health or the environment. The effectiveness of “No Further Action” would depend upon the demonstration that cleanup actions already undertaken at the site have achieved risk-based RAOs.

Institutional controls alone could be effective at limiting human exposures to the COPCs in the LDW, but are not expected to provide adequate protection to ecological receptors in areas where impacts are ongoing. When implemented in conjunction with more active technologies, institutional controls can be effective at assisting in the management of exposure risks for both human and ecological receptors. For example, covenants or deed restrictions associated with in-water containment structures could be an effective component of the overall cleanup strategy for some areas of the LDW.

5.3.2 Implementability

The No Action GRA is implementable under the LDW site conditions. Institutional controls are also implementable, but the administration of those controls would require the cooperation of the implementing agencies and local Native American tribes, as well as public acceptance.

5.3.3 Cost

Costs associated with the "No Action" or "No Further Action" GRAs are expected to be low, relative to more active removal, treatment, or isolation alternatives. Expected costs that could be incurred include a long-term monitoring program and institutional controls, where required. Costs for institutional controls are primarily related to the legal and administrative aspects of implementation, but may also include monitoring and enforcement activities. In general, institutional controls are a low-cost approach to managing the risks posed by contaminated media when compared to the costs of technology-based cleanup options that involve containment, removal, treatment, or disposal.

Table 5-1 Effectiveness and Implementability Evaluation of No Action and Institutional Controls

GRA	Technology Type	Process Option	Effectiveness				Implementability		
			Applicable to Site COPCs				Applicable to Site Conditions	Commercially Demonstrated at Similar Scale	Innovative Technology
			Metals	PCBs	Semivolatile Organics	TBT			
No Action	None	Required by NCP					√	Not applicable	–
Institutional Controls	Physical, Engineering or Legislative Restrictions	Consumption Advisory	+	+	+	+	√	Not applicable	–
		Access Restrictions	+	+	+	+	√	Not applicable	–
		Waterway Restrictions	+	+	+	+	√	Not applicable	–

Notes:

+ Potentially effective and applicable to LDW COPCs

– Not effective or applicable to LDW COPCs

± Potentially effective, but not within an acceptable time frame for LDW COPCs

Table 5-2 Effectiveness, Implementability, and Cost Considerations for No Action and Institutional Controls

GRA	Technology Type	Process Option	Effectiveness		Implementability				Cost
			LDW COPCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	
No Action	None	Not Applicable		Retained per NCP Requirement	Technically implementable for conditions within the LDW	—	—	Retained per NCP Requirement	Low
Institutional Controls	Physical, Engineering, or Legislative Restrictions	Consumption Advisories	Effective for LDW COPCs accumulated in fish or shellfish. Not effective for ecological receptors	Retained for Further Evaluation	Technically implementable for conditions on the LDW. Requires commitment and cooperation of implementing agencies and Native Americans with treaty fishing rights	Available and demonstrated, but industrial industrial waterway uses and tribal fishing rights may preclude some applications	—	Retained for Further Evaluation in the FS	Low
		Access Restrictions	Can be effective for LDW COPCs. Limited effectiveness if used as sole remedy, but effective when used in conjunction with active remedies.	Retained for Further Evaluation	Not implementable for the entire LDW. Active federally-authorized navigation channel and industrial uses limit applicability. Can be technically implemented for limited and specific portions.	Available and demonstrated, but industrial industrial waterway uses and tribal fishing rights may preclude some applications	—	Retained for Further Evaluation in the FS	Low
		Waterway Restrictions	Can be effective for LDW COPCs. Limited effectiveness if used as sole remedy, but effective when used in conjunction with active remedies.	Retained for Further Evaluation	Not implementable for the entire LDW. Active federally-authorized navigation channel and industrial uses limit applicability. Can be technically implemented for limited and specific portions.	Available and demonstrated, but industrial industrial waterway uses and tribal fishing rights may preclude some applications	—	Retained for Further Evaluation in the FS	Low

Note:

— Does Not Apply

6 Monitored Natural Recovery and Enhanced Natural Recovery

This section reviews natural recovery processes and describes MNR and ENR within the context of GRAs. Natural recovery may involve one or more natural processes that effectively reduce a chemical's toxicity, mobility, or volume. These processes can include biological degradation of the chemical by bacteria or fungi, slow diffusion from the sediments, dilution by mixing with clean, naturally deposited sediments, sorption of the chemicals onto sediment particles, volatilization out of the waterway and into the air, or chemical and biochemical stabilization of chemicals into unavailable or nontoxic forms. Both MNR and ENR could be applied to either chemical or toxicity-based cleanup goals. Following a discussion of MNR and ENR, a technology screening is presented that discusses the effectiveness, implementability, and relative cost for each.

6.1 Natural Recovery Process Options

As shown in Table 6-1, the primary process options associated with the natural recovery of contaminated sediments are:

1) **Biological degradation processes** that cause reductions in the mass, volume, or toxicity of contaminants through biodegradation or biotransformation

2) **Physical processes,** such as sedimentation/deposition, mixing, diffusion, dilution, volatilization, or transport

3) **Chemical processes,** including oxidation/reduction and sorption.

Biological processes include bacterial or fungal degradation or transformation of organic chemicals into less toxic forms. These processes may be effective for volatile and semivolatile organic compounds in well-mixed (i.e., well-oxygenated) sediments. For chlorinated hydrocarbons, available research on the natural biodegradation of PCBs in aquatic systems suggests that biological processes would not be expected to significantly influence PCB concentrations over reasonable time periods (EPA and USACE 2000; RETEC 2002b). Metals concentrations would not be expected to decrease through biological processes, although the natural production of sulfides may result in the formation of metal-sulfide complexes, thereby limiting the bioavailability of certain metals (EPA 2000e). TBT is known to biodegrade in the marine environment, but at slow rates that would not be expected to decrease concentrations within a reasonable time period (WHO 1990). Thus, biological processes are not likely to substantially decrease concentrations of COPCs within the LDW.

Physical processes include dilution through the ongoing sedimentation and burial or mixing of cleaner surface sediments with contaminated deeper sediments via burrowing organisms, ship scour, propeller wash, and natural water currents. Downstream dispersion/transport of contaminated sediments is another example of a physical process. However, downstream transport and dispersion, is typically the least preferable basis for MNR because, although it may reduce risk in the source area, it may result in contamination of downstream areas (OSWER 2005). Physical processes are believed to be the most important consideration for assessing the applicability of MNR or ENR in the LDW.

Chemical processes include the preferential sorption of organic compounds to naturally occurring carbon and humic sources within the sediments, abiotic dechlorination, photo-oxidation of semivolatile organic compounds, as well as changes in redox potential for metals related to the presence of sulfides in marine sediments.

All of these processes are likely to occur together and, at least to some extent, simultaneously.

6.2 Monitored Natural Recovery

MNR relies on natural recovery processes coupled with monitoring to ensure that recovery is occurring as anticipated. Natural recovery is defined as the effects of natural processes that permanently reduce risks from contaminants in surface sediments (Apitz et al. 2002) and that effectively reduce or isolate contaminant toxicity, mobility, or volume. Monitoring of these processes is conducted to determine their effectiveness within a prescribed time frame.

MNR is a risk management alternative that relies upon natural environmental processes to permanently reduce exposure and risks associated with contaminated sediments (Davis et al. 2004) MNR can be implemented as a sole alternative, but is more frequently combined with an active remedy and institutional controls. MNR differs from No Action in that, by definition, it must include source control, minimal potential for recontamination from upstream sources via sediment transport, and requires that assessment, modeling, and long-term monitoring take place to verify the remedy (Palermo 2002; Apitz et al. 2002).

Institutional controls such as fish consumption advisories, fishing bans, or waterway or land use restrictions are also commonly a component of an MNR remedy. In circumstances where MNR has been the selected remedy, it is often a contingent remedy. The monitoring component is conducted to ensure that expectations that contaminant concentrations will stabilize or lessen over time are met. If those expectations are not met, a contingent active remedy may be invoked.

The potential for natural recovery of sediment is determined through multiple lines of evidence related to the biological, physical, and chemical processes described above. Where MNR has been applied, the demonstration of sediment deposition (burial) and contaminant attenuation (reduction) processes have been major determinants of MNR. For the LDW, a weight-of-evidence approach is currently being evaluated as part of the Phase 2 RI (Windward 2004) that follows the general lines of evidence developed by the EPA (EPA 1999b) and MTCA (WAC 173-340-370(7)) and a similar approach developed by the Remediation Technologies Development Forum sediment workgroup (Davis et al. 2004).

Sediment transport and burial mechanisms have been used as major factors in the selection of MNR at certain sites. MNR as a sole alternative has been selected at only three sites:

- The Sangamo-Weston/Twelvemile Creek/Lake Hartwell CERCLA site in South Carolina (EPA 1994c; Brenner et al. 2004)
- Operable Unit 2 of the Lower Fox River (WDNR and EPA 2002)
- Green Bay, Wisconsin (WDNR and EPA 2003).

MNR is more common in conjunction with active remedial alternatives, such as at the Puget Sound Naval Shipyard site in Bremerton, Washington (Palermo 2002); portions of the Commencement Bay site in Tacoma, Washington (EPA 1989), the Ketchikan Pulp site near Ketchikan Alaska (EPA 2000b), the Burnt Fly Bog site in New Jersey (Palermo 2002); the Hudson River (EPA 2002b); OUs 1, 3, and 4 of the Lower Fox River (WDNR and EPA 2002); the Sheboygan River, Wisconsin (EPA 2000c); and the Shiawassee River, Michigan (EPA 2001a).

Where natural recovery has been monitored, decreases in sediment contaminant concentrations have been observed, but the long-term monitoring of fish tissue contaminant concentrations is either insufficient to fully evaluate risk reduction, or has shown mixed trends (e.g., EPA 2001b; EPA 2004b; Swindoll et al. 2000). For example, after five years of monitoring at the Sangamo PCB site, decreasing trends in sediment PCB concentrations are evident, but fish tissue PCB concentrations show mixed results. Some species are showing decreases (channel catfish) in some areas of the site, while other species have not responded measurably to changes in sediment PCB concentrations. In general, natural recovery occurs over a longer timeframe than a typical active remedy (such as dredging), and longer periods of fish tissue monitoring may be needed to measure the effect of natural recovery on tissue concentrations. However, the rates of natural recovery are site-specific. The potential success of MNR in the LDW will be evaluated on a site-specific basis and monitoring results from other sites cannot directly predict results in the LDW.

Sediment stability, burial, and potential transport can be evaluated using fate and transport models, sediment core profiles, critical sheer stress measurement (e.g. SEDFLUME) and actual changes in sediment bed elevations over time (Windward 2004). Using this information and other site-specific data, modeling and/or analysis of historical trends can be used to predict rates of natural recovery. The long-term success of natural recovery is measured through long-term monitoring, to assess statistically significant changes in contaminant concentrations in surface sediments or biological tissues and responses over time.

6.3 Enhanced Natural Recovery

ENR involves the placement of a thin layer of clean material over areas with relatively low contaminant concentrations to speed up, or enhance, the natural recovery processes already demonstrated to be occurring at a site (e.g., burial/mixing). Under ENR, thin layers of clean sand or sediments are carefully placed over areas where natural recovery processes are occurring, but are occurring at a rate that is insufficient to reduce risks within an acceptable time frame (OSWER 2005). Careful, controlled placement of the clean sediments is required to minimize disturbance of contaminated sediments and to avoid dispersion of contaminants during placement. In contrast to an engineered cap, which is intended to permanently remain stable and isolate contaminants in underlying sediment, material placed during ENR is intended to enhance mixing and burial processes and is not engineered to resist disturbances. ENR has been used in Puget Sound both as a sole remedy and in conjunction with removal actions to aid in the management of post-dredging contaminant residuals (refer to discussion of residual management in Section 8.5.5). ENR generally also includes a long-term monitoring component because it is a form of natural recovery that leaves contaminants in place.

ENR has been selected as a remedy component at Superfund sites in Commencement Bay (Tacoma, Washington) and Eagle Harbor (Bainbridge Island, Washington), at the Manchester Annex site and the Puget Sound Naval Shipyard (Kitsap County, Washington), and at the Ketchikan Pulp site (near Ketchikan, Alaska) (Thompson et al. 2003). ENR was also used as part of a comprehensive remedial action that included removal of mercury-contaminated sediments at the Alcoa (Point Comfort)/Lavaca Bay Superfund site in Point Comfort, Texas (ALCOA 2003). ENR was recently implemented by King County at the Duwamish/Diagonal Early Action site to address off-site dredging residuals resulting from the remedial action (King County 2005).

6.4 Natural Recovery Decision Factors

A weight-of-evidence approach for developing and evaluating appropriate MNR remedies at contaminated sediment sites has recently been developed by the Remediation Technologies Development Forum sediment workgroup (Davis et al. 2004) and is discussed as part of EPA's current draft sediment management guidance (OSWER 2005). As summarized below, the framework includes five interrelated elements that may be applicable to the LDW RI/FS. Because ENR relies on fundamentally the same processes as MNR, these elements also apply to decisions on ENR remedies.

1) **Characterize external contamination sources and controls.** A critical component in the evaluation of any sediment management option, including natural recovery, is to characterize both historical and current contaminant sources. Source characterization can be difficult, and the level of effort required is site-specific.

2) **Characterize fate and transport processes (both sediment and contaminant).** Assessment of contaminant fate and transport processes in support of MNR requires an understanding of environmental processes affecting both sediment and contaminants. Primary processes include sediment resuspension and settling/deposition as a result of hydrologic (e.g., floods) and anthropogenic (e.g., ship traffic) influences, long-term burial, bioturbation and biological

mixing in the bed, pore water diffusion and advection, and chemical partitioning. Information on sediment stability is often necessary to assess the long-term integrity of the sediment bed.

3) **Establish the historical record for contaminants in sediments.** Chemical concentration data assembled from past sampling events or from radioisotope-dated cores can be used to establish a historical record for contaminated sediments and confirm the rate and extent of prior natural recovery.

4) **Corroborate MNR based on biological endpoint(s) trends, if possible.** The objective is to confirm that risk reduction, as may be indicated by evaluation of chemical conditions, is corroborated using relevant biological measurements. These data are often the same data used in assessing human health or ecological risks for a site.

5) **Develop acceptable and defensible predictive tools.** The final element in developing MNR alternatives is evaluation of whether observed reductions in sediment risks can reasonably be expected to continue into the future at desired rates. In systems in which the fate and transport processes driving recovery may be complex and may change with time, simple extrapolation of historical trends may not be appropriate. In such cases, hydrodynamic models that simulate tidal, density, wind-driven flow, salinity, temperature, and sediment transport can be useful tools to predict future erosion and deposition in the system. Other natural recovery models can be useful tools to predict future contaminant concentrations of the system. Key natural recovery model input parameters include estimations of (1) net sedimentation rate, (2) depth of bioturbation/mixing layer, (3) depth of biologically active zone, and (4) contaminant concentrations in depositing sediments.

6.5 Retained Natural Recovery Technologies

As shown in Table 6-1, both MNR and ENR are applicable to the site conditions and both are largely applicable to the site COPCs. MNR has not been shown to be effective on a scale similar to the LDW, while ENR has been. Neither MNR nor ENR qualifies as an innovative technology.

Table 6-2 expands on the rationale for these findings and presents the screening decision, which is that MNR and ENR are both retained for further evaluation in the FS. The screening of MNR and ENR is discussed in detail below.

6.5.1 Effectiveness

All of the MNR processes listed in Table 6-2 and ENR are potentially effective for the LDW COPCs. MNR as a sole remedy may be insufficient to reduce the higher concentrations of the recalcitrant or bioaccumulative COPCs within an acceptable time frame, and may need to be combined with an active remedy, or with ENR. Following the Early Action removals, natural recovery may be sufficient for any remaining localized quiescent areas with low COPC concentrations and accumulating sediments. In areas where MNR processes are demonstrated, but quicker recovery rates may better meet the remedial action objectives, ENR may be appropriately applied. ENR can be effective at reducing COPC concentrations in areas where natural processes are already occurring, or as an integral component of an active removal that reduces residual chemical concentrations to acceptable levels.

6.5.2 Implementability

Both MNR and ENR are implementable in the LDW from a technical standpoint, because the means are available for monitoring environmental quality and modeling the rate of natural recovery.

6.5.3 Cost

MNR is in general a low-cost technology because no active sediment remediation occurs. The cost of monitoring is a consideration, depending on the term and magnitude of the monitoring program. The cost of ENR is low to moderate, because ENR involves the active placement of clean material as well as the potential for long-term, post-placement monitoring, and maintenance (i.e., replenishment) as required.

Table 6-1 Effectiveness and Implementability Evaluation of Monitored Natural Recovery and Enhanced Natural Recovery

GRA	Technology Type	Process Option	Effectiveness				Implementability		
			Applicable to Site COPCs				Applicable to Site Conditions	Commercially Demonstrated at Similar Scale	Innovative Technology
			Metals	PCBs	Semivolatile Organics	TBT			
Monitored Natural Recovery	Natural Chemical/ Physical Degradation	Desorption, Diffusion, Dilution, Volatilization	+	+	+	+	√	Not Applicable	–
	Natural Biological Degradation	Dechlorination, Metabolization	-	±	+	±	√	Not Applicable	–
	Natural Physical Processes	Sedimentation and Burial	+	+	+	+	√	Not Applicable	–
		Resuspension and Transport	+	+	+	+	√	Not Applicable	–
Enhanced Natural Recovery	Thin-layer Placement	Mechanical or Hydraulic Placement	+	+	+	+	√	Not Applicable	√

Notes:

\+ Potentially effective and applicable to LDW COPCs

– Not effective or applicable to LDW COPCs

± Potentially effective, but not within an acceptable time frame for LDW COPCs

Table 6-2 Effectiveness, Implementability, and Cost Considerations for Monitored Natural Recovery and Enhanced Natural Recovery

GRA	Technology Type	Process Option	Effectiveness Screening		Implementability				Cost
			LDW COPCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	
Monitored Natural Recovery	Natural Chemical/ Physical Degradation	Natural Desorption, Diffusion, Dilution, Volatilization	Potentially effective for immobilizing COPCs through TOC or sulfide sorption.	Retained for Further Evaluation	Technically implementable for conditions within the LDW	—	—	Retained for Further Evaluation in the FS	Low
	Natural Biological-Degradation	Natural Dechlorination (aerobic and anaerobic)	Effective for SVOCs and PAHs but does not result in complete destruction of PCBs or TBT in acceptable time frame. Not applicable to metals.	Retained for Further Evaluation	Technically implementable for conditions within the LDW	—	—	Retained for Further Evaluation in the FS for SVOCs only	Low
	Natural Physical Processes	Natural Sedimentation and Burial	Potentially effective for LDW COPCs via deposition and reburial. Requires demonstration of long-term deposition and burial.	Retained for Further Evaluation	Technically implementable for conditions within the LDW	—	—	Retained for Further Evaluation in the FS	Low
		Resuspension and Transport	Potentially effective for LDW COPCs. Requires demonstration that transport of bedded-COPCs is occurring.	Retained for Further Evaluation	Technically implementable for conditions within the LDW	—	—	Retained for Further Evaluation in the FS	Low
Enhanced Natural Recovery	Thin-layer Placement	Thin-layer Placement	Effective for all LDW COPCs. Applicable: (1) at areas where MNR processes are demonstrated, but faster recovery is required, or (2) as a residual management tool after completion of a removal action.	Retained for Further Evaluation	Technically implementable for conditions within the LDW	Thin-layer placements for ENR and residuals management have been applied in multiple locations in Puget Sound and nationally.	—	Retained for Further Evaluation in the FS	Low to Moderate

Note:

— Not applicable

7 Containment

Containment technologies include *in situ* capping, contained aquatic disposal, and confined disposal facilities (Figure 7-1). This section focuses on *in situ* capping. Although both contained aquatic disposal and confined disposal facilities typically involve in-water construction and containment, these technologies are also considered disposal alternatives and are therefore discussed as such in Section 11.

7.1 Capping

Capping is a well-developed and documented cleanup alternative in the Pacific Northwest and nationally. Representative capping projects that have been successfully implemented in the Pacific Northwest and nationally are listed in Table 7-1.

Capping isolates contaminants from the overlying water column and prevents direct contact with aquatic biota. Capping is considered effective at isolating low-solubility and highly sorbed contaminants like PCBs, where the principal transport mechanism is sediment resuspension and deposition. Cap placement as a remedial alternative assumes source control and minimal potential for recontamination from upstream sources via sediment transport. If the potential for scour from river currents or propeller wash exists, the cap will need to be designed in a way that protects it from scour. Capping may be applied to both chemical- and toxicity-based cleanup goals.

7.1.1 Types of Caps

- ***In Situ* Capping** (ISC) is defined as the placement of an engineered subaqueous cover, or cap, of clean isolating material over an *in situ* deposit of contaminated sediment (EPA 1994, 2002; NRC 1997, 2001; Palermo et al. 1998a, 1998b). Such engineered caps are also called isolation caps. *In situ* caps are generally constructed using granular material, such as clean sediment, sand, or gravel. Composite caps can include different types and multiple layers of granular material, along with geotextile or geomembrane liners (Figure 7-2). ISC capping may be considered as a sole remedial alternative or may be used in combination with other remedial alternatives (e.g., removal and MNR).

- ***In Situ* Capping with Partial Removal** is an option involving placement of an *in situ* cap over contaminated sediments that remain in place following a partial dredging action that removes contaminated sediment to some specified depth. This can be suitable in circumstances where capping alone is not feasible because of habitat, hydraulic, navigation, or other restrictions on minimum water depth. *In situ* capping with partial dredging can also be used when it is desirable to leave deeper contaminated sediment capped in place so as to preserve bank or shoreline stability. When ISC is used with partial dredging, the cap is designed as an engineered isolation cap, because a portion of the contaminated sediment deposit is not dredged.

- **Reactive Caps** are a new and potentially innovative technology that incorporates materials into the cap design that act to physically block, react with, and/or sequester the COPCs in the base sediments. There is as yet insufficient long-term monitoring to determine the efficacy of the technology. Reactive capping is discussed further in Section 7.1.4.

7.1.2 Capping Guidance Documents

Detailed guidance for subaqueous capping of dredged material and ISC for sediment remediation has been developed by the USACE and EPA. Detailed procedures for site and sediment characterization, cap design, cap placement, and monitoring of subaqueous caps are provided in the Draft *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (OSWER 2005), *Guidance for Subaqueous Dredged Material Capping* (Palermo et al. 1998a), and *Guidance for In-Situ Subaqueous Capping of Contaminated Sediments* (Palermo et al. 1998b).

In addition, multiple references that discuss physical considerations, design, and monitoring requirements for capping include the following:

- *Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett et al. 1990)
- *Design Requirements for Capping* (Palermo 1991a)
- *Site Selection Considerations for Capping* (Palermo 1991b)
- *Standards for Confined Disposal of Contaminated Sediments Development Document* (Ecology 1990)
- *Equipment and Placement Techniques for Capping* (Palermo 1991c)
- *Monitoring Considerations for Capping* (Palermo et al. 1992)
- *Subaqueous Capping of Contaminated Sediments: Annotated Bibliography* (Zeman et al. 1992)
- *Design Considerations for Capping/Armoring of Contaminated Sediments In-Place* (Maynord and Oswalt 1993)
- *Subaqueous Capping and Natural Recovery: Understanding the Hydrogeologic Setting at Contaminated Sediment Sites* (USACE 2002)
- *Multi-user Disposal Sites (MUDS) for Contaminated Sediments from Puget Sound – Subaqueous Capping and Confined Disposal Alternatives* (USACE 1998a).

7.1.3 ISC Construction and Placement Methods

Various equipment types and placement methods have been used for capping projects, including hopper barges at larger, open-water sites and both hydraulic and mechanical systems for placement at nearshore or shallow-water sites. Caps may also be placed in high intertidal areas from the shoreline using conventional upland equipment or placed intertidally during low tide sequences. Some of these methods are shown and described in Figures 7-3 through 7-9.

An important consideration in the selection of placement methods is the need for controlled, accurate placement of capping materials. Slow, uniform application that allows the capping material to accumulate in layers is often necessary to avoid displacement of or mixing with the underlying contaminated sediment. Slow application minimizes the resuspension of contaminated material into the water column (Cunningham et al. 2001).

Granular cap material can be handled and placed in a number of ways. Mechanically dredged materials that have been dewatered and soils that have been excavated from an upland site or quarry have relatively little free water. These materials can be handled mechanically in a dry state until released into the water over the contaminated site. Mechanical methods (such as clamshells or release from a barge) rely on gravitational settling of cap materials in the water column and could be limited in their application by operational depths (Figures 7-2, 7-3, 7-9 and 7-10). Granular cap materials can also be entrained in a water slurry and carried wet to the contaminated site, where they are discharged into the water column at the surface or at depth (Figures 7-4 through 7-7). These hydraulic methods offer the potential for a more precise placement, although the energy required for slurry transport could require dissipation to prevent resuspension of contaminated sediment. Armor layer materials can be placed from barges or from the shoreline using conventional equipment, such as clamshells.

More recently, techniques have been demonstrated for placing a cap under narrow tidal work windows and shallow water conditions. A removal and intertidal capping of contaminated sediments near the head of the Middle Waterway in Tacoma, Washington used a pneumatic blower to spread capping material to a thickness of 0.5 to 1 ft. during a low tide sequence (Moore et al, 2005).

7.1.4 Reactive Caps

Reactive capping is a developing, innovative technology that incorporates catalytic, sequestering, or blocking agents into the cap design (Figure 7-2). This may be done by specification of a total organic carbon content in the applied cap, or through additions of materials that have been shown to be effective in dechlorination, sequestering of metals or recalcitrant hydrocarbons, or providing a seal against contaminant migration through a cap. In recent Puget Sound projects, organic carbon additions have included application of granulated anthracite to the Pacific Sound Resources RA1 cap, addition of peat mixed with the sand cap in the Head of the Thea Foss Waterway project (DOF 2004), and the addition of granular activated carbon to the cap at the Olympic View

Resource Area. Coal-based reactive caps have recently been proposed by the Washington Department of Ecology to sequester PCB-contaminated sediments in the Spokane River (Ecology 2005).

At the Olympic View Resource area, organic material mixed with sand was placed as part of the lower layer of an isolation cap to protect against PCBs and dioxins. This "high TOC/sand" layer was 6 inches thick. The material was not thought of as a reactive cap, but was placed as a precautionary barrier (K. Keeley, EPA, personal communication). The cap design followed the standard USACE guidance calculations for caps. According to the design document, the granular activated carbon used was a "common commercial-grade product" mixed at 4 percent by volume (1.5 percent by weight) (Hart Crowser 2002).

The 23-acre sand cap constructed over contaminated sediments in the Willamette River at the McCormick & Baxter Superfund site is an example of a composite cap that was constructed using several different materials, including reactive, erosion, and habitat layers in the final cap design (EPA and ODEQ 2005). Approximately 600 tons of oil-absorbing clay was placed to contain creosote seeps, followed by 130,000 tons of sand over the remaining contamination. To protect against erosion, the clay and sand layers were armored using a combination of rock and concrete-block mats. Finally, a thin sand layer was placed over the entire cap to help reestablish fish habitat on the Willamette River. The project was completed in 2004; to date there are no long-term monitoring data to evaluate the efficacy of the cap.

A major demonstration of several of the more active-addition reactive cap designs is now underway on the Anacostia River in Washington, DC (HSRC 2004). The objective of the Anacostia River demonstration project, which began field trials in spring 2004, is to provide information on the design, construction, placement and effectiveness of these augmented caps. Initial bench-scale treatability testing assessed the feasibility and expected effectiveness of a range of active cap technologies, and identified the most promising technologies for field-scale demonstration. Although various cap technologies were evaluated, the following were selected for use in the demonstration:

- Sand, used in the Anacostia River demonstration as a control
- AquaBlok™, a commercial product designed to enhance chemical sequestering (e.g., through organic carbon amendments to the cap) and to reduce permeability at the sediment-water interface
- Apatite, which encourages precipitation and sorption of metals.

Of these three, AquaBlok™ is not recommended by the vendor for saline environments such as the LDW. Preliminary results in the fall of 2004 showed that placement of the caps in the Anacostia River was relatively successful. However, the low permeability AquaBlok™ cap showed evidence of heaving because of methane accumulation and release (HSRC 2004). Chemical isolation sampling is planned through 2005.

7.2 Cap Decision Factors

The principal design considerations for capping as a remedial alternative for contaminated sediments are that the cap must remain physically stable, and that the contaminants are effectively isolated. The National Research Council (NRC 1997) provided additional decision factors that should be evaluated for an *in situ* cap. These include

- Contaminant sources have been sufficiently abated to prevent re-contamination of the cap
- Contaminants are of moderate to low toxicity and mobility
- MNR is too slow to meet remedial action objectives (RAOs) in a reasonable time frame
- Cost or environmental effects of removal are very high
- Suitable types and quantities of cap materials are available
- Hydrologic conditions will not compromise the cap
- Bioturbating infauna will not compromise the cap
- Weight of the cap can be supported by the original bed
- Cap is compatible with current or future waterway uses
- Site conditions are not favorable for complete removal of contaminated sediment.

A well-designed, properly constructed and placed cap over a contaminated surface, along with effective long-term monitoring and maintenance, can prevent bioaccumulation by providing long-term isolation of contaminated sediments from bottom-dwelling organisms, and the prevention of contaminant flux into the surface water. Incorporation of habitat elements into the cap design can provide an improvement or restoration of the biological community.

One advantage of capping is that the potential for contaminant resuspension and the risks associated with dispersion of contaminated materials during construction are relatively low. With capping, the sediments are contained in-place, and do not require additional treatment or offsite disposal. Most capping projects use conventional and locally-available materials, equipment, and expertise. For this reason, in certain cases the ISC option may be implemented more quickly and may be less expensive than options involving removal and disposal or treatment. Depending on the location of the cap, the type of construction, and the availability of materials, a cap may be readily repaired, if necessary.

A principal consideration when implementing ISC is that contaminated sediment will be left in place and not removed from the site. Because ISC leaves the contaminants in place, the sediment is not treated or detoxified. Long-term cap performance monitoring and maintenance is therefore required. Capping sites within a river may be subject to catastrophic events, such as major floods or dam failures, and disturbance from propeller wash. These events are factored into the remedy selection, design, institutional controls, and monitoring to ensure long-term integrity of the cap.

Where practicable, a sediment cap could be designed to provide habitat for the local biological community. Within Puget Sound there are multiple examples, including the St. Paul cap in Commencement Bay and the cap in East Eagle Harbor. However, caps intended to provide suitable habitat may not be feasible in situations where the cap needs to be armored to provide scour resistance, or to discourage deep-burrowing organisms to limit bioturbation. To provide erosion protection, it may be necessary to use cap materials that are coarser than native bottom materials and can alter the biological community. Depending on the site and cap design, it may be desirable to select capping materials that discourage colonization by native deep-burrowing organisms to limit bioturbation. In either case, the cap may be relatively poor habitat for the local biological community. This effect can be minimized through the selection and placement of habitat-enhancing materials over armor layers.

Capping is a feasible and appropriate remedy when such important factors as the ability of the *in situ* contaminated sediment layer to support a man-made or naturally deposited cap, the compatibility of a capped area with waterway uses, or the potential for enhancing biological use of the site through application of capping material(s) are considered. In addition, institutional controls necessary to protect the cap (e.g., waterway restrictions) may not be reliable because there may not be an effective means of enforcement. The cost of routine cap maintenance and repair should be included in the cost analysis. Also, there are few data that currently exist on the long-term success of ISC projects.

Palermo et al. (2002) and the EPA (OSWER 2005) provided additional detailed considerations for design, placement, and long-term maintenance of a cap over contaminated sediments in a river that include:

- Evaluation of capping should consider the long-term application, operations, institutional controls and maintenance over specific in-water infrastructure such as pipelines, utility easements, bridge piers, etc.

- The impacts to habitat by cap placement should be considered, including changes to depth and substrate type.

- The composition and thickness of the cap components comprise the cap design. A detailed design effort for any selected capping remedy should address all pertinent design considerations.

- The cap should be designed to provide physical and chemical isolation of the contaminated sediments from benthic organisms.

- The cap should be physically stable from scour by hydraulic conditions including currents, flood flow, propeller wash, etc.
- The cap should provide isolation of the contaminated sediments in perpetuity from groundwater or diffusive flux or resuspension of contaminants into the overlying surface waters.
- The cap design should consider operational factors such as the potential for cap and sediment mixing during cap placement, resuspension during placement, and variability in the placed cap thickness.
- The cap design should incorporate an appropriate factor of safety to account for uncertainty in site conditions, sediment properties, and migration processes.
- Institutional/regulatory constraints associated with capping, such as capping Toxic Substances Control Act (TSCA) materials, river-bed ownership, deed restrictions, fiduciary responsibility, and long-term liability should be fully considered in selecting potential areas for capping and in design of caps for specific areas.

An additional design consideration for caps constructed in Puget Sound is the ability to withstand a specified magnitude of earthquake, considering the earthquakes encountered in the region.

7.3 Retained Capping Technologies

Capping is considered both implementable and effective for containing contaminated sediments in portions of the LDW where navigation or other public uses would not be impeded (Table 7-2). Of the various process options, conventional sand, armored, composite, and reactive caps may be best suited for consideration. (Table 7-3) All of them have had at least some application within Puget Sound or EPA Region 10, and may be applicable to areas within the LDW. Specific details regarding cap materials, thicknesses, and other design parameters would be selected based on site-specific conditions and design criteria.

7.3.1 Effectiveness

The retained capping technologies are applicable for all the COPCs identified for the LDW. To date, capping has been shown to be effective in isolating COPCs from the overlying water column and in preventing direct contact with aquatic biota. However, the performance data available are limited, and in all cases there are few data on the long-term effectiveness of capping beyond 10-15 years. Capping is considered effective for low-solubility and highly sorbed contaminants, like PCBs, phthalates, butyltins, and high molecular weight PAHs (e.g., benzo(a)pyrene). Capping has also been effective for the isolation of metals and low molecular weight PAHs, but the sorptive capacity of the cap material requires particular considerations for low molecular weight PAHs (e.g., naphthalenes). Capping is also applicable and effective for toxicity-based cleanup goals.

Reactive caps, although potentially promising, do not have any long-term effectiveness data against which to evaluate chemical isolation. Nevertheless, they are retained for further evaluation as an innovative candidate technology. More commonly, increasing the organic carbon content of the capping material may be employed as a means of increasing the "reactivity," or sorbent/sequestering capacity of the capping material.

The areas within the LDW where capping technologies would be applicable are dependent upon the type of cap. All caps are applicable to areas outside of the federally-authorized navigation channel (defined both horizontally and vertically), with low erosion potentials, and where groundwater outflow would not be expected to transport contaminants through the cap. Capping may be technically applicable to the navigation channel, provided it was placed deeper than the authorized depth. However, the administrative feasibility of this action will require further consideration in the FS. In deeper waters where cap thickness effects on habitat are not a concern, sand caps are applicable. In areas where a thinner cap may be appropriate or where a higher natural organic content is required, a conventional sediment cap is applicable. Where there is higher erosion potential, armoring the caps may be applicable. Finally, where groundwater advection or diffusive flux of contaminants could be a concern, composite or reactive caps could be considered.

A principal advantage of capping is that it is more effective than removal in minimizing resuspension and spreading of COPCs. A principal disadvantage is that COPCs remain in place. Cap designs must preclude the potential for sediment resuspension under normal and extreme (e.g., storm) conditions. Sand caps may be subject to deep-dwelling bioturbating organisms that can burrow through the cap and into the underlying contaminated sediments, in effect creating conduits for recontamination. In addition, in sediments with higher organic content, methane generation may need to be considered in cap design and implementation.

7.3.2 Implementability

All of the retained caps are implementable, and have at least some construction tradition in Puget Sound and EPA Region 10. The list in Table 7-1 shows that caps have been successfully implemented within the Puget Sound area, including sand, conventional sediment, armored, and composite caps. Reactive caps have also been implemented in Puget Sound, and are being considered for several other locations within Washington. Additional implementability considerations include planning for a long-term commitment to monitoring and maintenance, earthquakes, the potential requirement for long-term institutional controls over the capped site, and assessing site-specific impacts to habitat quality. For composite or reactive caps, the expected tidal ranges in the LDW may require additional planning and engineering considerations.

7.3.3 Cost

Costs for capping are moderate with respect to more intensive approaches involving removal, treatment, or disposal. The cost of capping projects is largely dependent on the thickness of the cap, cost of capping materials, and associated transportation and placement costs. Costs will also be dependent upon long-term monitoring and implementation of institutional controls.

Table 7-1 Representative Contaminated Sediment Capping Projects[1]

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (ft)	Cap Material	Year Built	Performance	Comments
Puget Sound							
One Tree Island Olympia, Washington	Heavy metals, PAHs		4	Sand	1987	• No chemical migration • No erosion of cap	Last monitoring occurred in 1989 showed that sediment contaminants were contained.
St. Paul Waterway Tacoma, Washington	Phenols, PAHs, dioxins	17-acre cap	2-12	Coarse sand	1988	• No chemical migration • Cap within specifications	Some redistribution of cap materials has occurred, but overall remains >1.5 m (4.9 ft). The deeply burrowing ghost shrimp *Callianassa Californiensis* was found in the sediment, but never >1 m (3.3 ft).
Pier 51 Ferry Terminal Seattle, Washington	Mercury, PAHs, PCBs		1.5	Coarse sand (4 acres)	1989	• No chemical migration • Cap within specifications • Recolonization observed	As recent as 1994, cap thickness remained within design specifications. Although benthic infauna have recolonized the cap, there is no indication of cap breach because of bioturbation.
Denny Way combined sewer overflow (CSO) Seattle, Washington	Heavy metals, PAHs, PCBs	Water depth 18-50 ft	2-3	Sand (3 acres) obtained from LDW upper turning basin	1990	• Cap stable • Some chemicals in cap, but external source	Cores taken in 1994 show that although cap surface chemistry shows some signs of recontamination, there is no migration of isolated chemicals through the cap.
Pier 53-55 CSO Seattle, Washington	Heavy metals, PAHs		1.3-2.6	Sand (4.5 acres) obtained from LDW upper turning basin	1992	• No chemical migration • Cap stable, and increased by new deposition	Pre-cap infaunal communities were destroyed in the rapid burial associated with cap construction.
East Eagle Harbor/Wyckoff Bainbridge Island, Washington	PAHs	East and West Eagle Harbor total cap acreage :70	1-3	Sand (275,000 cy)	1994	• No chemical migration • Cap erosion in ferry lanes • Some chemicals observed in cap	Cap erosion measured within first year of monitoring only in area proximal to heavily used Washington ferry lane. Chemicals also observed in sediment traps. Ongoing monitoring.

Table 7-1 Representative Contaminated Sediment Capping Projects[1]

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (ft)	Cap Material	Year Built	Performance	Comments
Pier 64 Seattle, Washington	Heavy metals, PAHs, phthalates, dibenzofuran		0.5-1.5	Sand obtained from LDW upper turning basin	1994	• Some loss of cap thickness • Reduction in surface chemical concentrations	Thin-layer capping was used to enhance natural recovery and to reduce resuspension of contaminants during pile driving.
West Eagle Harbor/Wyckoff Bainbridge Island, Washington	Mercury, PAHs	East and West Eagle Harbor total cap acreage :70	Thin cap 0.5 ft over 6 acres and Thick cap 3 ft over 0.6 acre	Sand (22,600 tons for thin cap and 7,400 tons for thick cap)	1997 – Partial dredge and cap	• No chemical migration	To date, post-verification surface sediment samples have met the cleanup criteria established for the project. Ongoing monitoring.
GP Lagoon Bellingham, Washington	Mercury	Shallow intertidal lagoon	3	Sand	2001	• No chemical migration at 3 months • Cap successfully placed	Ongoing monitoring.
Head of Thea Foss Waterway, Tacoma, Washington	Non Aqueous Phase Liquid (NAPL)	21 acres	3 ft. composite	Composite cap including sand, high density polyethylene (HDPE), and armoring	2003	• No data to date	Engineered cap that included partial dredging to increase depth, placement of HDPE to control ebullition of NAPL, armoring as scour protection near stormwater outfalls
Pacific Sound Resources, Seattle, Washington	Mercury PAHs	58 acre cap	2.5 – 6 feet	Sand Upland Borrow Source (287,000 cy) Sand LDW Dredging Use (230,000 cy)	2003 – 2005	• No data to date	Upland borrow-material included grain size specifications and organic content requirements. Site included a steeply sloping offshore area (50%) and deep (-240 ft) water capping with dredged material.
Duwamish Waterway / Diagonal CSO Seattle, Washington	PCB, phthalates, mercury	7 acres placed on cut-slope	Cap placed over slope on cut-in benches. Minimum placement is 3 ft., with an average of 5 ft. over the site	Composite cap that included sand for isolation, cobble to rip-rap for erosion control, and habit material (fish mix)	2003-2004	• Baseline data collected in 2004. First year monitoring in 2005.	Armoring for erosion control was required for most of the site, with additional armoring around a dock facility. The habitat enhancement layer was placed over areas shallower than -10 ft MLLW.

Table 7-1 Representative Contaminated Sediment Capping Projects[1]

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (ft)	Cap Material	Year Built	Performance	Comments
Middle Waterway Area C Intertidal Cap, Tacoma, Washington	Mercury PAHs	6 acres	0.5 – 1 ft	Quarry-run sand	2003	• No data to date	Capping of intertidal sediments of Area C was accomplished using a pneumatic blower to spread capping material during low tide.
Hylebos Waterway Commencement Bay, Washington	PCBs. mercury, Semivolatile organic compounds	800 ft. length by 20 - 25 ft. width	Cap placed over 2:1 cut slope to a total thickness of 3.5 ft.	Composite cap that included heavy non-woven geotextile as base layer, covered by 1.5 ft. quarry spalls, and finished with 2 ft. of pit-run compacted sand and gravel.	2004	• Operations, Monitoring and Maintenance Plan still in draft	Intertidal cap that was placed using conventional upland equipment during low tide sequences. Tidal elevations were between +12 and 0 MLLW.
Olympic View Resource Area	PCBs, dioxins	1.3 acre cap	Variable, depending upon the cap area (intertidal, subtidal, habitat)	Sand, GAC and river rock	2002	• Visible and physical monitoring confirmed cap remained in place at design thickness	Excavation of 11,438 tons of sediment from contaminated intertidal areas, followed by placement of 14,500 tons of sand backfill and capping materials. Rounded river rocks up to 6-inches in diameter were placed over portions of the restored intertidal areas to provide a minimum 6-inch thick surface erosion protection layer. Contaminated subtidal area was capped with approximately 9,000 tons of sand cap material placed from a barge-mounted tremie tube. In some areas, GAC was mixed at 4% by volume (1.5% by weight) as a precautionary barrier.

Table 7-1 Representative Contaminated Sediment Capping Projects[1]

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (ft)	Cap Material	Year Built	Performance	Comments
California and Oregon							
PSWH Los Angeles, California	Heavy metals, PAHs		15	Sand	1995	• No data to date	Overall effective cap was >15 ft. This was not a function of design, but rather a function of the low contaminated-to-clean sediment volume.
Convair Lagoon San Diego, California	PCBs	5.7-acre cap in 10-acre site; water depth 10-18 ft	2 ft of sand over 1 ft rock	Sand over crushed rock	1998	• No chemical migration • Cap was successfully placed in very shallow water • Some chemicals observed in cap	Ongoing monitoring for 20 to 50 years including diver inspection, cap coring, biological monitoring.
McCormick and Baxter Superfund Site, Willamette River, Oregon	Creosote, NAPL	23 acres	2 ft	Composite cap included organo-clay, sand, armoring, and habitat mix.	2004	• No data to date	The project was completed in 2004; to date there are no long-term monitoring data to evaluate the efficacy of the cap,
Great Lakes							
Sheboygan River/Harbor Wisconsin	PCBs		Unknown	Armored stone composite	1989-1990	• Undetermined cap effectiveness • Some erosion of fine-grained material	Demonstration bench-scale project.
Sheboygan Falls Wisconsin (pilot)	PCBs	9 hotspots totaling 1,200 sq yds	1 ft of coarse material and upper geotextile over lower geotextile fabric	Composite	1992	• No monitoring data	Composite armored cap required as sediments were located in high-energy river environment. Gabions placed around the corners for anchoring. Additional coarse material placed into voids/gaps.
Hamilton Harbor Ontario Canada	PAHs		1.6	Sand (2.5 acres)	1995	• No monitoring data	Cap completed.

Table 7-1 Representative Contaminated Sediment Capping Projects[1]

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (ft)	Cap Material	Year Built	Performance	Comments
New England/New York							
52 Smaller Projects New England	Metals, PAHs		1.6	Silt	1980-1995	• No chemical migration	Routine monitoring.
Central Long Island Sound Disposal Site (CLIS) New York	Multiple harbor sources		Unknown	Sand	1979-1983	• Some cores uniform structure with low-level chemicals • Some cores no chemical migration • Some slumping	Extensive coring study at multiple mounds showed cap stable at many locations. Poor recolonization in many areas.
Stamford-New Haven-N New Haven, Connecticut	Metals, PAHs		1.6	Sand	1978	• No chemical migration	Cores collected in 1990.
Stamford-New Haven-S New Haven, Connecticut	Metals, PAHs		1.6	Silt	1978	• No chemical migration	Cores collected in 1990.
New York Mud Dump Disposal Site New York	Metals (from multiple harbor sources)		Unknown	Sand (12 million cy)	1980	• No chemical migration	Cores taken in 1983 (3.5 years later showed cap integrity over relocated sediments in 80 ft of water.
Mill-Quinniapiac River Connecticut	Metals, PAHs		1.6	Silt	1981	• Required additional cap	Cores collected in 1991.
Norwalk, Connecticut	Metals, PAHs		1.6	Silt	1981	• No problems	Routine monitoring.
Cap Site 1 Connecticut	Metals, PAHs		1.6	Silt	1983	• No chemical migration	Cores collected in 1990.
Cap Site 2 Connecticut	Metals, PAHs		1.6	Sand	1983	• Required additional cap	Cores collected in 1990.
Experimental Mud Dam New York	Metals, PAHs		3.3	Sand	1983	• No chemical migration	Cores collected in 1990.
New Haven Harbor New Haven, Connecticut	Metals, PAHs		1.6	Silt	1993	• No chemical migration	Extensive coring study.
Port Newark/Elizabeth New York	Metals, PAHs		5.3	Sand	1993	• No chemical migration	Extensive coring study.

Table 7-1 Representative Contaminated Sediment Capping Projects[1]

Sediment Project	**Chemicals of Concern**	**Site Conditions**	**Design Thickness (ft)**	**Cap Material**	**Year Built**	**Performance**	**Comments**
International Projects							
Hiroshima Bay Japan		Water depth 21 m	5.3	Sand	1983	• No available data	
Rotterdam Harbor Netherlands	Oils	Water depth 5 to 12 m	2-3	Silt/Clay sediments	1984	• No available monitoring data	As pollution of groundwater was a potential concern, the site was lined with clay prior to sediment disposal and capping.

Note: Information in this table, particularly for the Performance column, is based on the last monitoring event. Please note that the amount of available data on these projects varies widely, and for many of the sites, monitoring data are quite limited, and some of the sites have not been monitored for several years.

[1] Table compiled based on the following sources: Sumeri, A., 1984. “Capped In-water Disposal of Contaminated Dredged Material: Duwamish Water Site.” In: Proceedings of the Conference Dredging ’84, Dredging and Dredged Material Disposal, Volume 2. United States Army Corps of Engineers, Seattle, Washington.

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Table 7-2 Effectiveness and Implementability Evaluation of Containment Process Options

GRA	Technology Type	Process Option	Effectiveness				Implementability		
			Applicable to Site COCs				Applicable to Site Conditions	Commercially Demonstrated at Similar Scale	Innovative Technology
			Metals	PCBs	Semivolatile Organics	TBT			
Containment	Capping	Conventional Sand Cap	+	+	+	+	√	√	–
		Conventional Sediment Cap	+	+	+	+	√	√	–
		Armored Cap	+	+	+	+	√	√	–
		Composite Cap	+	+	+	+	√	√	–
		Reactive Cap	+	+	+	+	√		√

Notes:

+ Potentially effective and applicable to LDW COPCs

– Not effective or applicable to LDW COPCs

± Potentially effective, but not within an acceptable time frame for LDW COPCs

Table 7-3 Effectiveness, Implementability, and Cost Considerations for Containment Process Options

GRA	Technology Type	Process Option	Effectiveness		Implementability				Cost
			LDW COPCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	
Containment	Capping	Conventional Sand Cap	Effective for contaminants with low solubility and high sorption where the main concern is resuspension and direct contact. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants.	Retained for consideration throughout the LDW	Applicable to LDW conditions. Easily applied *in situ;* however, scouring must be considered. Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation, and recreation.	Conventional sand caps have been applied in multiple locations in Puget Sound and nationally. See Table 7-1	—	Retained for consideration in the FS for all areas of the LDW	Low
		Conventional Sediment Cap	Effective for contaminants with low solubility and high sorption where the main concern is resuspension and direct contact. Sediment with silt and clay is effective in limiting diffusion of contaminants. Sediment caps are generally more effective than sand caps for containment of contaminants with high solubility and low sorption.	Retained for consideration throughout the LDW	Generally applicable to LDW conditions. Placement of clay cap is considered in shallow water depth areas where minimal cap thickness is required. Special engineering controls will be needed to place clay cap in the LDW.	Conventional sediment caps using river-dredged sediments have been applied in multiple locations in Puget Sound and nationally. See Table 7-1. Application of clay caps is relatively new, but demonstrated.	—	Retained for consideration in the FS for all areas of the LDW	Low
		Armored Cap	Applicable to LDW COPCs. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants.	Retained for limited use in high-energy sections of river	Applicable to areas of LDW where increased velocities from river flow, or potential scouring due to propeller wash might be expected. Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation, and recreation.	Armored caps have been implemented at several sites in Puget Sound and nationally. See Table 7-1.	—	Retained for limited use in the FS for high-energy sections of the LDW	Low to Moderate
		Composite Cap (geotextile, HDPE)	Effective for LDW COPCs. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Can be used: (1) to limit cap thickness, (2) for low solids underlying sediments where additional floor-support is required, (3) as a bioturbation barrier or (4) as a barrier for areas where methane generation may be an issue.	Retained for consideration throughout the LDW	Applicable to LDW site conditions. Application must consider that decreased water depth may limit future uses of waterway and impact flooding, stream bank erosion, navigation, and recreation.	Application of composite capping is relatively new, but commercially demonstrated for projects with similar size and scope	—	Retained for consideration in the FS for all areas of the LDW	Low to Moderate
		Reactive Cap	Reactive cap materials are specific to the types of contaminants being managed. For example, coal and/or coke breeze may be used to bind PCBs, PAHs and SVOCs, but not metals. Apatite is applied for metals	Retained	Reactive caps may be applicable to site conditions on the LDW.	Addition of materials to increase sorptive capacity of cap has been implement in Puget Sound. Long-term effectiveness data will be available during the LDW FS	Reactive capping is an innovative technology that is in the demonstration phase on the Anacostia River. Results of those tests are expected during the LDW FS.	Retained for consideration in the FS as an innovative technology	Low to Moderate

FIGURE 7-1 TYPES OF CAPPING, CONTAINED AQUATIC DISPOSAL, CONFINED DISPOSAL FACILITIES, AND UPLAND SOLID WASTE DISPOSAL

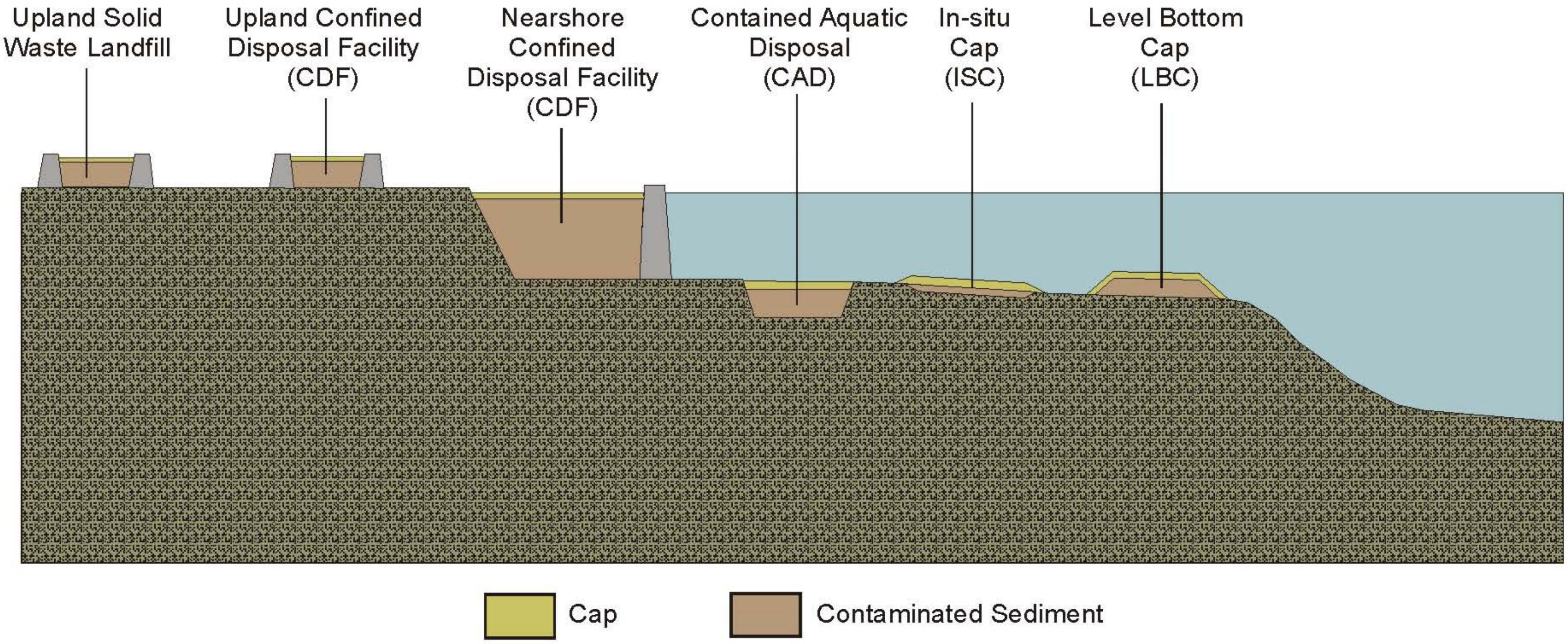
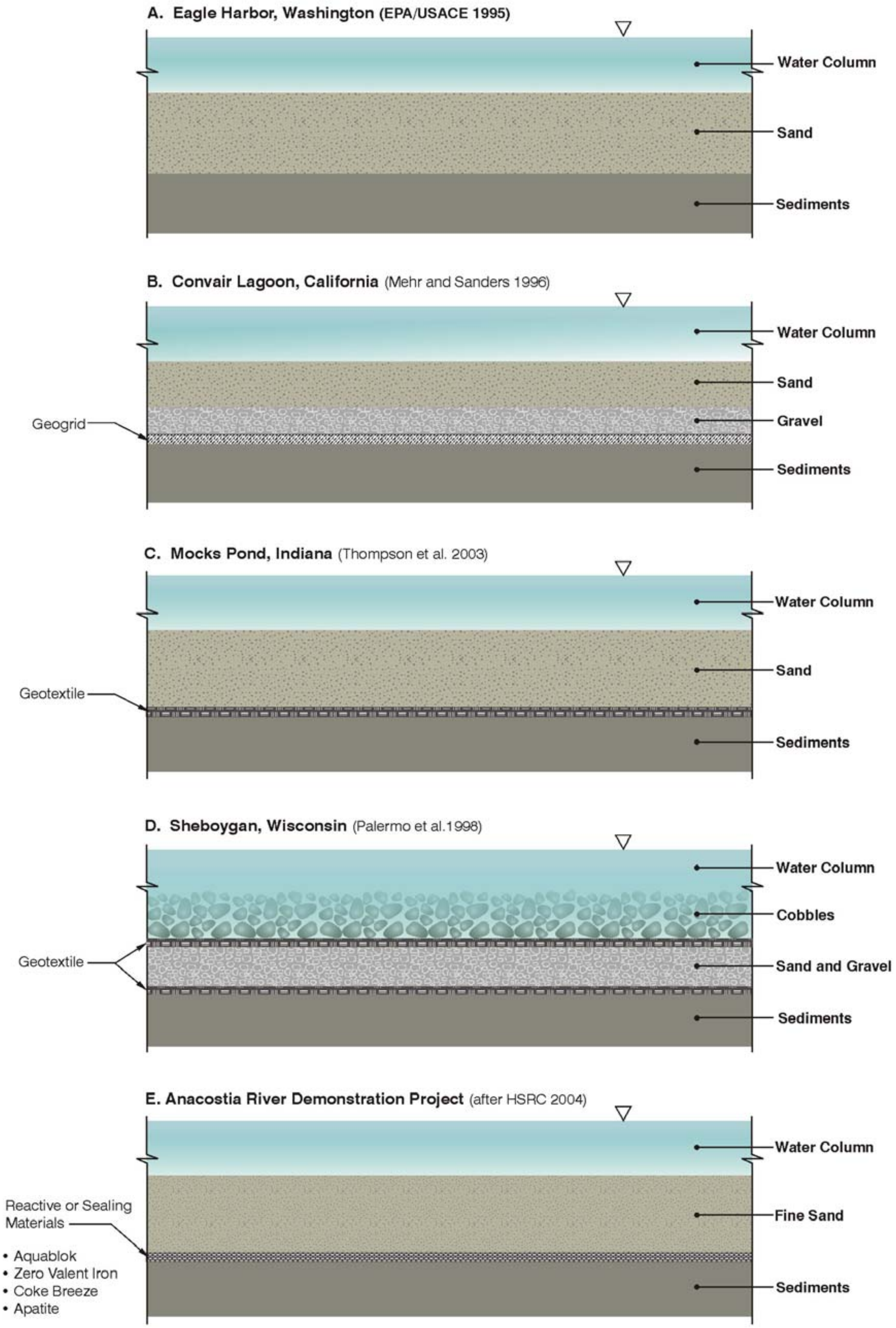


FIGURE 7-2 EXAMPLES OF CAP DESIGNS



A. Eagle Harbor, Washington (EPA/USACE 1995)

B. Convair Lagoon, California (Mehr and Sanders 1996)

C. Mocks Pond, Indiana (Thompson et al. 2003)

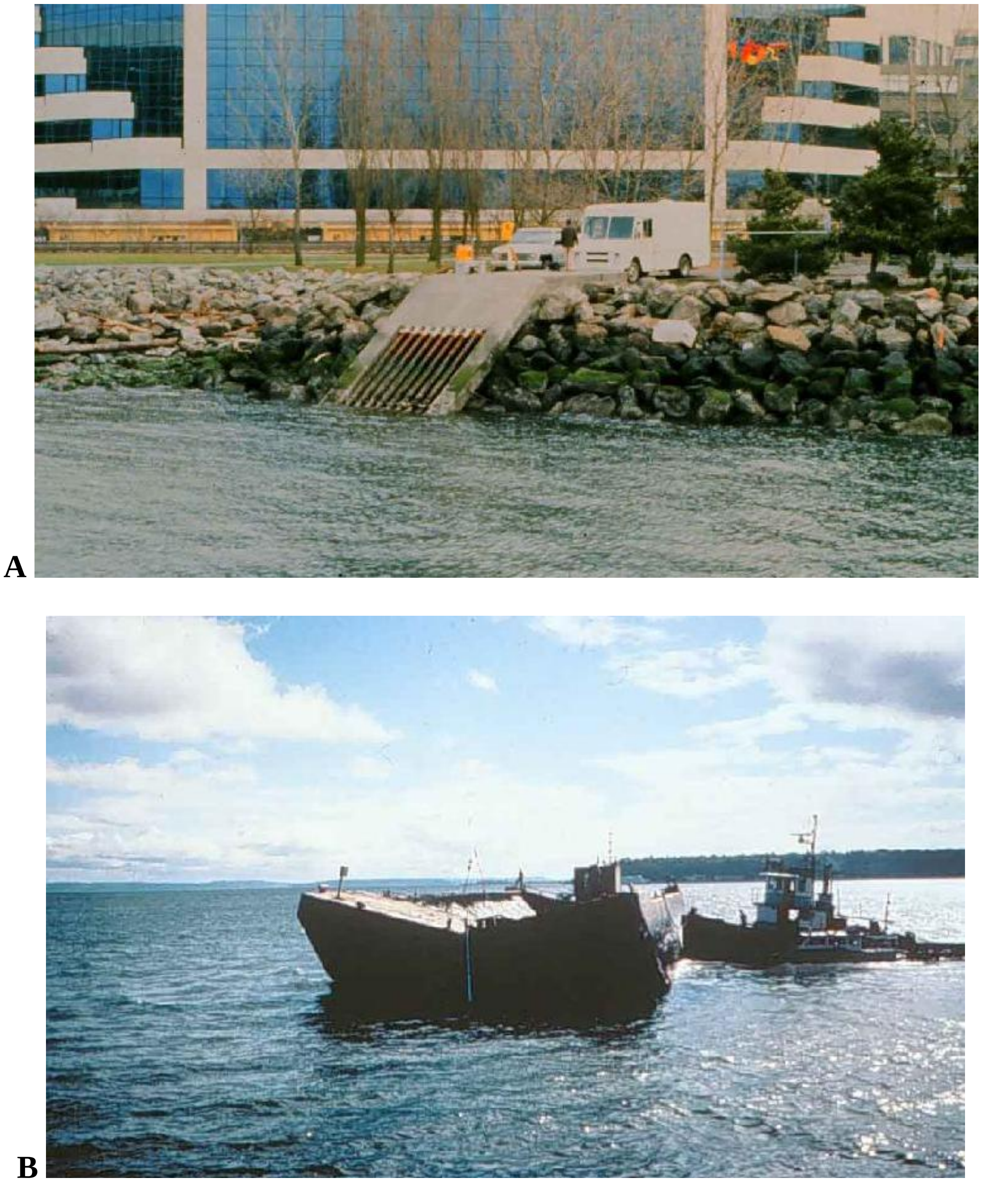
D. Sheboygan, Wisconsin (Palermo et al.1998)

E. Anacostia River Demonstration Project (after HSRC 2004)

FIGURE 7-3 PLACEMENT OF THE IN-SITU CAP AT THE EAST EAGLE HARBOR OPERABLE UNIT, BAINBRIDGE ISLAND, WASHINGTON

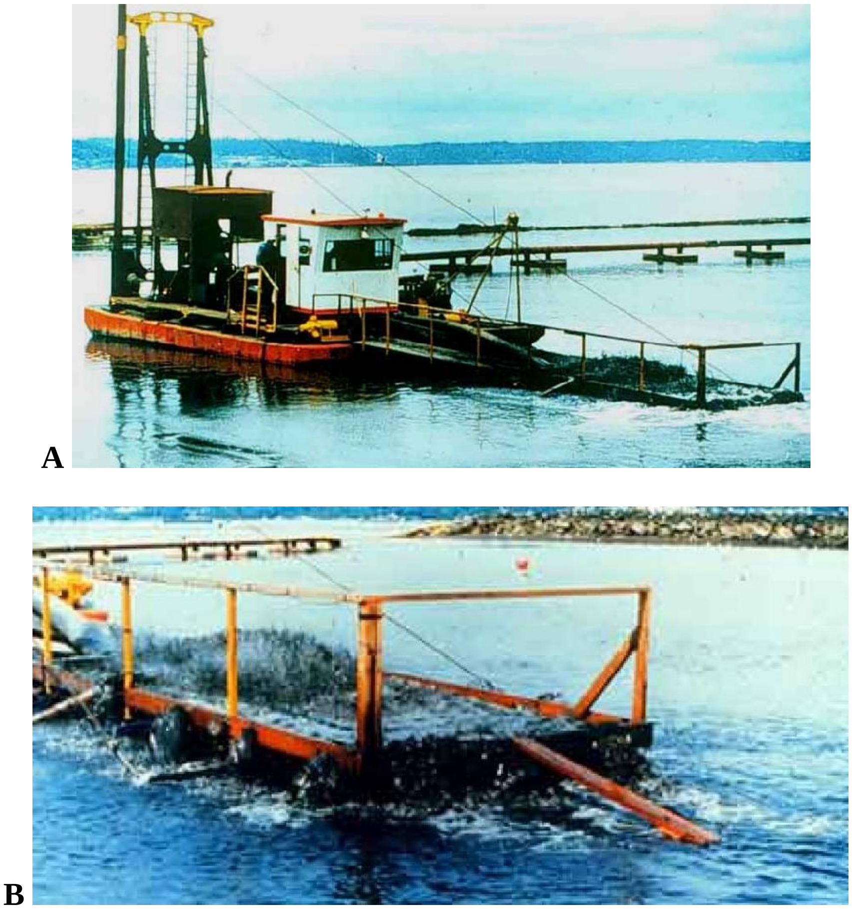
Placement sand was obtained from routine navigation dredging in the Snohomish River and placed on a spilt-hull barge (A), which was then used to place most of the cap. In shallower areas, the weight of impact from the sand caused a displacement of creosote into the surface water. In order to achieve a softer placement of material, sand was placed on a flat barge and sprayed off the barge with a fire hose (B,C) while the barge was pushed around the site by the tug (photos courtesy of USACE).

FIGURE 7-4 HOPPER DREDGE PLACEMENT AT THE DENNY WAY COMBINED SEWER OVERFLOW



Sediments contaminated with metals, polycyclic aromatic hydrocarbons (PAHs), and PCBs below the Denny Way combined sewer overflow in Seattle, Washington were capped in conjunction with a source control program in the 1980s (A). Contaminated sediments were capped using a partially opened split-hull bottom-dump barge that was pushed laterally across the site. The cap consisted of approximately 5,000 cubic meters of uniformly graded sand (mean diameter 0.4 millimeter) spread to a thickness within a range of approximately 60 to 90 cm (Sumeri 1991) (B) (photos courtesy of USACE).

FIGURE 7-5 HYDRAULIC PLACEMENT OF A CAP AT THE ST. PAUL WATERWAY, TACOMA, WASHINGTON

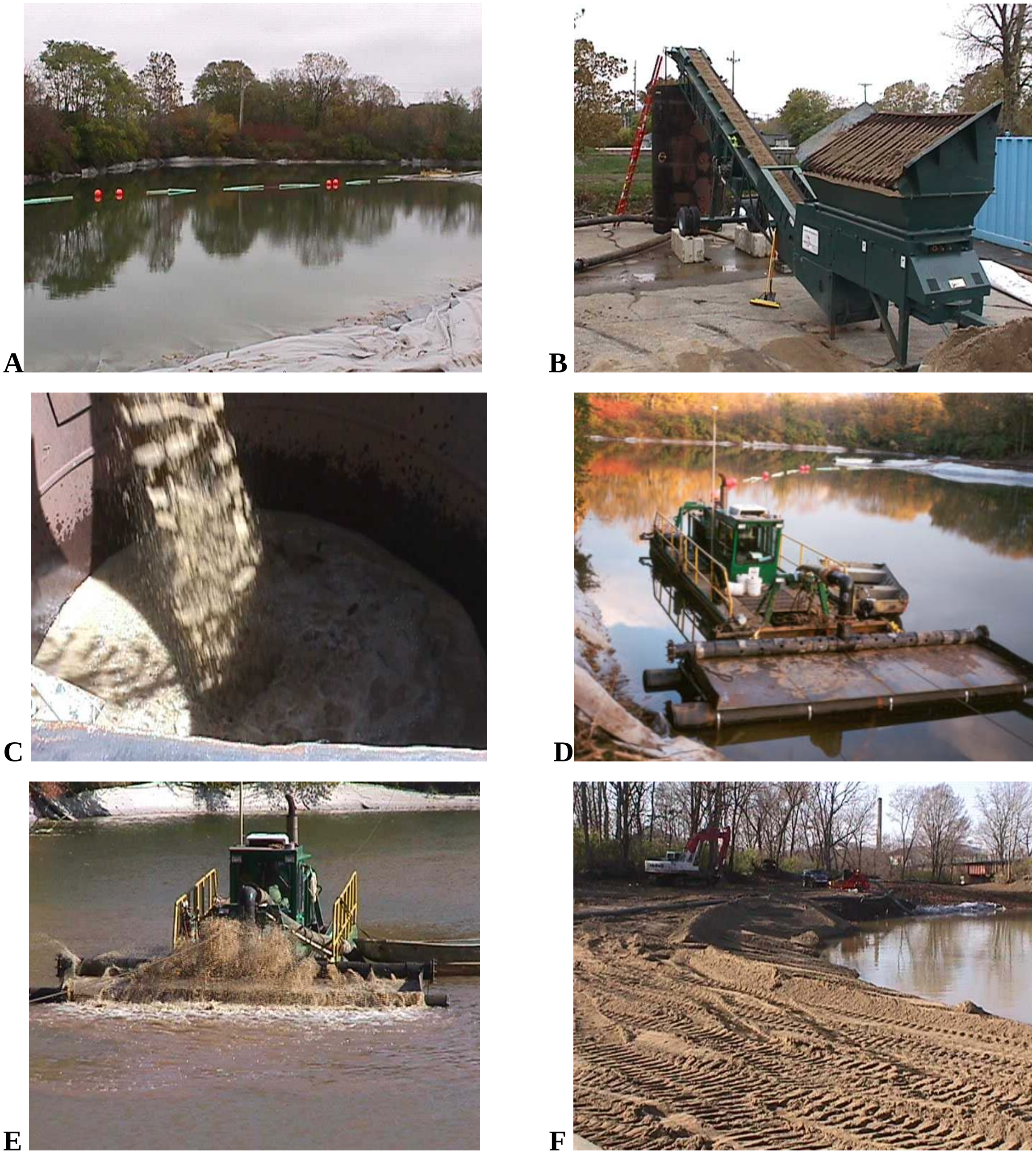


The dredged sand was piped to the site and discharged through a diffuser box that was fitted with baffles (A, B). The dredged material comprised approximately 85 to 95 percent medium sand, which included between 2 and 6 percent clays. Approximately 150,000 cubic meters of clean sand were spread over 6.9 hectares. The passes of the spreader barge included one-third overlap during placement to ensure adequate coverage. When completed, the cap ranged from 0.6 to 3.7 meters in thickness (Sumeri 1989) (photos courtesy of USACE).

FIGURE 7-6 HYDRAULIC PLACEMENT AT SODA LAKE, WYOMING

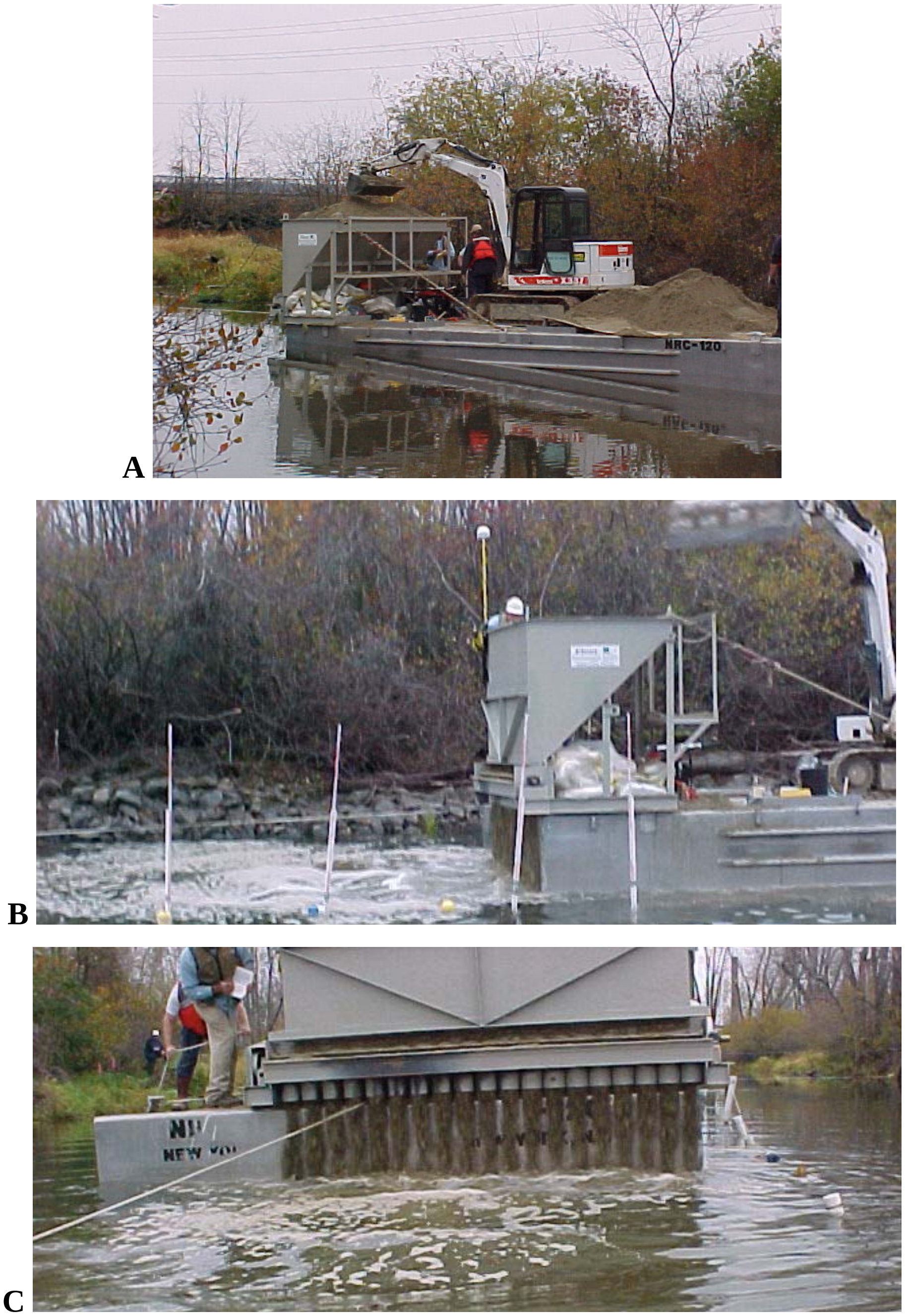
The Soda Lake, Wyoming pilot project placed up to 3 feet of sand over very soft, unconsolidated refinery residuals mixed with sediments. A fine sand was mined on site (A), and conveyed (B) to a blending tank where they were mixed with water to form a 30 percent slurry by volume. The slurry was then pumped using two 175-horsepower centrifugal pumps in series through 4-inch pipe (D) to the spreader barge (E) where it was distributed using an 8-foot-wide diffuser box. The pipeline discharge entered the diffuser box spraying the slurry upward against a baffled surface. This surface distributed the slurry in a lateral fashion less than 1 foot above the water column and promoted a uniform material distribution. The capping material then hit the water column, lost its kinetic energy, and fell vertically onto the bottom sediment. The reduction in slurry velocity resulting from contact with the diffuser plate minimized any potential for erosion of in-place material. The selected sand layer (lift) applied was 1.5 inches per pass to minimize disturbance of bottom sediment and allow time for increased sediment pore pressures to equilibrate. Accumulating cap thickness was monitored during placement using both lead lines and a fathometer. In shallower areas, the cap was placed using an aerial disbursement method (F).

FIGURE 7-7 GEOTEXTILE AND HYDRAULIC CAP PLACEMENT AT MOCKS POND, MUNCIE, INDIANA



The Mock's Pond cap consisted of over 2 feet of sand placed over soft, unconsolidated sediments in eight, 3-inch lifts. The pond bottom was first lined with a stabilization fabric in five separate sections, anchored to the shoreline (A). Sand was conveyed (B) to a blending tank where it was mixed with water to form a 30 percent slurry by volume. The slurry was pumped to the spreader barge using two 175-horsepower centrifugal pumps in series through 8-inch pipe, where it was distributed using a 16-foot-wide diffuser plate (C, D). This distributed the slurry in a lateral fashion less than 1 foot above the water column and promoted a uniform material distribution (E). Along the southwestern shore, where receded water levels had exposed the shelf, sand was placed directly using a bulldozer (F).

FIGURE 7-8 DRY CAP PLACEMENT AT THE PINE STREET CANAL DEMONSTRATION PROJECT, VERMONT



A test capping project was undertaken at the Pine Street Canal Superfund Site in Burlington, Vermont. The site is located next to a former manufactured gas plant, where the Consent Decree calls for construction of an ISC in the canal to prevent exposure to aquatic life. The initial demonstration project placed up to 3 feet of sand using a dry-sand placement system mounted on a 16- by 40-foot barge with a shallow (2- to 3-foot) draft. A sand diffuser, consisting of a series of tremies, is attached to a feed hopper (A). A front-end loader is used to transport sand from the barge to the hopper. Sand from the hopper is distributed to the tubes via a rotating paddle located between the hopper and the tubes. This system, which is similar to that used at the Hamilton Harbor, Ontario capping site, uses a series of tremie tubes arrayed across an approximately 10-foot span (B). The barge is pulled along the installation path via a cable-and-pulley system (C). At this trial site, the diffuser was set to deliver either 0.5- or 0.75-foot lifts (photos courtesy of The Johnson Company).

FIGURE 7-9 MECHANICAL PLACEMENT AT WARD COVE, ALASKA

Ward Cove near Ketchikan, Alaska was capped as part of a CERCLA action in 2000–2001. Contaminants at Ward Cove were byproducts of the paper waste product that was released during wastewater discharge. The USEPA wanted to evaluate a thin-layer capping (6 inches) alternative as a method for enhancing natural recovery and as a habitat improvement action. The underlying material was very soft, unconsolidated sediment with low *in-situ* shear strength and high water content. Placement was with an 8.5-cubic-yard bucket that was welded to hold an exact amount of material that was equivalent to a 6-inch placement over the 300-square-foot arc across which the bucket was swung. The material was released below the water surface within 10 to 20 feet of the bottom. Sediment grain size for the cap was a fine to medium sand that was less than 5 percent non-plastic silt. The contract was written so that the contractor was paid by the amount of material placed. Gravity probes were used to confirm that the project was successful; a final cap thickness of 6 to 9 inches was achieved (photos courtesy of Greg Hartman).

8 Removal

Removal refers to excavation or dredging of sediments. The discussion of removal process options herein integrates site knowledge, practical dredging experience, dredging sediment case studies, and demonstrated successful application under similar conditions. In addition to documents cited in Section 4, the following provided practical implementation information for sediment remediation projects in the United States:

- *Assessment and Remediation of Contaminated Sediments (ARCS) Program, Remediation Guidance Document* (EPA 1994b)
- *Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett et al. 1990)
- Removal of Contaminated Sediments: Equipment and Recent Field Studies (Herbich 1997)
- *Innovations in Dredging Technology: Equipment, Operations, and Management, USACE DOER Program* (McLellan and Hopman 2000)
- *Dredging, Remediation, and Containment of Contaminated Sediments* (Demars et al. 1995).

Wherever possible, Puget Sound or riverine practical experience will be utilized to assess the applicability of a specific removal technology. Specific technologies are listed in Section 8.1 and discussed in Sections 8.2 through 8.4. Dredging decision factors that will be used to evaluate these technologies are discussed in Section 8.5. Best management practices that should be considered to minimize the potential environmental effects associated with dredging operations are listed in Section 8.6. Section 8.7 presents an evaluation of the retained dredging technology types based upon effectiveness and implementability, and discusses relative costs of these technology types.

There are several sediment remediation projects underway or recently completed that provide site-specific information on the implementability and effectiveness of dredging in the LDW. These projects include: the 2004 Duwamish/Diagonal Way Combined Sewer Overflow (CSO) and Storm Drain Early Action Removal Project, the 1999 Norfolk CSO Early Action Removal Project (both located in selected reaches of the LDW[10]), and the 2004 Harbor Island East Waterway Sediment Phase 1 Cleanup Project, located at the mouth of the Duwamish River. The latter project was a relatively large-scale removal project, dredging from a 20-acre area, with disposal of 200,000 cubic

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[10] While both the Duwamish Diagonal CSO and Norfolk CSO removal projects were identified as candidate Early Action Area projects for the LDW, they were conducted as part of the Elliott Bay/Duwamish Restoration Program projects under a Natural Resource Damage Consent Decree.

yards (cy) of sediment to an upland landfill and another 59,000 cy to the Elliott Bay Disposal Area. Two additional sediment remediation projects located within the Harbor Island Superfund Site are currently dredging contaminated sediments using a closed bucket, with landfill disposal of wet sediments. These are the Lockheed Shipyard Sediment Operable Unit (dredging 130,000 cy with disposal at an upland landfill and capping of deeper sediments) and the Todd Shipyard Operable Unit (dredging 200,000 cy with disposal at an upland landfill and capping of underpier areas). Finally, the cleanup of the Hylebos Waterway within the Commencement Bay Superfund site will also be presented, and discussed.

8.1 Removal Process Options

For the purposes of this document, dredging is defined as the removal of sediment in the presence of overlying water (subtidal and intertidal) utilizing mechanical or hydraulic removal techniques and operating from a barge or other floating device. Excavation is defined as the dry or shallow-water removal of sediment using typical earth moving equipment such as track- or wheel-mounted excavators and backhoes operating from exposed land.

Mechanical dredges remove material at near *in situ* conditions, typically 1 part solids to 2–3 parts water by volume (v/v). The dredged material is taken up through the water column to a barge for off-site transport. Mechanical dredges may be used for a wide range of material types (loose to hard consolidated and compacted material). A subset of mechanical dredges, excavators, are often used to pre-remove large debris prior to dredging, or used in difficult to access, shallow, and backwater areas.

Hydraulic dredges remove material as a low-density slurry; ranging from 1 part solids to 12-25 parts water v/v. The cut and vacuumed dredged material is transported through a pipeline to a selected land-based dewatering facility. Hydraulic dredges are typically used for relatively loose, unconsolidated material.

Dredging in the United States is typically conducted by one of these basic methods depending upon accessibility, the volume of sediment to be removed, the disposal option selected, and site conditions. Factors affecting the selection process are discussed in Section 8.5.

The concept of remedial ***components*** and ***systems*** was presented in Section 1.3 and in Figure 1-2, and is important to the discussion in this section on the selection of appropriate removal technologies, and to the discussion of the supporting ancillary equipment and processes in Section 9. Hydraulic, mechanical, or excavation dredges represent appropriate process options. ***Components*** of a dredge system discussed in this section include:

1) **Point of dredging** components include the cutterhead, auger screw, dustpan, and matchbox of hydraulic dredging systems, as well as various mechanical means, such as clamshell or backhoe excavator buckets.

2) **Support components** include the support barge or pontoon, jack-up platforms, amphibious systems, monitoring and confirmation sampling, and positioning systems.

3) **Discharge components** include pumps, pipelines, dewatering and water treatment facilities, barges, and transport.

Systems are the combination of the point of dredging component with a support and discharge component. Each component of the system must be carefully selected and matched to balance required removal rates with physical bottom conditions (sediment, debris), contaminant type and concentration, depth and tidal ranges, dredge windows, permit requirements (e.g., resuspension water quality limits), and the dewatering, treatment (where applied), and disposal components (EPA 2004c).

An important engineering concept is that dredging systems are designed *in reverse:* from how and where the material will be disposed of, backwards to match the dredge train and operations to the rate-limiting treatment or disposal equipment. For example, in a hydraulic system the size and throughput of the dewatering and water treatment system will dictate the size of the dredge, rate of pumping and periods of operation, pump characteristics, and pipeline size. Many environmental hydraulic dredging systems are designed with a retention/storage pond so that while the dredges may only operate 10-15 hours/day, the dewatering and water treatment plant operates 24 hours/day. A mechanical system would be designed to accommodate the rate of barge transport, off-loading, and transport to a landfill. A system could include the clamshell bucket, crane, crane barge, and haul/dump barge. However, variations are occasionally used, such as a hydraulic-actuated bucket on the end of a boom excavator placing the dredged material into a hopper and pumping the sediment through a pipeline to shore for treatment or disposal.

Selection of dredging equipment and methods used will depend on several factors, including: physical characteristics of the sediments to be dredged, the quantity and dredge depth of material, distance to the disposal area, the physical environment of the dredge and disposal areas (especially tidal range), contaminant concentrations in the sediment, method of disposal, production rates required for removal, equipment availability, amount and type of debris present, and cost (EPA 2004c). These issues are discussed in Section 8.5.

8.2 Mechanical Dredging

A mechanical dredge typically consists of a suspended or manipulated bucket that bites the sediment and raises it to the surface via a cable, boom, or ladder (Figure 8-1). The sediment is deposited on a haul barge or other vessel for transport to disposal sites. A mechanical dredge and haul operation is currently used for routine maintenance dredging of the federal navigation channel in the LDW and East/West Waterways near the mouth of the Duwamish River and Harbor Island. Mechanical dredges have been the principal tool used for environmental dredging in Puget Sound.

Under suitable conditions, mechanical dredges are capable of removing sediment at near *in situ* densities, with almost no additional water entrainment in the dredged mass and little free water in the filled bucket. A low water content is important if dewatering is required for ultimate sediment treatment or upland disposal. Mechanical dredges will release sediment to the water column if the bucket fails to close completely. However, proper instrumentation of the bucket can alert the operator to the failure to close, thereby allowing the operator to take alternative actions and prevent sediment releases.

Clamshell buckets (open, closed, hydraulic-actuated), backhoe buckets, dragline buckets, dipper (scoop) buckets, and bucket ladder are all examples of mechanical dredges. Dragline, dipper (scoop), and bucket ladder dredges are open-mouthed conveyances and are generally considered unsuitable where sediment resuspension must be minimized to limit the spread of sediment contaminants (EPA 1994a). Consequently, dragline, dipper, and bucket ladder techniques are not considered further in this CTM.

8.2.1 Clamshell Bucket Dredge

The clamshell bucket dredge, or grab dredge, is widely used in the United States and throughout the world. It typically consists of a barge-mounted floating crane maneuvering a cable-suspended dredging bucket, with or without teeth. A heavy bucket with teeth can dig harder sediments than can a lighter bucket without teeth. The crane barge is held in place for stable accurate digging by deploying vertical spuds into the sediment. The operator lowers the clamshell bucket to the bottom, allowing it to sink into the sediment on contact. The bucket is closed, then lifted through the water column to the surface, swung to the side, and emptied into a waiting haul barge. When loaded, the haul barge is moved to shore where a second clamshell unloads the barge for rehandling or transport to treatment or disposal facilities. Clamshell dredges work better in water depths less than 100 ft to maintain production efficiency. Using advanced positioning equipment (e.g., differential global positioning systems [DGPS]), dredging accuracy is on the order of 1 ft horizontally and 1 ft vertically for cable-suspended buckets, and about 0.5 ft vertically for instrumented boom-suspended buckets. Clamshell buckets are designated by their digging capacity when full and range in size from less than 1 cy to more than 50 cy. Table 8-1 provides a representative list of typical dredging equipment and the environmental dredging sites where they have been used.

A conventional clamshell bucket may not be appropriate for removal of contaminated sediments in some areas. Conventional buckets have a rounded cut that leaves a somewhat cratered sediment surface on the bottom. This irregular bottom surface requires the need to overdredge (typically 1 to 2 ft) to achieve a minimum depth of cut, and multiple passes to achieve adequate removal. Furthermore, the conventional open clamshell bucket is prone to sediment losses over the top during retrieval. Recent innovations in bucket design have reduced the spill and sediment resuspension potential by enclosing the bucket top (Figure 8-2). Also, buckets can be fitted with tongue-in-groove rubber seals to limit sediment losses through the bottom and sides. Finally, local Puget Sound dredging contractors have recognized the need to minimize resuspension while using a clamshell bucket, and have developed modifications to both their equipment and to the operations to reduce sediment loss.

8.2.2 Environmental Buckets

A recent development in the environmental dredging field has been the advent of specialty level-cut buckets (Figure 8-3). These buckets offer the advantages of a large footprint, a level cut, the capability to remove even layers of sediment, and, under careful operating conditions, reduced resuspension losses to the water column. A level-cut bucket reduces the occurrence of ridges and winnows that are typically associated with conventional clamshell buckets.

The Cable Arm™ bucket is one such environmental bucket that has been successfully demonstrated for contaminated sediment removal at a number of sites in the Great Lakes (Cleland 1997; SEDTEC 1997), and was used in a removal action in the summer of 1997 at a creosote-contaminated site in Thunder Bay, Ontario. In 1993, the first full-scale sediment remediation project at Pickering Nuclear Generator Plant, Ontario, Canada, had strict water quality limits for the power plant's cooling water intake pipe. Bucket overfilling and sediment resuspension occurred at the beginning of the project because of a lack of training with the new equipment, but after appropriate experience water quality limits were rarely exceeded.

Several of the Puget Sound area dredging companies own and use Cable Arm closed buckets (Wang et al. 2003). Local projects where the closed buckets have been used include Pier D at the Puget Sound Naval Shipyard in Bremerton, and at the East Waterway of the Duwamish. Environmental buckets have been shown to be effective in loose sands and in low-solids soft-sediments with little to no debris. Although they are useful under these conditions, they are not effective when digging in heavier sand or where a significant amount of debris is expected. The light construction of the bucket makes it unsuitable for dredging dense or native material.

Closed buckets also have difficulty with cohesive sediment, such as clay. The cohesiveness of clay tends to limit the penetration of the bucket. Cohesive materials will adhere to the bucket surface, requiring a more prolonged rinse cycle (Wang et al. 2003). The conventional clamshell has a more rounded (curvilinear) shape, whereas the typical environmental clamshell is boxy and has protruding reinforcing vanes that tend to collect cohesive materials. The "rinse cycle" refers to the attempt to remove adhering fine sediment from the mechanical bucket prior to lowering the bucket to the bottom for another bite of dredged sediment.

The rinse cycle typically involves the following steps:

- After the sediment from the bucket is dumped into the dredge material scow, the bucket is swung over to a rinse-water holding tank or partitioned portion of the barge.

- The bucket is raised and lowered into the rinse-water one to several times to remove the clinging material.

- When sufficiently clean, the bucket is swung over to the next dredge target area and lowered to the bottom.

Based on knowledge of the LDW and East Waterway areas, one local contractor (A.H. Powers and Company) suggested that a closed bucket (such as the Cable Arm) would not be able to dredge sediments adequately downstream from the 1st Avenue South Bridge (i.e., sediments are too dense or stiff) (Wang et al. 2003). This was tested recently during the East Waterway removal action, where an environmental bucket was used while dredging softer overlying sediments, but the contractor switched to a clamshell bucket when harder clays and other compacted sediments were encountered (D. Hotchkiss, personal communication).

8.2.3 Excavator Dredges

This is a subset of mechanical dredges, which includes barge-mounted backhoes or excavators, both of which have limited reach capability. Excavators can also be used for dry excavation after the overlying water is removed. Special closing buckets are available to reduce sediment losses and entrained water during excavation.

A conventional excavator bucket is open at the top, which may contribute to sediment resuspension and loss during dredging, although careful operation can minimize losses. Various improved excavating buckets have been developed that essentially enclose the dredged materials within the bucket prior to lifting through the water column. A special enclosed digging bucket, the Horizontal Profiling Grab (HPG), was successfully used on the large excavator – the Bonacavor (C. F. Bean Corp.) for remediation of highly contaminated sediment at the Bayou Bonfouca Site (Slidell, Louisiana) (NRC 1997), and is currently being used to dredge contaminated sediments in the Hylebos Waterway in Tacoma (Figure 8-4). The bucket has a capacity of 4.5 cubic meters and can operate in water depths up to 13 meters. Dredged material removed by backhoe exhibits much the same characteristics as for clamshell dredging, including near *in situ* densities and limited free water.

8.3 Hydraulic Dredging

Hydraulic dredges remove and transport large quantities of dredged materials as a pumped sediment-water slurry. The sediment is dislodged by mechanical agitation, cutterheads, augers, or by high-pressure water or air jets. In very soft sediment, it may be possible to remove surface sediment by straight suction or by forcing the intake into the sediment without dislodgement. The loosened slurry is then vacuumed into the intake pipe by the dredge pump and transported over long distances through the dredge discharge pipeline. Figure 8-5 provides an example of a hydraulic dredging project with a pipeline to an upland mechanical dewatering unit. A key difference between hydraulic dredging and mechanical dredging is the generation of a high volume of contaminant-containing water that must treated before discharge. This is discussed further in Section 8.5.9.

Common hydraulic dredges include three main categories: the conventional pipeline dredge (round cutterhead, horizontal auger cutterhead, open suction, bucket wheel, dust pan, etc.), the self-propelled hopper dredge, and sidecasting dredge (EPA 1994; Herbich 2000). A sidecasting dredge takes dredged material excavated from the mud and "side casts" the material from the dredge to adjacent shoreline areas. It can be used to replenish beaches, but is not used for environmental dredging.

Hydraulic dredges have four key components: the dredgehead, which is in contact with and digs the sediment, a support structure (wire or ladder) for the head assembly, the hydraulic pump to provide suction, and the pipeline that carries sediment slurry away from dredging operations. Specialty hydraulic dredges are available that limit resuspension losses at the dredgehead and increase the solids content of the dredged slurry. These include the auger-, cleanup-, airlift-, and refresher-type dredges. Hydraulic dredges are rated by discharge pipe diameter, ranging from smaller portable machines in the 6- to 16-inch category, to large 24- to 30-inch dredges. The most suitable and available hydraulic dredges for the LDW are the pipeline and cutterhead types. These are discussed below.

8.3.1 Pipeline and Cutterhead Dredges

Suction dredges are open-ended hydraulic pipes that are limited to dredging soft, free flowing, and unconsolidated material. Because suction dredges are not equipped with any kind of cutting devices, they produce very little resuspension of solids during dredging. However, the presence of trash, logs, or other debris in the dredged material will clog the suction and greatly reduce the effectiveness of the dredge (Averett et al. 1990). Suction dredges have been used in the Northwest for difficult access areas such as the underpier areas of the Sitcum Waterway Superfund Site (Tacoma, Washington) and at the Port of Portland T4 Pencil Pitch Removal Project (Portland, Oregon), often with diver assistance.

The hydraulic pipeline cutterhead suction dredge is the most commonly used method in the United States, with approximately 300 operating nationwide. The cutterhead is considered efficient and versatile (Averett et al. 1990). It is similar to the open suction dredge, but is equipped with a rotating cutter surrounding the intake of the suction pipe. The combination of mechanical cutting action and hydraulic suction allows the dredge to work effectively in a wide range of sediment environments. Resuspension of sediments during cutterhead excavation is strongly dependent on operational parameters such as thickness of cut, rate of swing, and cutter rotation rate. Proper balance of operational parameters can result in suspended sediment concentrations as low as 10 milligrams per liter (mg/L) in the vicinity of the cutterhead. More commonly, cutterheads produce suspended solids in the 50 to 150 mg/L range (10 to 20 percent solids by weight) (EPA 1994b). Slurry uniformity and density are controlled by the cutterhead and suction intake design and operation. By pivoting the spuds used to anchor the barge in place, the dredge "steps" or "sets" forward for the next swing. Cutterhead dredges have been used at numerous sites in the Northwest and nationally, including the Sitcum Waterway Superfund Site (Washington), Lower Fox River (Wisconsin), and New Bedford Harbor (Massachusetts) (Table 8-1).

The horizontal auger dredge is a relatively small portable hydraulic dredge designed for projects where a small (50 to 120 cy/hr) discharge rate is desired. In contrast to a cutterhead, the auger dredge is equipped with horizontal cutter knives and a spiral auger that cuts the material and moves it laterally toward the center of the auger, where it is picked up by the suction. There are more than 500 horizontal auger dredges in operation. A specialized horizontal auger dredge has been used at the Manistique Harbor Superfund site (Manistique, Michigan), the Marathon Battery Superfund site (Massena, New York), and the Lake Jarnsjon sediment remediation site (Sweden).

8.3.2 Hopper Dredge

The hopper dredge is a self-enclosed, non-stationary operational unit consisting of suction pipes and a ship-type hull with an internal hopper to hold dredged material. Material is brought to the surface through suction pipes fitted to draghead arms, and then discharged to the hopper. The drag is moved along the bottom as the vessel moves forward at speeds up to 3 miles per hour (mph) (Anchor Environmental 2003). Once fully loaded, the hopper moves to the disposal site to unload before resuming dredging. Bottom doors are opened for in-water disposal at the designated site. Dredged material slowly sinks through the water column and settles on the mudline bottom. However, this method is not suitable for dredging and disposing of contaminated sediments.

8.3.3 Specialty Dredges

The Toyo™ pump is a proprietary electrically driven compact submerged pump assembly that is maneuvered into position using a derrick barge. This pump is capable of high solids production in uncohesive sediment and can be equipped with a rotating cutter or jet ring to loosen sediment. This is a lower head pump that typically discharges through 6- to 12-inch-diameter pipes and may require a booster pump for long pipeline distances. Typically, slurry discharges are at a density of approximately one-third the *in situ* density. This specialty dredge was used at the mouth of the Hylebos Waterway (Tacoma, Washington, Area 5106) to remove 32,000 cy of contaminated sediment, treated by slurry aeration, and pumped into the Blair Slip 1 confined disposal facility between October 2002 and March 2003 (Figure 8-6).

The Pneuma™ pump is a proprietary pump developed in Italy that uses a compressed air and vacuum system to transport sediments through a pipeline. It may be suspended from a crane or barge and generally operates like a cutterhead dredge. The Pneuma™ pump was used on the LDW in 1974 to assist in the removal of an estimated 260 gallons of PCBs spilled into the waterway near Slip 1 (EPA 1977). This specialty pump was used at the Collingwood Harbor Project (Ontario, Canada) demonstration dredging project (EPA 1994a).

The Mudcat™ is a proprietary dredge device fitted with a vibrating auger head assembly and positive displacement pump specifically designed to excavate difficult, soft, thixotrophic material. The dredge unit is designed to float in very shallow water and is moved using onshore winching cables and pulleys.

Mudcats™ are one of the most commonly employed dredging units in the country, and have been used at various environmental dredging projects, including the Sydney Tar Ponds, Nova Scotia; Manistique Harbor, Michigan; SMU 56/57 in the Lower Fox River

Wisconsin; and at the New Bedford PCB remedial action site (Figure 8-7). Mudcats™ may also be fitted with cutterheads, but more commonly with horizontal augers.

Diver-operated smaller hydraulic dredges have been used for removing materials under or around piers, pilings, or in other under-structure places where conventional dredging equipment is unable to reach. While an advantage of this method is the ability to dredge in these otherwise unreachable locations, consideration must be given to the diver's limited visibility to be effective and the overall safety of the diver from physical hazards and from potentially being exposed to resuspended contaminants.

8.4 Excavation

Excavation refers to the removal of sediments in the absence of overlying water. This often involves the use of conventional excavating equipment, and is generally restricted to removal of contaminated sediment and debris in shallow-water environments, dry excavations (areas that are bermed, then dewatered for access by land-based equipment), or during low tides. Dewatering of an area for dry dredging involves hydraulic isolation/removal of surface water using: (1) earthen dams, (2) sheet piling, or (3) rerouting the water body using dams. Although normally land-based, excavators can be positioned on floating equipment (e.g., spud barge) for dredging in shallow environments.

Dry excavation provides several advantages as compared to working in the water when the tides are in and the land is submerged. These advantages include:

- Allows operators to see the work area and accurately place the bucket to ensure complete removal of the impacted material
- Allows the operators and oversight staff to see the excavated face and adjust the depth of excavation based on observed conditions
- Maintains the material to be removed in an intact state, and avoids the potential for creating a soupy mix of sediment and water that can be difficult to capture in the excavator bucket
- Minimizes the potential to entrain impacted material in the water column.

For the LDW, this would be conducted by either operating with specialty equipment during periods of low tide, or by isolating an area using sheet piling, earthen dams, coffer dams, or inflatable dams and pumping the area dry. If conducted dry behind dams, conventional excavation equipment may be used. If conducted during the twice-daily low tides, contaminated sediments can be removed by amphibious dredges, or by smaller conventional equipment mounted on low-displacement vehicles.

For the removal and capping of contaminated intertidal marine sediments near the head of the Middle Waterway in Tacoma, Washington discussed in Section 7, the excavation of intertidal sediments of Area C was accomplished by creating individual cells using steel divider sheets (Moore et al. 2005). Contaminated sediments within each cell were then removed to a depth of about 4 ft below the original sediment surface using a tracked excavator. After excavation, the individual cells were backfilled with clean materials. This technique allowed for the progression of removal and fill outward from the shoreline edge across the tide flats, and the completed cells provided a stable platform for vehicle and equipment access.

The Amphibex and Aquarius amphibious excavators are examples of barge-mounted backhoes, capable of turning 360 degrees. These systems work optimally in water depths of 8 to 13 ft, but can also work on emergent shoreline and tide flats, according to the manufacturers. The excavators are mounted atop barges that have been fitted with “legs” with cylindrical wheels that provide mobility. The Amphibex amphibious excavator can operate in either straight mechanical or hydraulic transport modes. The Aquarius amphibious excavator only operates in mechanical dredging and transport modes. The DRE Technologies – Dry Dredge integrates a closed bucket mechanical dredge with a positive displacement pump for high solids dredged material transport.

Various track-mounted excavators have been developed to access shallow water marsh environments for dike construction, dredge material disposal operations, pipeline crossings, and have been adapted for intertidal dredging excavation. Conventional backhoes, crane buckets, dragline, and other excavator types have been adapted to self-propelled, tracked assemblies that can travel over low bearing capacity soils and shallow water environments. A floating amphibious tracked excavator that makes use of outboard pontoons and spuds for floatation and mobility in deeper water was used to excavate and transport PCB contaminated sediments to shore for treatment on a sediment remediation project in New Jersey. These systems work optimally in shallow water depths and emergent shoreline and tide flats. The production capacity of these excavators is generally limited, and depends upon the bearing capacity of the intertidal sediments and the size equipment needed for the dredge areas.

8.5 Dredging Decision Factors

Although the advances described above in environmental dredging equipment are important, they do not replace the need for adequate site characterization, matching equipment to site conditions, performance-based contracting, and skilled environmental dredging contractors and operators. Adequate site characterization includes: (1) the horizontal and vertical extent of contaminated sediment requiring removal, (2) ship traffic and current/tidal ranges, and (3) the expected range of sediment physical properties (i.e., density, grain size, plasticity). These issues are critical to the selection of appropriate equipment. Good contract management and oversight of contractors is another important element of ensuring the success of dredging projects.

Selection of the appropriate type of dredging technologies and their potential effectiveness is dependent upon more than one variable. It is a formulaic effort considering multiple variables ranging from water depth to disposal sites. Significant operating parameters and constraints considered in selecting and applying the appropriate dredging equipment for the LDW will include sediment characteristics, site conditions, potential for sediment resuspension and transport, use of turbidity barriers, amount and type of debris, equipment availability, and removal accuracy. As noted previously, production rates, and water management will be key in determining the size of equipment selected. Work sequencing and management are also important factors to consider during the remedial design. Each of these variables is discussed below.

8.5.1 Sediment Characteristics

The physical characteristics of the sediments, including particle size, density, cohesion (strength), and plasticity (stickiness), interact and affect dredge performance and efficiency (USACE 1995). These factors should be considered when selecting dredge types, designing sediment dewatering facilities, calculating settling rates, and planning other aspects of remedial activities.

Rocks and debris, if present, can interfere with dredging and delay the cleanup process, often creating more water quality resuspension problems. A combination of hydraulic and mechanical dredging has been used for some cleanup projects (Sitcum Waterway, Washington; Black River, Ohio; Marathon Battery, St. Lawrence River, New York; Lake Jarnsjon, Sweden) where debris interfered with large-scale dredging or access was difficult. Recent sediment dredging projects have incorporated pre-removal of boulders, wood timbers, and other debris using excavator equipment prior to initiating dredging (Grasse River, Massena, New York; GM Foundry/St. Lawrence River, New York). This requires a complete investigation (debris survey) to identify where debris is present.

8.5.2 Site Conditions – Water Depth and Site Access

All dredges have ideal ranges of operation and minimum/maximum water depths for operation. In shallow areas where the depth of water is less than 8 ft, specialized equipment or dewatering with dry excavation may be suitable and economical. Small hydraulic dredges have been successfully used in river depths as shallow as 3 ft, whereas mechanical dredges are typically limited to minimum water depths of 8 to 10 ft. The latter is principally because of the draft of the transport barges required to move the dredged materials to shore, which can partly be overcome by the reach of the dredge boom from the barge. Where water depths are greater than 8 ft, both hydraulic and mechanical dredging options may be considered. However, hydraulic dredging is limited by the length of the ladder and mechanical dredging operations are generally limited to water depths of less than 100 ft for production and cycle time efficiency.

Another consideration is site access. Difficult to access areas (i.e., near pilings, floating docks/marinas, riprap slopes, and between pilings and bulkheads) may require use of specialized equipment to adequately remove contaminated sediments. Recent projects have included multiple removal techniques in the remedial design to address these difficulties. For example, the Port of Vancouver Copper Spill Project (Vancouver, Washington) used a hydraulic cutterhead dredge in open areas with 0.5 ft of overdredge and diver-assisted suction dredging in underpier areas. The Port of Portland T4 Pencil

Pitch Site (Portland, Oregon) used a shrouded[11] environmental clamshell bucket for open-water areas, while nearshore and underpier areas were excavated with an airlift pump. Yet another example includes the Wyckoff/West Eagle Harbor Superfund Site where environmental clamshell buckets were used for open-water areas and backhoes were used for underpier areas at low tide. The method carried forward in the FS will depend upon sediment removal volumes, site access, upland space capacity for dewatering, and disposal.

Shoreline access is also a factor. Adequate space is required to establish shoreline staging areas for equipment, water pumps, dewatering equipment, personnel, sand cap material, and offloading/onloading of barge and dredge equipment. Shoreline access is likely limited or unavailable in certain stretches of the LDW. Availability of land-based space for support operations may factor into the selection of dredge type.

To protect migrating salmonids and bull trout, the National Marine Fisheries Service and USFWS limit the period in which in-water construction can be performed. Washington State Hydraulic Code rules (WAC 220-110) also define allowable in-water work periods. The LDW in-water work window is currently expected to be limited to October 1 through February 14 (USFWS 2003) an approximate 19.5-week period. The specific in-water work periods will be refined during remedial design, in consultation with NMFS and USFWS. In some cases, work periods may be extended if monitoring indicates that threatened/endangered fish species are not significantly present in the project vicinity. In-water work near residential areas may be restricted to 15-hour work periods in order to minimize disturbance to the residents, depending upon the nature of the work. Dredging can also be limited by the ability to transport, dewater, and dispose of excavated material. Another limiting constraint for dredging may be the availability of on-land property for staging and support activities, rehandling, and off-site transport of dredged sediment.

8.5.3 Resuspension Potential

A major consideration for dredge design is the capability for removing targeted sediments with a minimum amount of sediment resuspension and loss during dredging (Anchor 2003; Averett 1997; Averett et al. 1999; Havis 1988). Sediment resuspension is unavoidable to some extent, regardless of the type of dredge employed, but can be minimized with operational techniques (e.g., controlling the dredge speed or cycle time). Although several specialty dredges (Cable Arm™ Bucket, Bonacavor) have been developed to reduce sediment resuspension, proper operation by an experienced contractor is an important factor to minimizing contaminant loss. Incentives can be offered in the specifications for the operator to dredge in a manner that minimizes sediment loss and resuspension (see Section 8.5.10). The degree of sediment resuspension is also dependent on site conditions and variables, including sediment

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[11] The shroud is a metal curtain attached to the sediment removal device (clamshell, auger, cutterhead) to help contain sediment during removal. On a clamshell, the shrouds are extra plates along the sides of the bucket that overlap during closure to help contain the sediment. The shroud is a metal curtain along the backside of a horizontal auger (usually) or around the upper radius of a cutterhead (rarely) to minimize the flinging of sediment upward or outward, respectively, thereby reducing turbidity, sediment resuspension, and sediment residuals.

properties and size fractions (ability to resuspend), river flow hydraulics and hydrodynamics (extent of offsite transport), and ambient water quality (chemical partitioning into the water column).

Data recently compiled for Scenic Hudson (Cleland 2000) and the Los Angeles Contaminated Sediments Task Force (Anchor 2003) determined that hydraulic and pneumatic dredges generally resuspend less sediment than mechanical dredges at the point of dredging. Average resuspension rates for hydraulic dredges were 0.77 percent compared to 2.1 percent for mechanical dredges when all other factors are equal (Anchor 2003). Resuspended sediment concentrations, measured as TSS, are generally highest near the bottom of the water column and these TSS concentrations decrease rapidly with increasing distance from the dredge, typically within 100 to 200 meters (Collins 1995; Anchor 2003). The vast majority of sediments settle close to the dredge within 1 hour of initial resuspension; only the finer fraction takes longer to settle (Van Oostrum and Vroege 1994).

Common forms of measuring suspended sediment concentrations are as nephelometric turbidity units (NTU) and TSS (mg/L), but the relationship between these measures is site-specific. Thackston and Palermo (2000) recommend that site-specific correlation should be developed for turbidity, TSS, and ideally, chemical concentrations or other surrogate measures, if anticipated. These correlation studies can be developed in the laboratory or by synoptic field measurements conducted early in the dredging project. Ambient background concentrations could also be considered and monitored regularly when deriving action levels for resuspended sediment and potential environmental effects associated with offsite transport of contaminants.

8.5.4 Turbidity Barriers

Turbidity barriers are specialized equipment that can be used as an engineering control to minimize downstream transport and loss of suspended solids during dredging operations. Because of their inherent logistical difficulties, they are typically employed where experience has shown that other operational controls (see Section 8.3) cannot adequately meet water quality criteria.

Turbidity barriers can be placed into two categories: structural and non-structural. Structural barriers are semi-permanent or permanent features to control the movement of sediment. The most common type is the sheet pile wall, a series of interlocking steel sections driven into the sediment to the same depth below mudline. This technology is expensive but effective in rivers with strong currents or tidal action. It is often used in nearshore areas for dewatering and dry excavation. Project examples listing the types of turbidity barriers used during sediment remediation and the water quality monitoring results are presented in Table 8-2.

Non-structural, flexible barriers include oil booms, silt curtains, and silt screens. They are less expensive, easy to set up, and more movable than the structural barriers. Oil booms are utilized where dredged material may release oil residues on the water surface. Silt curtains are impervious fabrics that block, deflect, or substantially minimize the flow of water and suspended sediments. Silt screens are semi-permeable fabrics that allow water to pass while impeding the flow of coarse- to medium-grained fractions of the suspended load. Silt screens and curtains are typically suspended by floatation devices at the water surface and secured vertically in-place by a ballast chain within the lower hem of the skirt and anchored to the river bottom. These barrier systems are relatively cheap and easy to re-locate, but are limited by water depth (less than 21 ft), strong river currents (less than 1.5 ft/sec), and tidal cycles. If the curtains and screens are oriented parallel to the direction of net river flow, these systems can be operational at up to 3 ft/sec flow rates. Turbidity curtains in the LDW have not been demonstrated to be effective given the multi-directional forces of currents, freshwater/saltwater lenses, and tides. Tidal ranges within the LDW can be as much as 16 ft. Under these conditions, screens or curtains may be ineffective because although the barrier may be operational at high tide, it will potentially be loose and lie on the bottom during low tide.

Other portable barrier systems include the Portadam™ and AquaBarrier™, which have been used at sediment remediation sites for dewatering and containment, and for the diversion of water flow. These are low-cost alternatives to sheet pile walls for constructing a dry excavation site, but are generally limited to water depths of 10 ft or less. The Portadam™ is a free-standing steel support structure with an impervious fabric membrane that stands on the existing sediment bed. The AquaBarrier™ is a series of water-filled vinyl polyester-reinforced tubes coupled together to form a barrier of any length. This system is not as resilient as the Portadam™, but is easy to repair and more resistant to changes in weather. These systems may be suitable for sediment removal by dry excavation in shallow backwater embayments or secondary channels located along the LDW.

8.5.5 Residual Sediments

All in-water removal operations will leave behind some level of residual contamination after completion of dredging. Residual contamination can result from various causes:

1) Incomplete characterization of depth-of-contamination in the Remedial Design
2) Incomplete dredging to the specified cut-depth
3) Furrows or ridges created by incomplete horizontal removal
4) Turbidity flows from cut slope failures
5) Material resuspended by the bucket during its bite
6) Material resuspended outward by the auger or cutterhead beyond the influence of the pump suction and left behind
7) Vertically positioning the auger or cutterhead at too great of a cut depth, resulting in material riding over the dredge head
8) Material adhering to the outside of the bucket and washed off on its upward travel through the water column, then settling back down to the bottom

9) Material dripping from a partially closed bucket on its upward travel through the water column, then settling back down to the bottom

10) Sloughing of cut banks.

Although resuspension with subsequent resettling is one factor that can influence the residual concentrations of contaminants, other factors such as the type and size of dredging equipment, level of operator skill, positioning equipment used during dredging, dredge sequencing, depth of dredge cut, type and volume of debris encountered, and the substrate type and bottom topography all combine to influence the post-dredging residuals.

Managing dredging residuals is difficult simply because the dredge operator cannot see and manage the removal operation. A commonly observed phenomenon in both hydraulic and mechanical dredging is the creation of furrows or ridges between passes of the dredge equipment. The substrate and topography can greatly influence residuals. Where bedrock or hard clay underlies contaminated sediments, complete removal to low residual concentrations is both difficult and costly. When dredging on a slope, material often slumps and flows after being undercut during a removal path, resulting in recontamination of the just-dredged area. Hydraulic dredges generate residuals when the cutterhead is placed too low in the sediment or if the rate of advancement is too fast; both causing sloughing of the side cuts or flow of material over the cutterhead. If the bite is sufficiently deep, the bucket can also leave sloughing side cuts.

In recent years, many dredging contractors have become more experienced and sophisticated at minimizing residuals. Bid documents prepared for remedial dredging include both horizontal and vertical specifications to account for uncertainty in the dredging footprint, and often specify a minimal number of passes within the footprint to achieve complete removal. However, residuals have been observed at sites after multiple dredge passes. Overlap between dredging lanes is often required, as well as the use of computer-aided positioning equipment and software, such as WINOPS, to ensure accurate and complete coverage of the dredge footprint. Matching the appropriate equipment to the dredging conditions, coupled with water quality monitoring during removal, aids in minimizing resuspension and recontamination.

Even with these controls, dredging operations can still leave behind contaminant concentrations indicative of residuals at the conclusion of operations. Where dredging to a clean surface is a project objective, the design should identify specific procedures for residuals management, potentially including (but not limited to):

- Post-dredge verification sampling
- Overdredge an additional lift of material
- Thin-layer placement
- Placement of a thick cap.

The appropriate combination of these actions is a site-specific determination. Appropriate planning can ensure that the best management actions can be taken within the construction timeframe. More detailed data on dredge residuals is currently being compiled (EPA 2005; Stern and Patmont 2005).

8.5.6 Debris

The amount and type of debris to be found in the dredge zone will influence the type of dredging equipment and affect the production rate. Examples of debris include sunken logs, large rocks, shopping carts, engine blocks, rope, chain, concrete chunks, sunken boats, propane tanks, pilings, dolphins, rip rap, and other materials. A debris survey, using divers, a video-equipped remote-operated vehicle, or side-scan sonar can aid in characterizing the debris. However, these methods are only successful if there is a surface expression of the debris. Completely buried debris will not be seen.

Debris prevents mechanical buckets from closing, which causes loss of sediment during the buckets vertical assent through the water column and increases the rate of resuspension. The loss of sediment and the extra time devoted to disposing of debris reduces the production rate. Debris may need to be handled differently from the sediment when it is brought onboard the haul barge. Large, hard debris may be washed down and recycled, but small and soft debris may need to be handled as hazardous waste and deposited in an approved landfill.

Debris may also clog hydraulic dredge cutter or suction heads and pipeline, causing an increase in resuspension and requiring a temporary shutdown to remove the obstruction, thereby slowing the production rate. However, resuspension can be minimized with proper management. The dredge is shut down when the vacuum is reduced and the material caught in the dredge, pump, and pipeline is discharged into a containment area before cleanout. These procedures were used for the New Bedford Harbor hot spot remediation at the recommendation of the New England Division of the US Army Corps of Engineers.

8.5.7 Equipment Availability

Availability of dredging equipment is an important consideration. A number of floating clamshell dredges and small hydraulic dredges are available in the Puget Sound region for use in the LDW. Large construction backhoes and equipment barges are also available. However, many of the specialty dredges identified in the literature (e.g., amphibious, pneumatic, refreshers, cleanup, matchbox dredges) are not available locally or would require transport to the area or fabrication of new dredging equipment and a period of time to acquire operating experience.

8.5.8 Dredge Accuracy and Removal Rates

Removal efficiency is the capability for removing the target contaminated sediment layer in a single (or minimum number of) pass(es) with the dredge equipment, while minimizing the quantity of over dredged material to be treated and disposed.

The costs and schedule for environmental dredging are largely dependent on the amount of sediment to be removed and the rate of removal. The rate of removal is affected by several variables, including water depth, type of excavation (wet or dry), the number and sizes of dredges used, the dredge operational speed, and the capacity of transport barges for mechanical or sediment dewatering, and water treatment systems for hydraulic dredging. Uncontrollable factors also affect the removal rate, such as passing ships and navigation restrictions, adverse weather conditions, unexpected presence of debris or bedrock, noise level restrictions, seasonal fish window restrictions, and tribal fishing rights.

As discussed in Section 8.4, land-based excavation is generally considered to allow for more accurate excavation than dredging. More recently, dredging accuracy has been greatly improved by advances in precision equipment and differential GPS location control. Several differential GPS units are used in the dredging operation, and placed on the barge and the dredge bucket or hydraulic cutterhead itself to provide a three-dimensional, real-time orientation of the equipment. High-resolution measurements provide the operator with real-time, sub-meter location precision and accuracy. These data, coupled with computer location software, allow the operator to know: (1) exactly where the dredge is collecting sediment from, (2) the amount of overlap needed to remove a swath of sediment, and (3) the exact depth of each dredge cut. In the past, system inaccuracies required remedial designs to operate on the order of 4-ft dredge prisms. With precision equipment and navigational aids, dredge operators can consistently operate to depth prisms with greater reliability and accuracy. Cable-supported buckets can achieve cuts on the order of 1 to 1.5 ft accuracy. Instrumented hydraulic cutterheads and augers can achieve cuts on the order of 1 ft, depending on the material to be dredged. Instrumented boom-supported buckets can achieve cuts on the order of 0.5 ft. The need to accurately manage dredge over-cut is important. Dredged material volume resulting from inaccuracies can increase the volume of material requiring handling and disposal, in proportion to the area (surface) that is dredged, and can significantly increase project costs.

8.5.9 Dewatering and Water Treatment

Another decision factor is water management, and the practicality of managing large volumes of water associated with dredged material that will require collection and treatment prior to discharge of return flow to the river. The water volumes range from moderate amounts of free water and drainage arising from mechanically-dredged sediment to significant continuous volumes associated with return flow from a hydraulic dredge. For example, in a mechanically-dredged system, removal of 100,000 cy of in-place sediments will result in the generation of up to 50,000 cy v/v (10 million gallons) of water that will potentially require treatment and discharge. By contrast, the same system hydraulically-dredged will produce 1,200,000 – 2,400,000 cy v/v (242 – 484 million gallons) potentially requiring treatment. Dewatering and water treatment is discussed in more detail in Section 9.2.

8.5.10 Contractual and Operator Skills

The need exists for contractual commitments, skilled operators, preparation time for the operators to become familiar with the site, and good contract management and contractor oversight. Adequate site characterization includes: (1) the vertical extent of contaminated sediment requiring removal, (2) ship traffic and current/tidal ranges, and

(3) the expected range of sediment physical properties (i.e., density, grain size, plasticity), and these issues are critical to the selection of appropriate equipment. The contractual agreements between the project engineer and the general contractor/dredge contractor are equally important. The emphasis should be carefully placed on the quality of removal and not solely on the speed/cost of removal, with financial incentives to encourage minimal loss of dredged material. During the selection process, the experience and skill of equipment operators should be evaluated. If experience is less than optimum, on-site training time with the equipment (i.e., pilot test) should be included in the scope of remedial activities.

In addition to selecting skilled and experienced contractors to conduct a dredging operation, operator experience can be managed in-part by performance-based contracts to help ensure compliance with environmental monitoring and criteria. These contracts should allow the contractor flexibility to select or modify dredge equipment in order to meet the project objectives, but require compliance with the overall project objectives, including water quality goals. In the case of Puget Sound area projects, such as the Hylebos Waterway, the Sitcum Waterway and the Wyckoff/West Eagle Harbor projects, the contractor was aware of the project objectives, given flexibility to meet these objectives, and held accountable through performance-based contracting.

Coupled with performance-based contracting and skilled operators is the requirement for skilled and knowledgeable independent oversight, as well as an adequate water quality monitoring program. A separate oversight contractor provides an independent verification of achievement of project goals and objectives. The water quality monitoring program provides immediate feedback on the overall performance to both the dredging and oversight contractors. Water quality monitoring is discussed further in Section 9.4.

8.5.11 Other Considerations

Two recurring themes often emerge during discussions of dredge selection, operational success, and efficiency. These themes are adequate site characterization and operator experience. Although not directly described as decision factors, they are important considerations during the FS and remedial design phases of a project.

Dredging equipment often has trouble effectively removing material between rocks and debris. Often these materials clog the dredging/dewatering equipment thereby slowing down production rates and increasing resuspension. Adequate characterization of site conditions is needed to develop realistic target goals and to select the most appropriate removal technology. For example, the Ford Outfall and Manistique sediment removal projects encountered cobbles, rocks, and debris, which compromised removal efficiency of equipment selected to handle soft sediment conditions (USACE 1998; Hahnenberg 1999). Recently, at the Lockheed Shipyard sediment removal alongside Harbor Island, significant and unexpected debris resulted in dredging inefficiencies, large accumulations of residuals at the site, and serious delays in schedules and cost overruns. In the case of both the Manistique Harbor and Lockheed Shipyard sediment removal projects, many of these obstacles were not adequately characterized prior to mobilization for dredging, and thus were not anticipated. On the other hand, both the

Grasse River and GM Foundry sediment removal projects anticipated significant amounts of rocks and cobbles at the site and mobilized excavation equipment to specifically remove larger material before large-scale dredging equipment was mobilized, alleviating much of the burden during dredging.

Adequate understanding of site conditions also includes sediment stratigraphy. At the Manistique Harbor site, sediment core refusal by buried slab and wood debris was inappropriately confused with a hardpan layer, when the actual stratigraphic horizon with clean material occurred much deeper in the profile, at the bedrock or hardpan interface (Hahnenberg 1999). At the GM Foundry site, although soft sediment containing most of the contaminant mass was removed, the verification samples had PCB concentrations above the cleanup criteria. The explanation for these exceedances was the underlying glacial till; samples were scraped from the hardpan, which had either absorbed the PCBs or samples were collected from cracks and crevices in the hardpan where soft sediment containing PCBs was encountered (BBL 1996). Post-verification sampling and acceptance criteria should be based on mass removal and risk reduction, and not solely based on residual chemical concentrations.

Table 8-3 lists numerous design and operational measures that may be employed to minimize potential environmental impacts to water quality during dredging. These anticipated measures are organized by type of dredging decision factor, as described above. Water quality management and monitoring is also discussed in Section 8.9.4.

8.6 Retained Dredging Technologies

Hydraulic, mechanical, and excavation dredging technologies are all retained for consideration for the LDW (Table 8-4 and 8-5). However, only a subset of the specific dredging components is applicable, implementable, effective, and make sense from a cost perspective for the LDW. These are discussed below.

8.6.1 Effectiveness

All three removal technologies (hydraulic and mechanical dredging, and excavation) are effective in removing LDW sediments for either chemical- or toxicity-based cleanup goals, with certain restrictions on each technology. Hydraulic dredging is effective in removing soft or loose sediments with high water content. It is capable of potentially lower resuspension rates at the point of dredging, as well as lower in-water residual production, than mechanical dredging. Hydraulic dredging creates a large secondary waste stream of return water that requires treatment prior to discharge, as well as the disposal of materials retained by the water treatment process.

Mechanical dredging is effective in removing stiffer or denser sediments than is hydraulic dredging. However, it requires a greater effort to keep resuspension rates and residual production lower than hydraulic dredging. For both hydraulic and mechanical dredging, in-water contaminated residuals will also require management strategies (e.g., ENR) to achieve clean-up goals.

Dry excavation is potentially capable of removing all contaminated sediment within its operational sphere without leaving behind any residuals. However, it is operationally limited to shoreline and shallow nearshore areas. In Puget Sound and the lower reaches of the LDW, dry dredging refers to excavation during low tides. To prevent resuspension and/or recontamination, dry dredging needs to leave a clean surface when the next tide comes in and inundates an area that has been excavated (unless there is a water barrier).

8.6.2 Implementability

Most of the restrictions described above involve implementation limitations. These limitations include how the dredging equipment handles the sediment or how the equipment physically fits into the environment.

The dust pan, suction, and specialty pump dredge heads are restricted to removing soft or loose, non-plastic sediment. They are less suitable for hard or moderately dense sediment, or sediment that is sticky. Cutterhead and augerhead dredges can remove harder, denser, and more plastic sediments than the purely suction dredges; but as the sediments become harder, the size and power of the cutterhead has to be increased exponentially. The presence of a large amount of debris can adversely affect hydraulic dredging operations, and may require a pre-dredge debris sweep. The depths to which the hydraulic dredging plants can operate are restricted by the length of the ladder or support cable. The draft of the supporting barge or ship limits the shallowest depths in which the equipment can work. Pipelines are capable of moving any material that the dredge heads and pumps can deliver. Although the pump on the dredger may be limited as to how far it can pump the slurry (typically 5,000 ft or less), a series of booster pumps can extend the length substantially (limited only by the economics of the project to support the booster pump stations). Hydraulic dredging will require the subsequent separation of sediment and water prior to disposal. Slurry separation and disposal rates (in cy/hr) can be slower than dredging rates and may thereby limit the rate of dredging. This may in part be managed by the use of appropriately-sized retention ponds or holding tanks.

The clamshell bucket can remove moderately hard, dense, or plastic sediment. Because the clamshell is an open bucket, some spillage of sediment is likely and would have to be controlled to meet water quality standards. The closed environmental bucket attempts to address this concern, but it is a lighter bucket and cannot dig the harder or denser sediments. The presence of rocks or debris can prevent the buckets from closing tight and leakage of sediment becomes a water quality concern. The depths to which the cable supported dredging plants can operate are restricted by the length of the cable on the spool, but more commonly are restricted by the economics of the cycle time. Boom-supported buckets are depth-limited. The draft of the supporting barge and the length of the boom arm limit the shallowest depths in which the equipment can work. Because of the open-bucket used in the dragline and bucket ladder dredges, they will violate water quality standards during dredging and are expected to leave unacceptable concentrations of residuals after dredging. Therefore, the dragline and bucket ladder dredges are not applicable to LDW dredging and are dropped from further consideration.

Excavation (dry land) equipment is typically restricted to calm shallow water (typically less than 10 ft) for the amphibious platform-mounted equipment. Track-mounted digging equipment is usually limited to even shallower water (less than 3 ft, but preferably dry) because of sediment stability or economic (associated with enhanced corrosion) issues.

8.6.3 Cost

The overall costs for hydraulic dredging are moderate to high. The actual cost of dredging is low, but the handling of sediments after removal drives up the costs into the moderate to high range. Handling includes pre-dredge debris sweeps, sediment settling, water treatment, any sediment treatment, and sediment disposal. If all of these handling steps are required, the costs can be high. By eliminating or economizing on any of the post-dredging steps, the costs can be moderated.

The overall costs of mechanical dredging costs are typically low to moderate. Actual mechanical dredging costs are similar to hydraulic dredging, but some of the extra handling steps, and the associated costs, can be eliminated. Mechanical dredging usually does not require sediment settling and treatment. If the water content is low and can be included in the sediment disposal, water treatment can be eliminated at a considerable savings to the project.

Like mechanical dredging, the overall costs for dry excavation are typically low to moderate. Actual excavation costs are less than dredging and extra handling of the sediments can be minimal. Similar to mechanical dredging, excavation typically does not require sediment settling and treatment. Water content is usually low and can be included in the sediment disposal. Water treatment is eliminated at a considerable savings to the project. However, if overdredging is not controlled, the costs can go from moderate to high with the mixing of uncontaminated sediments into the contaminated dredged material, thus increasing the volume of dredged material that requires handling, transfer, and treatment or disposal.

Table 8-1 Examples of Environmental Dredging Projects and Types of Equipment Used

Site Name	Primary Contaminants of Concern	Sediment Removal Methods	Sediment Treatment/Disposal	Sediment Volume (cy)
102nd Street Embayment	PCBs; Organics	Dry Excavation	On-Site Disposal	28,500
Ashtabula Fields Brook Site	PCBs; Organics; Metals	Dredging	Off-Site Treatment and Disposal	14,000
Ashtabula River and Harbor	PCBs	Mechanical Wet Dredging	CDF	1,000,000
Baird & McGuire	Dioxin; Organics; Metals	Wet Excavation	Incineration	1,500
Bayou Bonfouca	PAHs	Wet Excavation	Incineration	169,000
Black and Bergholtz Creeks (Love Canal)	Dioxin; Organics	Dry Excavation	Incineration; Off-Site Disposal	17,200
Black River (USX/KOBE)	PAHs; Cadmium	Hydraulic and Mechanical Dredging	On-Site Disposal	60,000
Bloody Run Creek	Dioxin; Organics	Unknown Removal	nd	27,000
Buffalo Color – Area D	PAHs; Metals; Organics	Dredging	On-Site Disposal	35,000
Buffalo River	PCBs; PAHs; Organics; Metals	Hydraulic, Mechanical, Pneumatic Dredging	CDF	10,200
Collingwood Harbor	PCBs	Pneumatic Dredging	CDF	8,000
Columbus McKinnon	PCBs	Dredging	Off-Site Disposal	2,349
Commencement Bay - Hylebos Waterway	PCBs, PAHs, metals	Mechanical dredging, dry excavation	CDF, Off-Site Disposal	1,025,000
Commencement Bay – Occidental (Hylebos Waterway)	VOCs	Hydraulic dredging	Treatment (slurry aeration) and CDF Disposal	36,000
Commencement Bay – Thea Foss Waterway	PAHs, PCBs, metals	Hydraulic and mechanical dredging	CDF, Off-Site Disposal	528,000
Commencement Bay – Middle Waterway	Metals, PAHs	Mechanical dredging, dry excavation	CDF, Off-Site Disposal	112,000
Commencement Bay – Sitcum Waterway	Metals, PAHs	Hydraulic and mechanical dredging	CDF	1,225,000
Cumberland Bay	PCBs	Hydraulic Dredging	Off-Site Disposal	150,000
Depont Newport Plant	Metals; Organics	Dry Excavation	Off-Site Disposal	1,500
Duwamish Diagonal	Metals, Organics, PCBs, PAHs	Mechanical Dredging	Off-Site Disposal	66,000
East Waterway	Metals, PCBs, PAHs	Mechanical Dredging	Off-Site Disposal	260,000
Formosa Plastics	Ethylene Dichloride	Hydraulic and Mechanical Dredging	Stabilization; Off-Site Disposal	7,500
Fox River – Deposit N Demo	PCBs	Hydraulic Dredging	Off-Site Disposal	8,190
Fox River – SMU 56/57 Demo	PCBs	Hydraulic Dredging	Off-Site Disposal	29,000
Frontier Pendleton	Metals; Organics	Dredging	nd	56,000
Gill Creek – DuPont	PCBs; Organics	Dry Excavation	Stabilization; Off-Site Disposal	8,020
Gould (Portland)	Organics; Metals	Hydraulic Dredging	On-Site Disposal	11,000
Grand Calumet River/Indiana Harbor	PAHs; PCBs; Metals	Hydraulic and Mechanical Dredging	CDF	4,500,000
Grasse River (ALCOA) – Pilot	PCBs	Hydraulic Dredging	On-Site Disposal	3,500
Housatonic River – Hot Spot 1	PCBs	Dry Excavation	Off-Site Disposal	6,000
Housatonic River – River Sediment	PCBs	Dry Excavation	Off-Site Disposal	113,000
Kalamazoo River (Bryant Mill Pond)	PCBs	Dry Excavation	On-Site Disposal	165,000
Lapiri Landfill (Sediments)	Organics; Metals	Wet and Dry Excavation	Thermal Desorption; On-Site Disposal	163,500
Lavaca Bay	Mercury	Hydraulic Dredging	CDF	90,000
Lockheed Harbor Island, WA	metals, TBT	Mechanical Dredging	Upland Landfill	130,000
Loring Air Force Base	PCBs; PAHs; Lead; DDT; Chlordane	Wet and Dry Excavation	On-Site Disposal	162,000
Lower Rouge River	Zinc	Mechanical Wet Dredging	CDF	34,500
LTV Steel	PCBs; Oil	Hydraulic Dredging	Off-Site Disposal	116,000
Mallinckrodt Baker	DDT	Dry Excavation	Off-Site Disposal	4,000
Manistique Harbor	PCBs	Hydraulic Dredging	Off-Site Disposal	130,000
Marathon Battery	Cadmium	Hydraulic and Mechanical Dredging; Dry Excavation	Off-Site Disposal	100,200
Menominee River	Arsenic; PCBs; PAHs; Organics	Dredging	nd	10,000
Middle Waterway	Mercury, copper, PAHs	Wet and dry excavcation	On-Site CDF	90,000
Monguagon Creek	PAHs; PCBs; Metals; Organics	Unknown Removal	nd	21,128
National Zinc	Metals	Dry Excavation	Stabilization; Off-Site Disposal	6,000

Table 8-1 Examples of Environmental Dredging Projects and Types of Equipment Used

Site Name	Primary Contaminants of Concern	Sediment Removal Methods	Sediment Treatment/Disposal	Sediment Volume (cy)
Natural Gas Compressor Station	PCBs	Dry Excavation	Off-Site Disposal	75,000
New Bedford Harbor – Phase 2	PCBs	Hydraulic Dredging	CDF	500,000
New Bedford Harbor – Phase I	PCBs	Hydraulic Dredging	CDF	14,000
Newburgh Lake	PCBs	Dry Excavation, Hydraulic and Mechanical Dredging	Off-Site Disposal	588,000
Niagara Mohawk – Cherry Farm	PAHs	Hydraulic Dredging	On-Site Disposal	50,000
North Avenue Dam/Milwaukee River	PCBs; PAHs; Metals	Mechanical Dredging	nd	8,000
North Hollywood Dump	Organics; Metals	Hydraulic Dredging	On-Site Disposal	40,000
Ottowa River (Tributary)	PCBs	Dry Excavation	Stabilization; Off-Site Disposal	10,000
Pacific Sound Resources	PCBs, PAHs, mercury	Mechanical Dredging		10,000
Petit Flume	Phenol	Hydraulic Dredging	Off-Site Disposal	2,000
Pine River – Hot Spot	DDT; PBB; Organics	Dry Excavation	Off-Site Disposal	21,500
Pine River – St. Louis Impoundment	DDT; PBB; Organics	Dredging	Off-Site Disposal	260,000
Pioneer Lake	PAHs; Organics	Hydraulic Dredging	Off-Site Disposal	6,600
Queensbury – Nearshore	PCBs	Dry Excavation	Off-Site Disposal	5,000
Randle Reef (Hamilton Harbor)	PAHs	Dredging	nd	30,000
River Raisin – Ford Outfall	PCBs	Mechanical Dredging	Stabilization; On-Site Disposal	28,500
Ruck Pond	PCBs	Dry Excavation	Off-Site Disposal	7,730
Saganaw River	PCBs; Dioxin; Metals	Dredging	CDF	320,000
Sheboygan River/Harbor – Full	PCBs; Metals	Dredging	Off-Site Disposal	118,200
Sheboygan River/Harbor – Pilot	PCBs; Metals	Mechanical Dredging; Wet Excavation	On-Site CTF	3,800
Shiasawssee River (pre-ROD)	PCBs	Mechanical Wet Dredging	Off-Site Disposal	1,805
Sinclair Inlet		Mechanical Dredging	On-Site CAD	
St. Lawrence River – GM	PCBs	Hydraulic Dredging; Cap	On- and Off-Site Disposal	13,800
St. Lawrence River – Reynolds Metal	PCBs	Dredging	On- and Off-Site Disposal	77,000
Tennessee Products – Phase 1	Coal Tar	Dry Excavation	Off-Site Disposal	21,400
Todd Shipyard	PCBs, TBT	Mechanical Dredging	Off-Site Disposal	200,000
Town Branch Creek	PCBs	Dry Excavation	Off-Site Disposal	17,000
Trenton Channel (Black Lagoon)	PCBs; PAHs; Mercury	Dredging	CDF	20,625
Union Road	Lead	Unknown Removal; Cap	On-Site Disposal	5,600
United Heckathorn	DDT	Mechanical Wet Dredging	Off-Site Disposal	108,000
Upper Rouge River	PCBs	Dry Excavation	Off-Site Disposal	7,000
Ketchikan Pulp Company Site	Organics, PAHs, mercury	Mechanical Dredging	Upland Landfill	20,000
Waukegan Harbor	PCBs, PAHs	Hydraulic Dredging	Thermal Desorption; On-Site Disposal	50,000
Willow Run Creek	PCBs; Metals	Dry Excavation	On-Site Disposal	450,000
Wolf Creek (unnamed tributary)	PCBs; Lead	Dredging	Off-Site Disposal	13,000
Wyckoff Co. – Eagle Harbor #2	PAHs; Mercury	Mechanical Wet Dredging	Stabilization; CDF; Off-Site Disposal	3,000

Notes:
na – Not applicable
nd – No data available
CDF – Confined Disposal Facility
CTF – Confined Treatment Facility

Table 8-2 Contaminant Barrier System and Water Quality Monitoring Results

Project	Barrier System	Water Quality Monitoring Results
Bayou Bonfouca, Louisiana	Silt curtains and oil booms, sheet pile for banks	Not specified.
Black River, Ohio	Oil booms	Not specified.
Collingwood Harbor, Canada	Unknown	Water quality turbidity criteria met during dredging.
Ford Outfall/River Raisin, Michigan	Silt curtains (disturbed from passing ship)	No major exceedances of water quality (turbidity).
GM Foundry/St. Lawrence River, New York	Silt curtains then switched to sheet pile wall	After modification to sheet pile wall, minimal turbidity exceedances which corresponded to a storm event. No PCB chemical exceedances.
Grasse River, New York (pilot)	Silt curtains	Turbidity exceeded during boulder removal, but not 2,300 ft downstream. No PCB chemical exceedances. Caged fish had elevated PCBs during dredging.
Hylebos Waterway	None	Water quality monitoring of turbidity/TSS and dissolved oxygen indicators at 300 ft. mixing zone boundary. No significant exceedances noted.
Lake Jarnsjon, Sweden	Silt curtains	No significant exceedances of water quality (turbidity).
Fox River Deposit N, Wisconsin	HDPE plastic barrier	No exceedances of water quality (turbidity).
Fox River SMU 56/57, Wisconsin	Silt curtains	No exceedances of water quality (turbidity); dissolved PCBs detected downstream of dredge site.
Manistique River, Michigan	Silt curtains and oil booms, sheet pile walls for certain areas	Unknown water quality results. Caged fish had higher than background concentrations but no statistical differences between during and baseline conditions.
Marathon Battery, New York	Silt curtains, earthen berm for dry excavation	Unknown.
Minamata Bay, Japan	None	No major exceedances of water quality.
New Bedford Harbor, Massachusetts	Silt curtains, but removed; surface booms and shroud on dredge	PCB mass transport was monitored. Unknown if turbidity was monitored, however, water column acute toxicity had minimal exceedances compared to reference. Deployed mussels were within seasonal variability.
Port of Portland T4 Pencil Pitch, Oregon	Unsure if silt curtain was installed	Turbidity was within normal range of variability for the river. No exceedances of pencil pitch chemical criteria.
Port of Vancouver Copper Spill, Washington	None	No copper chemical exceedances detected at midpoint or downstream boundary of dilution zone.

Table 8-2 Contaminant Barrier System and Water Quality Monitoring Results

Project	Barrier System	Water Quality Monitoring Results
PSNS Pier D, Washington	Oil booms	Water quality samples were collected but results were not available for review.
Sheboygan River, Wisconsin (pilot)	Silt curtains (occasionally toppled from currents)	Some turbidity and chemical water quality exceedances observed downstream. Caged fish had higher concentrations during dredging.
Sitcum Waterway, Washington	None	No significant exceedances of water quality (turbidity) measured 300 ft from dredge.
Thea Foss Waterway	Silt curtains, sheet pile	No water quality exceedances reported. Some recontamination of remediated surfaces reported.
Waukegan Harbor/Outboard, Illinois (Upper Harbor)	Silt curtains, sheet pile wall around confined disposal facility	No water quality exceedances measured during dredging (turbidity).
Wyckoff/West Eagle Harbor, Washington (OU-3)	Silt curtains	Turbidity exceedances were within compliance criteria (less than 20% exceedances at 200-ft mixing zone boundary).

Table 8-3 Potential Measures to Minimize Environmental Impacts During Dredging

Dredging Decision Factors	Preventive Measures	Details
Sediment Characteristics	Sediment Properties	Analyze samples for geotechnical properties (grain size, density, percent solids, etc.)
	Identify Presence of Debris	Identify presence of problematic debris and logs that will require pre-removal
Site Conditions	Accurate Bathymetry	Conduct fine-resolution hydrographic surveys including slope and backwater areas
	Adequate Site Characterization	Advance deep sediment cores to ensure characterization of substrate conditions and extent of vertical contamination
Sediment Resuspension and Transport	Water Quality Monitoring	Conduct near-field and far-field surface water quality monitoring
		Conduct mixing zone modeling and establish TSS/contaminant action limits
	Specialized Equipment	Use turbidity barriers oriented parallel to water flow
	Operational Controls	Use a closed, environmental bucket
		Bucket: Increase the cycle time for equipment, which reduces the upward velocity of a loaded bucket through the water column, which reduces the potential for sediment washing. It also reduces the resuspension of bottom sediments during initial contact with the bucket on the down cycle
		Bucket: Eliminate multiple bites and bottom stockpiling, which reduces the amount of sediment available for resuspension at the time of bucket operation
		Bucket: Eliminate barge overflow, which reduces turbidity and sediment loss
		Bucket: Add filters and screens at barge scuppers, which reduces turbidity of receiving water
		Hydraulic: Reduce cutterhead rotation speed, which reduces potential for sidecasting of material away from cutterhead and suction pipe entrance
		Hydraulic: Reduce swing speed, which reduces potential for sediment resuspension and ensures that cut rate is not faster than rate of suction and pipe transport to the surface
		Hydraulic: Reduce thickness of each lift and bank undercutting (cut height should be less than cutterhead diameter) or creation of steep slopes in dredge prism, which reduced potential for sediment sloughing and resuspension
		Hopper: Lower the fill level within the hopper unit
		Complete dredge prism at end of season and minimize exposure of elevated surface sediment concentrations in active areas

Table 8-3 Potential Measures to Minimize Environmental Impacts During Dredging

Dredging Decision Factors	Preventive Measures	Details
Equipment Availability	Local Contractors	When applicable, use local experienced resources
		Stage removal activities by season for equipment type
Dredging Accuracy and Removal Rates	Specialized Equipment	Use high-precision dredging equipment with real-time digital kinematics
		Use level-cut environmental buckets where appropriate to minimize ridges and troughs
		Monitor slurry density to disposal site using advanced monitoring equipment which minimizes amount of water required
		Use diver-assisted equipment in underpier areas
	Operational Controls	Ensure that operators are experienced with equipment
		Minimize dredging during peak tidal exchange periods
		Consider permeable turbidity barrier, but account for river current and tidal exchange.
	Pre-removal of Debris	Use excavator equipment to remove problematic debris and logs
	Construction Monitoring	High level of water quality monitoring with quick analytical feedback to dredge and oversight contractors.
	Independent Oversight	Knowledgeable, skilled and independent oversight to ensure achievement of project objectives
	Post-construction Oversight	Include post-verification sampling after each removal area is completed
Dewatering and Water Treatment	Water Quality Discharge	Conduct pilot study to determine water quality prior to remedy implementation and water discharge back to river after treatment
		Water may also be discharged to a local wastewater treatment plant if it meets pretreatment requirements, is permitted, and evaluated subject to site-specific volume limitations.

Table 8-4 Effectiveness and Implementability Evaluation of Removal Process Options

GRA	Technology Type	Process Option	Effectiveness				Implementability		
			Applicable to Site COCs				Applicable to Site Conditions	Commercially Demonstrated at Similar Scale	Innovative Technology
			Metals	PCBs	Semivolatile Organics	TBT			
Removal	Dredging	Mechanical Dredging	+	+	+	+	√	√	–
		Hydraulic Dredging	+	+	+	+	√	√	–
		In-water Excavator	+	+	+	+	√	√	–
	Excavation	On-land or Intertidal excavators, backhoes, specialty equipment	+	+	+	+	√	√	–

Notes:

+ Potentially effective and applicable to LDW COPCs

– Not effective or applicable to LDW COPCs

± Potentially effective, but not within an acceptable time frame for LDW COPCs

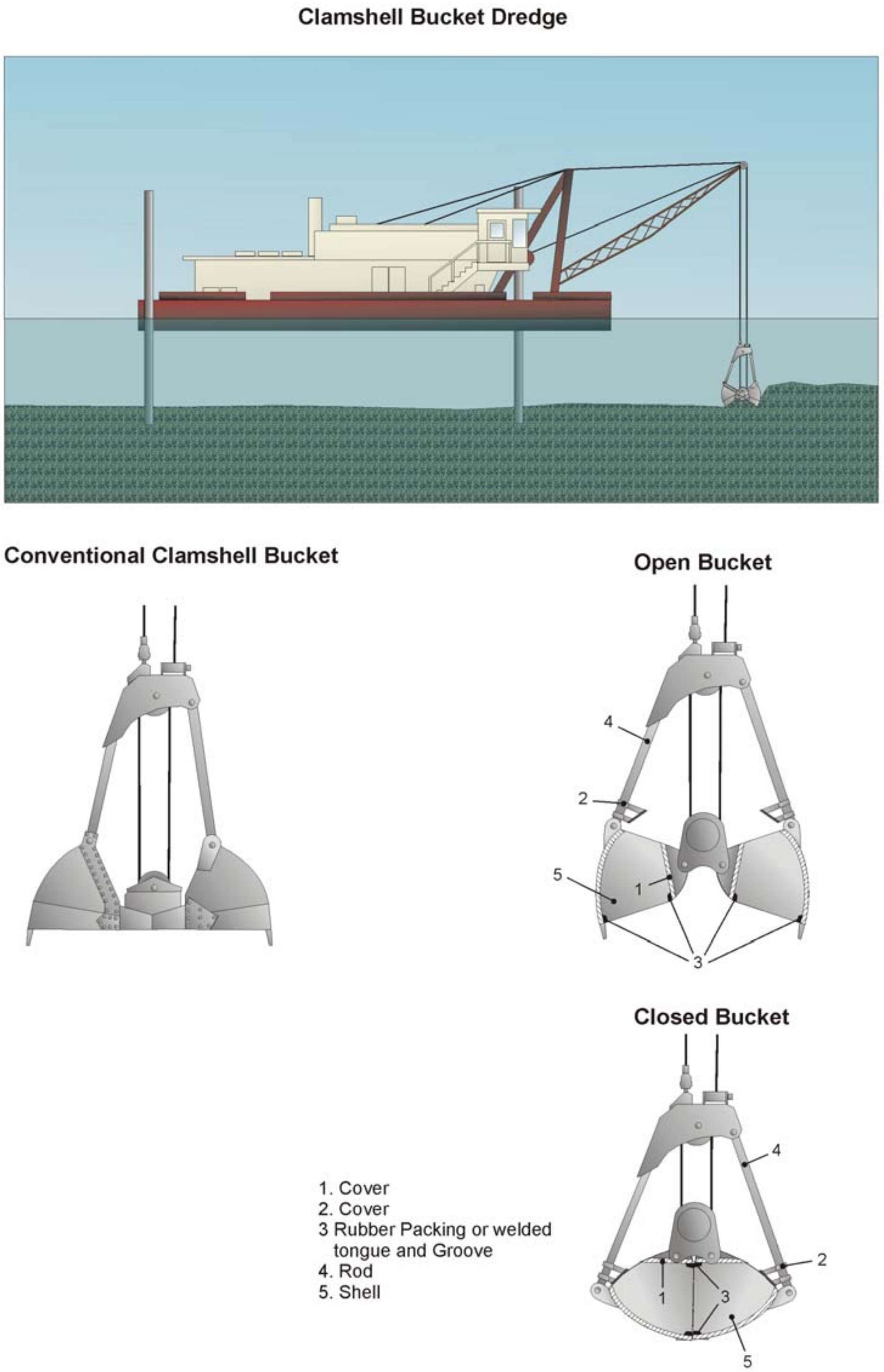
Table 8-5 Effectiveness, Implementability, and Cost Considerations for Removal Process Options

GRA	Technology Type	Process Option	Effectiveness		Implementability				Cost
			LDW COPCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	
Removal	Dredging	Hydraulic Dredging	Applicable to all LDW COPCs	Retained for consideration throughout the LDW	Generally applicable to LDW in-water site conditions. Best suited to low density, high water solids with little debris. Requires nearshore dewatering facilities and right-of-way for slurry pipeline. Water treatment and disposal required	Hydraulic environmental dredging is available and demonstrated in similar size projects, but is less frequently used for projects in Puget Sound.	—	Retained for consideration in the FS for all areas of the LDW	Moderate
		Mechanical Dredging	Applicable to all LDW COPCs	Retained for consideration throughout the LDW	Generally applicable to LDW in-water site conditions. Better suited for higher density, low water solids, and more effective at handling debris. Environmental buckets suitable for softer materials with low debris; clamshell buckets suitable for harder, dense sediments.	Mechanical environmental dredging is available and demonstrated in similar size projects, and is commonly employed for projects in Puget Sound.	—	Retained for consideration in the FS for all areas of the LDW	Moderate
		In-water Excavator	Applicable to all LDW COPCs	Retained for consideration throughout the LDW	Generally applicable to LDW in-water site conditions. Better suited for higher density, low water solids, and more effective at handling debris. Environmental excavators are suited for all materials (soft and dense), better able to handle debris, but may be depth limited.	In-water excavators are available and demonstrated in similar size projects, including projects in Puget Sound	—	Retained for consideration in the FS for all areas of the LDW	Moderate
	Excavation	On-land or Intertidal excavators, backhoes, specialty equipment	Applicable to all LDW COPCs. Effective for nearshore and/or intertidal areas where depths limit conventional dredging equipment	Retained for further consideration for intertidal or nearshore areas in the LDW	Limited in application to nearshore shallow and/or intertidal areas that can be reached from shore or by specialty equipment designed to work on soft unconsolidated sediments.	Equipment is commercially available and has been applied on projects of similar scope in Puget Sound	—	Retained for consideration in the FS for shallow and/or intertidal areas of the LDW	Moderate

Note:

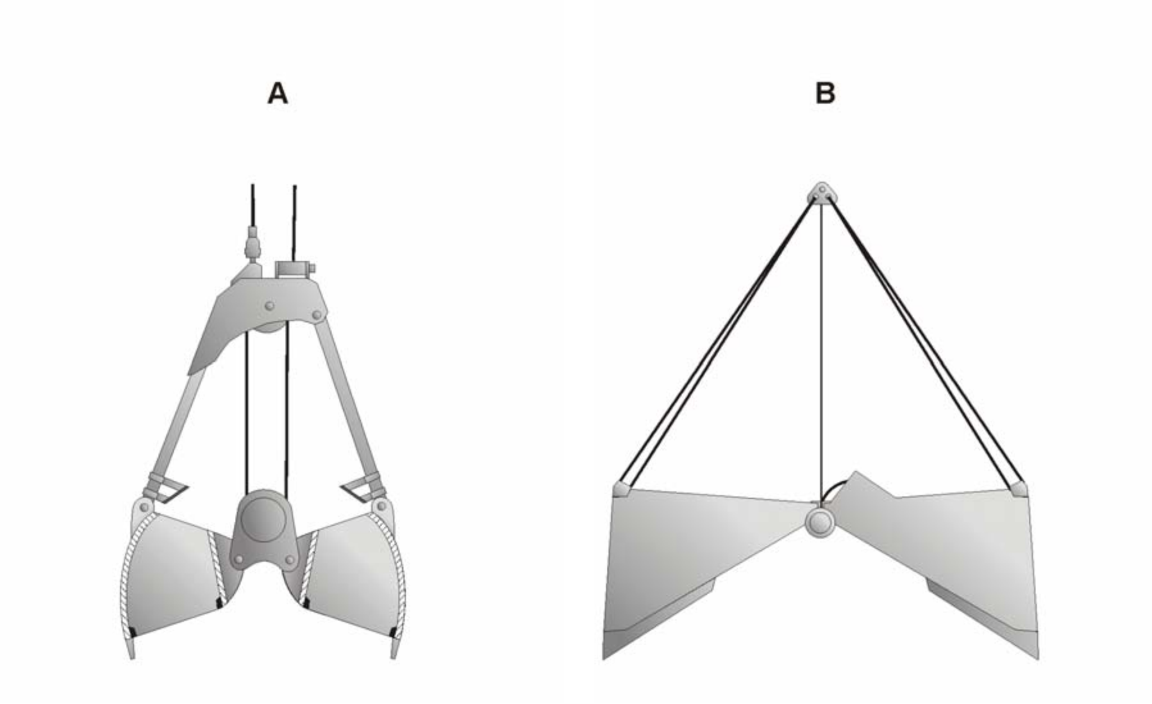
— Not applicable

FIGURE 8-1 EXAMPLE OF A MECHANICAL DREDGING BARGE AND CLOSED CLAMSHELL BUCKET



A closed clamshell bucket is similar to a conventional open bucket; however, a closed bucket generally has features that include some combination of covers, exterior pulleys, and sealed joints. The enclosed nature of this type bucket is intended to help reduce the amount of sediments that can spill or flow out of the bucket during digging. Clamshell buckets are principally used as digging buckets in heavier sediments or with high debris. (Figure after Anchor Environmental).

FIGURE 8-2 COMPARISON OF A CLAMSHELL DREDGE BUCKET WITH AN ENVIRONMENTAL LEVEL-BOTTOM CUT BUCKET



Clamshell dredge buckets are the most common mechanical dredge used in North America and in the Pacific Northwest (A). The bucket is designed principally as a digging bucket, and consists of a cable-operated, two-piece, hinged bucket operated from a crane or derrick mounted on a floating barge. Conventional clamshell buckets allow for sediment resuspension at any vertical point in the water column from the bottom to above the water surface. Level-bottom cut environmental buckets (B) have been developed in recent years to minimize loss of sediment during dredging and to improve dredging precision. These typically work on a two-cable system; one cable is attached to four spreader cables, which control opening and closing of the bucket, while the second cable draws the two sides of the bucket together and lifts, thus creating a level-cut. This configuration helps to reduce the amount of allowable overdredging that is typical of a clamshell bucket and, when fully closed, also helps to prevent sediment from washing out of the bucket as the bucket is raised through the water column.

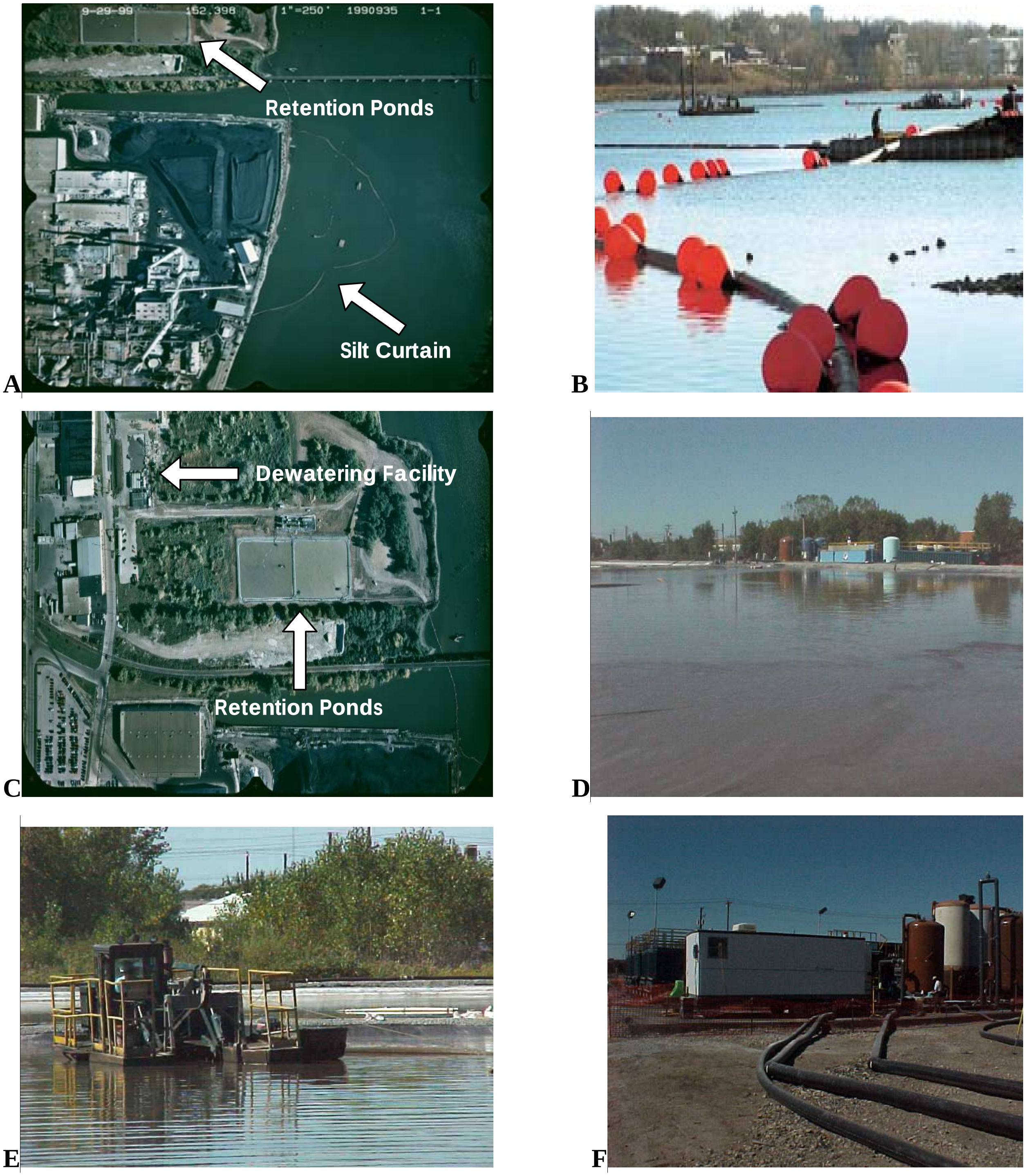
FIGURE 8-3 ENVIRONMENTAL BUCKET USE AT THE EAST WATERWAY PHASE 1 REMOVAL ACTION

For the Phase 1 Removal Action at the East Waterway of The Lower Duwamish River, a level-bottom cut environmental bucket was employed to remove soft contaminated sediments (A). The bucket was deployed from a dredge barge (B), and the removed materials were placed into a barge (C) for transfer to the offloading facility (D). Sediments were off-loaded at a facility located at the Port of Seattle's Terminal 25, where the material is re-handled (E) into specially-designed closed container boxes for off-site transport to the Roosevelt Landfill in Eastern Washington.

FIGURE 8-4 EXCAVATOR BUCKET ON THE BONACAVOR AT THE HYLEBOS WATERWAY

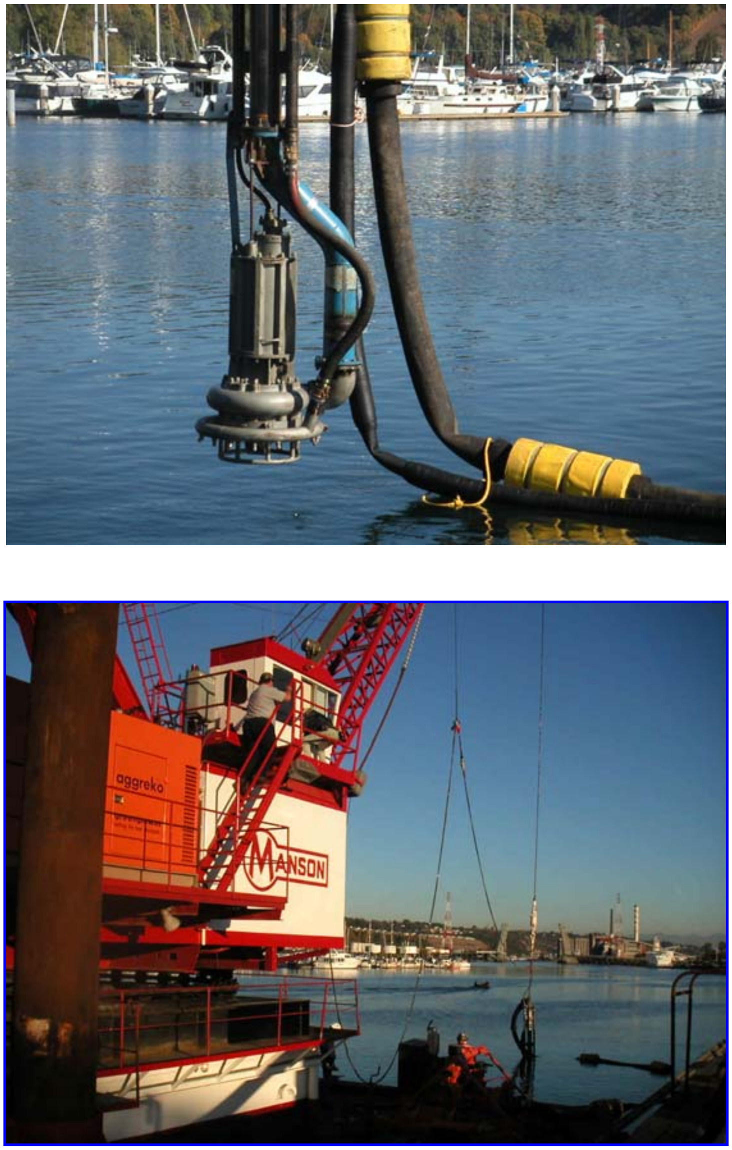
A special enclosed digging bucket, the Horizontal Profiling Grab, is currently being used to dredge contaminated sediments in the Hylebos Waterway in Tacoma. The bucket has a capacity of 4.5 cubic meters and can operate in water depths up to 13 meters. Dredged material removed by backhoe exhibits much the same characteristics as for clamshell dredging, including near *in situ* densities and limited free water (Photo courtesy of C.F. Bean Corporation).

FIGURE 8-5 HYDRAULIC DREDGE SYSTEM ON THE LOWER FOX RIVER SMU 56/57



A hydraulic plant for the demonstration project at SMU 56/57 on the Lower Fox River in Wisconsin included a silt curtain around the overall site (A), within which materials were dredged and pumped (B) to a pair of large retaining basins (C). The purpose of the retaining basins (C) was to increase the solids content of the dredged material and (2) allow for the dewatering/water treatment plant to operate 24 hours per day to keep pace with the dredging (D). Materials were re-dredged (E) and pumped to the filter presses for dewatering, with sand filtration and carbon treatment of the decant water (F).

FIGURE 8-6 TOYO™ SPECIALTY SUBMERSION PUMP BEING USED AT THE HYLEBOS WATERWAY



A Toyo™ pump was used at the mouth of the Hylebos Waterway (Tacoma, Washington, Area 5106) to remove 32,000 cy of contaminated sediment and pumped into the Blair Slip 1 CDF between October 2002 and March 2003. The principal of this specialty dredge is that a proprietary electrically-driven compact submerged pump assembly is maneuvered into position using a derrick barge. This pump is capable of high solids production in uncohesive sediment and can be equipped with a rotating cutter or jet ring to loosen sediment. (Photos from Javeler Construction and Manson Construction web sites).

FIGURE 8-7 MUDCAT® AUGER DREDGE

The Mudcat™ is the most commonly employed hydraulic dredging units in North America. This is a proprietary device fitted with a vibrating auger head assembly and positive displacement pump specifically designed to excavate difficult, very soft sediments in shallow waters. The dredge unit is moved using onshore winching cables and pulleys. The Mudcat™ has been used at several environmental projects including the New Bedford Harbor, Manistique Harbor (A), and Lower Fox River demonstration projects, and at Soda Lake in Wyoming (B).

9 Ancillary Technologies

Ancillary technologies and processes are essential elements of many remedial alternatives, mostly related to waste management and monitoring. Ancillary technologies are not subject to the same screening evaluation as remedial alternatives; however, they are discussed in this section as important considerations during selection of remedial process options (Table 9-1). Ancillary technologies and processes described in this section include:

- Dewatering
- Wastewater treatment
- Transportation
- Surface water quality management and monitoring.

9.1 Dewatering

Sediment dewatering is a requirement for most disposal and treatment processes. This can include passive and mechanical dewatering. Passive dewatering (also referred to as gravity dewatering) involves the gravity separation of water and solids in a sedimentation basin. Mechanical dewatering involves the use of equipment such as centrifuges, hydrocyclones, belt presses, and plate and frame filter presses to remove moisture from the sediments. Treatment of wastewater generated during sediment dewatering may be required to meet water quality requirements for either discharge to a municipal wastewater treatment system, or back to the LDW. At a minimum, treatment would involve gravity sedimentation and possibly filtration for solids removal. Residual solids (dewatered sediments) will require transportation to the final disposal site or beneficial use site.

Dewatering involves the removal of water from dredged sediment to produce a material more amenable to handling. Dewatering is conducted to some degree on all removal actions, whether it is to meet landfill disposal criteria (e.g., paint filter test and compaction specifications); to minimize that amount of water being transported to a landfill that accepts wet dredged material; to separate sand from treatable/disposable finer solids; as a pre-treatment prior to a thermal desorption, vitrification, or addition of a solidifying agent; or after a soil-washing treatment. Selection of an appropriate dewatering technology depends on the physical characteristics of the material being dredged, the dredging method, and the target moisture content of the dewatered material. Dewatering technologies can be grouped into the following three categories:

- Mechanical dewatering
- Passive dewatering
- Solidification.

9.1.1 Description of Dewatering Process Options

After removal, the dredged solids typically have moisture contents that must be reduced for effective treatment. Mechanically-dredged sediments typically have a solids content of approximately 2 parts sediment to 1 part water by volume. Hydraulically-dredged sediments are in a slurry, with a solids content typically in the range of 1 part sediment to 12 to 25 parts water by volume[12] (10 to 20 percent by weight per OSWER (2004) or 3.8 to 7.5 percent by volume**)**. As noted previously, 100,000 cy of mechanically-dredged sediments would result in up to 10 million gallons, while 100,000 cy of hydraulically-dredged sediments would result in 242 to 484 million gallons of decant water. Dewatering these sediments requires management of the contaminated water.

Mechanical Dewatering

Mechanical dewatering equipment physically forces water out of sediment, and are typically paired with hydraulic removal systems. Four techniques are typically considered for dewatering dredged sediments: centrifugation, diaphragm filter presses, belt presses, and hydrocyclones.

Centrifugation uses centrifugal force to separate liquids from solids. Water and solids are separated based upon density differences. The use of a cloth filter or the addition of flocculent chemicals assists in the separation of fine particles. Centrifuges are suitable for areas where larger passive dewatering systems (operations) are impractical. The process works well with oily sediments and can be used to thicken or dewater dredge slurries.

Hydrocyclones are continuously-operated devices that use centrifugal force to accelerate the settling rate and separation of sediment particles within water. Hydrocyclones are cone shaped. Slurries enter near the top and spin downward toward the point of the cone. The particles settle out through a drain in the bottom of the cone, while the effluent water exits through a pipe exiting the top of the cone. The production rate and minimum particle size separated are both dependent upon the diameter of the hydrocyclone. Generally, a wider hydrocyclone has a greater production rate, whereas narrower hydrocyclones are better at separating out smaller particles, albeit at lower throughput rates. Hydrocyclones were used during the Lower Fox River Deposit N demonstration project to remove +200 sieve material (i.e., sand) after removal of gravel sized stones and debris (RETEC 2002b).

Diaphragm filter presses are filter presses with an inflatable diaphragm, which adds an additional force to the filter cake prior to removal of the dewatered sediments from the filter. Filter presses operate as a series of vertical filters that filter the sediments from the dredge slurry as the slurry is pumped past the filters. Once the filter's surface is covered by sediments, the flow of the slurry is stopped and the caked sediments are removed from the filter. Filter presses are available in portable units similar to the centrifuge units. Although very costly and labor intensive, production rates for a single unit vary from 1,200 to 6,000 gpm.

Belt presses use porous belts to compress sediments. Slurries are sandwiched between the belts, resulting in high pressure compression and shear, which promotes the

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[12] Using a volume-to-weight conversion factor of 2.65.

separation. Flocculents are often used to assist the removal of water from the sediments. The overall dewatering process usually involves gravity-draining free water, low pressure compression, and finally high pressure compression. Belt presses can be fixed based or transportable. They are commonly used in sludge management operations at municipal and industrial wastewater treatment plants.

Belt press efficiencies are dependent upon belt speeds, tension, material composition, feed concentrations, and flocculent dosing. A type of belt press, called the recessed chamber filter press has been used for dewatering hydraulically-dredged sediments in the Midwest. The press was used after a gravity-settling stage and polymer conditioning to enhance filter performance. The filter cake produced was sufficiently dewatered for transport and disposal off site.

Passive Dewatering

Passive dewatering refers to gravity settling of solids. Passive dewatering can occur on sediment barges, within confined disposal facilities, and in specially built lagoons or ponds. The process requires sufficient retention time to allow sediment particles to settle, after which the clarified water may be discharged (or treated and then discharged depending on composition and discharge limitations). Passive dewatering in confined disposal facilities is commonly used for mechanical navigation dredging throughout the Great Lakes region (USACE 1987) and was used as part of the overall Milwaukee Fill project in Tacoma. A passive dewatering cell was employed for contaminated PCB sediments at the New Bedford Harbor CERCLA site in Rhode Island (Figure 9-1) (Foster Wheeler 2001).

Dewatering in large upland ponds is typically used in conjunction with hydraulic dredging. The dredged sediments are pumped to the pond and allowed to settle. Clarified water is decanted and thickened sediment is removed once the pond fills to a level that reduces settling performance. The addition of baffles to the settling pond increases the effective holding time and separation. Typically, passive dewatering cells require a minimum of four acres for projects in the 100,000 cy-range.

On barge dewatering is typically used in conjunction with mechanical dredging. Sediment is deposited inside the haul barge and some passive separation of solids and water occurs within the barge (Figure 9-2). Haul barges may be equipped with side drains that allow the water to flow from the barge into the water body, or may be fully-contained and the water is pumped off separately and treated at the off-load facility. The latter type of operation is more typical of recent contaminated sediment projects in the LDW and in the Hylebos Waterway.

Solidification

Solidification involves mixing a chemical agent with dredged sediments to absorb moisture. Portland cement, pozzolan fly ash, fly ash/Portland cement mixtures, and lime kiln dust are common additives. The chemical agent and sediments may be mixed in a pug mill or in a contained area (e.g., a roll off box or pit) using an excavator, depending upon sediment production rates and work space areas. Solidification is commonly used for sediments that have been partially dewatered by another means. Mechanically-dredged sediments can sometimes be solidified directly. Solidification is not a practical method for dewatering hydraulically-dredged sediments in the absence of thickening the solids by some other means, because the amount of chemical agent required becomes cost prohibitive.

9.1.2 Other Considerations

The principal considerations for evaluating dewatering methods are the type of removal option(s) selected, available land for construction and operation of a dewatering facility (passive or active), and consideration of the amount of water content that can/should practicably be achieved prior to transporting wet sediments to a landfill. Additional operating parameters and technical constraints that must be considered in selecting the appropriate dewatering technique include:

- **Production Rate.** The selected dewatering technique should produce dewatered sediments at a rate equivalent to the sediment removal rate. This allows sediment to be removed by the dredges without concern for sediment storage prior to dewatering.
- **Effectiveness.** The selected dewatering technique must be capable of consistently meeting the specific requirements for disposal. This requirement is at least 50 percent solids without the addition of any solidification agents.
- **Siting.** Whether land is available near the dredge site to construct dewatering facilities.
- **Discharge Water Quality.** All water removed from the dredged sediments must meet certain regulatory requirements prior to discharge to a publicly-owned treatment works (POTW) or to the LDW.

9.2 Wastewater Treatment

Water from the dredged sediment dewatering operation may require treatment to meet effluent water quality criteria for discharge to the receiving system. The receiving system may be a permitted discharge to the LDW, a POTW, or an industrial wastewater facility. Although smaller projects could potentially discharge to the Metro-King County system, it is not likely that larger volumes of water from hydraulically-dredged sediments could be accommodated. Flow rates are limited by wastewater conveyance system capacity. Thus, water treatment to NPDES discharge criteria (e.g., Washington State water quality standards) would likely be required. Treated wastewater would then be returned to the LDW.

Water quality may be adversely affected in and around dredging operations through resuspension and dispersion of contaminated sediments. Therefore, controls on suspended solids are an important consideration in the development of remedial alternatives involving sediment removal, and were discussed with respect to the effectiveness of dredging (see Sections 8.5.3 and 8.5.10). Water quality is also an issue in dewatering operations where produced water may require treatment to meet discharge standards.

9.2.1 Water Treatment

Mechanical Dredge Water Treatment

Free water derived from mechanical dredging may accumulate within the haul barges, or at the consolidation (stockpile) facility. Haul barges are left idle before off loading to allow for collection of free water at the surface of the load by sediment self consolidation. The free water can then be decanted and pumped ashore to a water treatment system, if necessary, before unloading the dredged material (this also minimizes tendency for washout/spillage during the off load swing). An onshore water treatment system may consist of one or several Baker tanks for primary sedimentation of solids, coagulant-aided secondary flocculent settling of remaining suspended solids, and filtration (i.e., sand, mixed media, activated carbon), if needed, to meet water quality requirements.

Recent mechanically-dredged projects in Puget Sound have developed innovative ways of managing residual water in the haul barges prior to off-loading to the upland transfer facilities. At the East Waterway project, the barges were outfitted with filter fabric and wick drains to contain the suspended solids, while allowing the decant water to drain from the barge. Intensive water quality monitoring showed that as long as the filter fabric and wick drains were functioning properly, there was no appreciable increase in the concentrations of total suspended solids or COPCs in the water column (D. Hotchkiss, personal communication). At the Hylebos Waterway dredging, all water that was placed in the barge from the bucket (environmental closed bucket) was contained, with no barge overflow allowed (P. Fuglevand, personal communication). The sediment in the barge was allowed to settle overnight, and the captured water was pumped to a settling pond and then discharged back into the Hylebos Waterway as dredge return water. For these projects, the COPCs were found to be closely associated with the TSS. Allowing the sediment to settle out captured water was found to be a sufficient management practice.

If the sediment is very fine grained, or contaminants such as PCB oils or chlorinate solvents are in the sediments, then additional treatment steps may be needed for the return water. Water treatment may be required to meet water quality requirements for discharge back to the LDW. At a minimum, treatment would involve gravity sedimentation and possibly filtration for solids removal. The disposal cell could be designed with a compartment for quiescent settling with or without coagulant addition. More involved treatment, depending on discharge criteria, could involve the use of standard process options such as:

- Coagulation, flocculation, and settling
- Filtration (i.e., sand, mixed media)
- Adsorption using granular activated carbon
- Ozone, ultraviolet/ozone, or ultraviolet/peroxide oxidation.

Finally, at the sediment transfer facility, shore-side stockpile areas can be graded, bermed, and lined to contain and collect sediment drainage and rainfall runoff. Once sufficiently dewatered, stockpiled material may be treated on site, or loaded onto trucks or rail cars for transport to the treatment or disposal facility.

Hydraulic Dredge Water Treatment

Hydraulic dredging results in a large volume of sediment water slurry to be managed. Flow rates in small dredges can range from as little as 900 gpm (267 cy/hr) for a 6 inch dredge, to more than 4,000 gpm (1,188 cy/hr) for a 14 inch dredge. Hydraulic dredging rates in contaminated sediment removal are frequently limited by the capacity and treatment rates of the dewatering and water quality system.

Methods for dewatering hydraulically-dredged sediments were described in Section 9.1. With gravity-separation ponds, the return water flow is decanted over a weir to skim the clarified water from the surface in order to meet water quality requirements before discharge. For mechanically-dewatered sediments, the decant water may be returned to a secondary quiescent pond for solids separation, or may be treated directly through a series of sand filters, adsorption on granular activated carbon, or additional treatment such as ultraviolet or peroxide oxidation in order to meet discharge water quality.

Other means of solids removal for hydraulic dredging have been tested (EPA 1994a; SEDTEC 1997). In 1995 through 1996, approximately 100,000 cy of hydraulically-dredged contaminated sediment was dewatered by adding a coagulant aid to the slurry stream and routing the flow through a set of two clarifiers for thickening and then through belt presses for landfilling (Ohio River Dredge and Dock, Inc.). A proprietary process (Solomon Venture, Lakewood, Colorado) reports success in using a system of screens and grids to remove particles down to 1-micron size at dredge flows of 1,200 gpm (356 cy/hr).

An emerging solids separation technology uses geomembrane tubes designed to pass water, but not selected sediment sizes. Sandy sediments have been pumped into such tubes for separation of solids. However, the membranes may be subject to blinding (plugging) for high concentrations of fine-grained materials. This is currently being evaluated at the Hylebos Waterway.

9.3 Transportation

Transportation methods will be needed for any remedial alternative that involves removal of contaminated sediments. The transportation methods included in each remedial alternative will be based upon the compatibility of that transportation method with the other process options. Finding a suitable location to stage upland transfer and transport of dredged sediments often presents difficulties at sediment cleanup sites.

The following provides a description of each of the transportation methods, including a summary of the compatibility of these methods:

- **Barge.** Barge transport of high-solid, mechanically-dredged sediments to an associated upland transfer facility on the shoreline is commonly employed in Puget Sound dredging programs. Barge-to-rail car transfer facilities have been located on both the East and West Waterways of the Duwamish River to support environmental dredging projects (see Section 11.3).

- **Rail.** The two transfer facilities on the Duwamish River were structured to support transport of wet dredged-sediment by railroad using closed containers.
- **Truck.** Transport of dewatered sediment over public roadways could include using dump trucks, roll-off boxes, or trailers.
- **Pipeline.** Transport of low-solid sediments through pipelines directly from dredge equipment to a receiving point on the shoreline for processing is commonly employed for hydraulically-dredged sediments.

No screening evaluation is necessary for transportation. However, in the absence of a suitable transfer facility for dredged sediments, implementation of dredging may be difficult. Effectiveness and implementability considerations, along with relative costs, are given in Table 9-1.

9.4 Surface Water Quality Monitoring

Water quality impacts from sediment resuspension during dredging or capping are potential issues when planning a sediment cleanup. Operational controls involving modified construction practices, specialized equipment, and containment systems can be effective in controlling sediment resuspension and off-site losses.

As discussed in Section 8.5.10, dredge contractor compliance with the project objectives and RAOs is dependent upon continuous, consistent, and daily regular oversight and water quality monitoring. Although monitoring *per se* is not part of the technology screening process, monitoring is a key component of sediment remediation to verify project progress and success. For contaminated sediment projects, monitoring can be grouped into five categories: 1) baseline monitoring; 2) short-term monitoring during implementation; 3) verification monitoring immediately following an action; 4) operation and maintenance monitoring of containment (confined disposal facility or cap) sites; and 5) long-term performance monitoring to determine whether RAOs are attained. This discussion focuses on implementation monitoring to determine the effectiveness of Best Management Practices during remedy operations.

Implementation monitoring of surface water quality during dredging or capping operations is typically conducted to ensure effectiveness of Best Management Practices and contract specifications, to minimize downstream transport of contaminants, ensure compliance with surface water quality requirements, and provide real-time feedback to dredge operators regarding performance.

The most common monitoring parameter utilized at dredging and/or capping sites is surface water sampling at various depths through the water column at a pre-determined distance downstream of operations. Background water quality profiles (for chemicals of concern and TSS) are typically collected for comparison to upstream (or up-current depending upon tidal flow in the LDW) samples. The scope of implementation-based sampling events will vary depending upon the phase of the remedy effort, RAOs specified for the project, and the regulatory agency. When compared to other recent environmental dredging and cap placements in the LDW (PSR capping, Todd Shipyards, Lockheed, East Waterway), the required monitoring is likely to include:

- Dredge or cap-released particulate characteristics and concentrations (typically measured as total suspended solids [TSS] and turbidity)
- Dredge or cap-released COPC concentrations
- Up-current receiving water characteristics including TSS, turbidity, and COPC concentrations.

Additional monitoring parameters may include bathymetry or water quality profiles (for turbidity, temperature, and dissolved oxygen).

Some dredging contractors have designed specialized monitoring equipment comprised of acoustic Doppler current profilers, precision location control, flow meters, and pump samplers for collecting data at numerous depths in the water column. Data is transmitted back to the on-deck operations for real-time quantity determinations of suspended material in the water column and rate of transport downstream. Operators can immediately modify the rate of production to meet water quality action levels without significant down-time.

Table 9-1 Summary of Ancillary Technologies

Technology	Process Option	Description	Effectiveness and Implementability Considerations	Screening Decision
Passive Dewatering	On-barge	Mechanically-dredged sediments are placed within a barge, which either allows excess water to flow into the LDW, or to accumulate in an on-board sump where it is removed and treated.	Water drained from sediment on barge into the LDW may not meet NPDES discharge standards. Gravity-drained water may contain high concentrations of TSS. Not all LDW segments may be accessible to a barge.	Retained
	Dewatering Lagoons/ Ponds	Dredged sediments are placed within constructed lagoons where sediments are allowed to gravity settle.	Limited land space to construct dewatering sites. Construction costs may involve contingencies to address potential spills and leaks. Effluent water may contain high concentrations of TSS. Average annual rainfall and evaporation approximately equal. Retention time affects production rates.	Retained
	Solidification	Dredged sediments are mixed with amendments (e.g., Portland cement, lime, or fly ash mixture) to produce a product that passes regulatory requirements (e.g., paint filter test).	Staging, mixing, and curing areas required. Solidified sediments have higher mass than the unsolidified sediments because of the addition of amendments. Most effective on partially-dewatered/high-solid sediments.	Retained
Mechanical Dewatering	Centrifugation	Rapidly rotates fluid mixture to separate the components based upon mass. Flocculants are often used to increase effectiveness.	Production rate is based on size and quantity of centrifuges used to dewater. Typical production rate of a single centrifuge is 20-500 gpm. Because of handling issues, more effective on dredge spoils containing a low percent of solids.	Retained
	Belt Press	Uses belts that compress sediments against rollers to achieve high-pressure compression and shear to remove water from dredged sediments.	Production rate is based on the size and quantity of belt presses used. Typical production rate of a single belt press is 40-100 gpm. Sediments are initially gravity-drained, which could produce high concentration of TSS.	Retained
	Hydrocyclone	Continuous operating cone-shaped device which uses centrifugal force to accelerate settling.	Production rate and minimum separation size depend upon size of hydrocyclone (larger capacity provides a larger minimum separation size). Typical production rate of a single hydrocyclone is 50-3,500 gpm.	Retained
	Diaphragm Filter Press	Dewaters dredged sediments by passing slurry through a vertical filter. Uses inflatable diaphragms to increase pressures on sediments prior to removing sediments from filter.	Production rate is based on the size and quantity of filter presses used. Typical production rate of a single filter press is 1,200-6,000 gpm. Because of nature of operation, does not allow for continuous operation.	Retained

Table 9-1 Summary of Ancillary Technologies

Technology	Process Option	Description	Effectiveness and Implementability Considerations	Screening Decision
Wastewater Treatment (for mechanical dredging)	Sedimentation	Passive physical separation in a dewatering cell to remove solids.	Basic form of primary treatment used at wastewater treatment facilities. Gravity settling is used most extensively.	Retained
	Filtration	Water is fed through sand or mixed-media filter for solids retention. Gravity or pressure pumped.	Filtration media are commonly used in confined disposal facilities. Most organic compounds, especially hydrophobic ones, are generally removed with the solids.	Retained
	Coagulation Aid, Flocculation and Settling	Coagulant aid added to slurry stream, and then flowed through clarifiers for thickening.	Coagulant and polymer flocculents used in pilot projects to promote removal of silty clay. Limited full-scale application.	Eliminated
	Adsorption Carbon Filter	Uses granular activated carbon.	Useful for removing organic substances. Spent carbon must be frequently disposed of.	Retained
	Oxidation	Oxidation of organic molecules to carbon dioxide and water by chemical or ultraviolet oxidation.	Technology is effective for removing organic compounds including PCBs, but not effective with metals.	Eliminated
Solid Residuals Management	Mechanical	Discussed under Dewatering Process Options		
	Sediment	Discussed under Disposal Technologies		
	Water	Discussed above and returned to the LDW or transported to POTW for treatment and disposal.		
	Air Emissions	Treated on site and discharged at generation site.		
	Other Solids (i.e., PPE)	To local municipal landfill.		
Transportation	Truck	After dewatering, stockpiled solids placed in sealed trucks by backhoes.	Portable and flexible. Readily available.	Retained
	Rail	Sediment placed in railcars for hauling long distances.	Readily available and currently used on LDW cleanup actions.	Retained
	Barge	High-solids dredged material mechanically placed in barge. After dewatering, offloaded using backhoe and trucks.	Used with mechanical dredging operations. Consider dewatering limitations on barge.	Retained

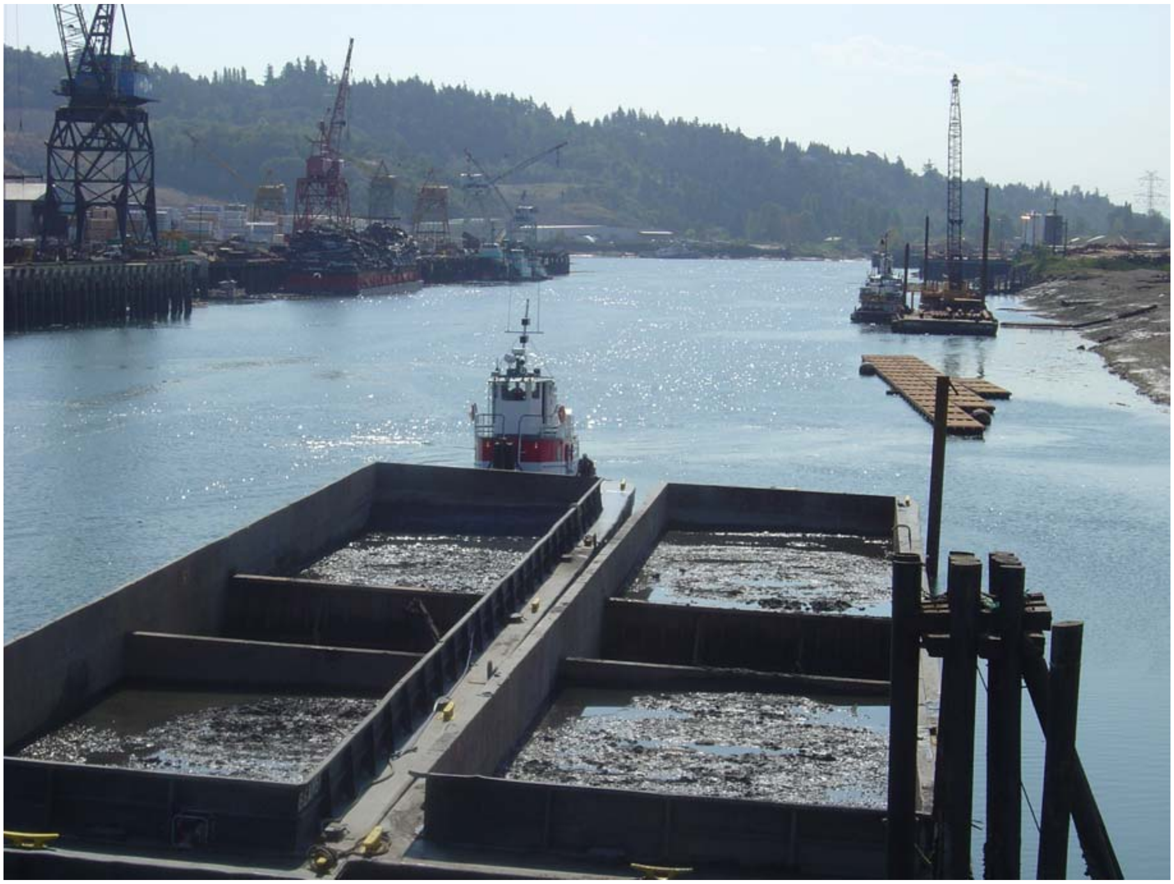
Table 9-1 Summary of Ancillary Technologies

Technology	Process Option	Description	Effectiveness and Implementability Considerations	Screening Decision
Transportation (continued)	Pipeline	Transports dredged material in slurry form directly to disposal site or treatment site if necessary.	Preferred for hydraulic dredging and transport over short distances (<3 km). Booster pumps need consideration. Requires sufficient land space near dredging operations to serve as slurry transfer station between the dredge and pipeline.	Retained
Water Quality (in-water)	Containment Structures	Placement of physical barriers (silt screens, curtains, sheet pile walls) to lower TSS transport.	Mixed effectiveness. Highly dependent on site conditions.	Retained
	Operator Modifications	Use slower dredging rates and speeds.	Effective, but requires monitoring. Selection of a qualified dredge operator may have the largest influence on dredge or cap implementation.	Retained

FIGURE 9-1 PASSIVE DEWATERING CELL AT THE NEW BEDFORD HARBOR SUPERFUND SITE

For the New Bedford Harbor PCB Superfund Site, an on-shore dewatering cell and CDF were constructed. The system consisted of: (A) the primary cell that received the incoming sediments and served principally to gravity-settle the solids; (B) the secondary cell received the decant water from the first cell from which water was drawn into (C) the water treatment facility, after which the cleaned water was returned to the holding area (D) where it was held until return and discharge. A closed-cell in the CDF is also shown (E). (Photo courtesy of Bean Environmental).

FIGURE 9-2 PASSIVE DEWATERING OF DREDGED SEDIMENTS IN BARGES ON THE HYLEBOS WATERWAY



For the Hylebos Waterway removal action, mechanically-removed sediments are placed into barges for transport and for partial dewatering. The dredged sediments are allowed to settle in the barges overnight. The decant water is pumped off to a separate on-land treatment facility, and dredged materials are placed into rail cars and shipped wet for disposal at the Roosevelt Regional Landfill (photos courtesy of Bean Environmental and DOF).

10 Treatment Technologies

Treatment technologies refer to biological, chemical, or physical techniques that can be applied to sediments in place (*in situ*), or to dredged sediments to reduce the concentration of, decontaminate, or permanently bind the contaminants. For the CTM, treatment technologies were evaluated by obtaining information from federal and state resources (listed below), reviewing the available technical information in the scientific and engineering literature, and contacting vendors for specific information on performance and costs.

Treatment technologies are reviewed here, with an initial screening based upon implementability and effectiveness at destroying or immobilizing LDW COPCs that include semivolatile organic compounds, PAHs, PCBs, TBT and metals. Treatment technologies in this section are evaluated relative to the screening criteria previously presented in Section 1.4. Treatment technologies would be applicable for chemical-based cleanup goals, but achieving chemical-based cleanup goals may not address toxicity-based cleanup goals. There are no demonstrated technologies that address toxicity-based cleanup goals. It is acknowledged that COPC concentrations vary widely over the LDW, and that some technologies that may not appear to be applicable for the LDW as a whole may later be found to be applicable for some portions of the LDW.

10.1 Resources for Evaluating Treatment

10.1.1 Federal Resources for Sediment Treatment

The decontamination and potential use of contaminated sediments have been an important research and development goal of the EPA, the USACE, and other federal agencies (e.g. Department of Defense). A list of those technical reports, publications, and databases accessed for this CTM is provided in Table 10-1.

The EPA has sponsored the development of innovative treatment and monitoring processes through the SITE program. SITE demonstration project information for sediments was accessed through the website at http://www.epa.gov/ORD/SITE. Another important EPA resource for treatment is the Hazardous Waste Clean-Up Information (CLU-IN) website at http://clu-in.org. CLU-IN provides an online database of information on bench-scale, pilot-scale, and full-scale treatment options that can be applied to hazardous materials for various media, including sediments.

EPA's GLNPO ARCS program includes several useful documents and summaries of sediment management issues, including treatment. Developed jointly with the USACE, the documents cited in Table 10-1 provide information on the selection, design, and implementation of sediment remediation technologies, including feasibility evaluation, testing technologies, relative costs, and effectiveness.

10.1.2 Washington State MUDS Program

The MUDS program was conducted jointly by the resource agencies with responsibility for managing contaminated sediments in Puget Sound. This multi-year program's objective was to assess the feasibility of establishing one or more multi-user/multi-source facilities for the disposal or treatment of contaminated sediments (USACE 2003). A programmatic EIS completed in October 1999 demonstrated a need to remove a large volume of moderately contaminated sediment from the Puget Sound region and transfer it to one or more appropriate locations for disposal or treatment.

Within or related to the MUDS program, a number of treatment and disposal options were evaluated for implementation, effectiveness, and cost (Ecology 2001a,b; Hart-Crowser 2001; USACE 2003). Eleven potentially viable *ex situ* treatment processes were evaluated based on their previous performance in treatment studies conducted as part of the Port of New York/New Jersey's contaminated sediment management program (Hart-Crowser 2001). Of those, seven programs were offered commercially by vendors, and examined in more detail based on their technology and costs. Of those, three processes involved at least some thermal treatment of contaminated sediments (Cement-Lock, Harbor Rock, Global Plasma vitrification); two used stabilization or solidification of contaminants by the addition of cement or other suitable pozzolan (Georemediation, JCI/Upcycle); one involved bioremediation (Battelle); and one system involved sediment separation (sand from contaminated fine-grained material), followed by washing and treatment by the addition of surfactants, chemicals or chelators to destroy or immobilize contaminants (BioGenesis).

Of the MUDS-reviewed treatment technologies, none provided specific information on destruction of PCBs and dioxins for full-scale treatment processes. Most focused on mercury, volatile organic compounds, and semivolatile organic compounds (Ecology 2001a; Hart-Crowser 2001). No information was included on potential air emissions during thermal treatment of PCBs, and disposal costs for specific waste streams were all assumed to be beneficial use (i.e., no disposal cost or cost-recovery from sales).

Although the goals of the MUDS program were different from those of any cleanup action on the LDW, the conclusions of the 2003 MUDS Feasibility Study have relevance to the FS process for the LDW. The goal of the MUDS program was to evaluate the efficiency and economies of scale associated with a regional sediment management facility. Multiple cleanup projects, combined with potentially high volumes of materials, might result in low-cost treatment applications. A key conclusion of the 2003 MUDS Feasibility Study is that while there are a number of relevant and applicable treatment technologies that would be applicable to the Puget Sound region, environmentally acceptable and cost-effective management of contaminated marine sediment can be met by the existing solid waste landfills. Given the amount of sediment that might be removed from the LDW, the conclusions of the 2003 MUDS Feasibility Study are likely applicable.

In an associated study, Ecology (2001b) identified the various challenges to siting a viable contaminated sediment treatment facility. Many of the issues discussed in that study would require legislation, regulatory amendments, or policies that provide significant incentives for contaminated sediment to be treated rather than disposed. Some of the more important issues related to siting a treatment facility included:

1) A consistent flow of sediments to the treatment/manufacturing process
2) Public resistance to siting of facility
3) Lack of established standards for the products of treatment
4) Viability dependent on a public/private partnership and the cost of the waterfront property needed for the site

Finally, the MUDS Feasibility Study Phase Final Report (USACE 2003) concluded that as advances occur in sediment treatment technology, along with associated reduction in cost or demonstrated regional application, there remains the possibility for a public/private sediment treatment partnership.

10.1.3 CERCLA PCB Sediment Feasibility Studies

The CERCLA Feasibility Studies conducted for PCB contaminated sediments in the Lower Fox River (RETEC 2002), and the Hudson River (EPA 2001a) evaluated in detail the potential for treatment at those sites. Only the Lower Fox River FS, and subsequent Record(s) of Decision, identified vitrification as a potentially viable economic treatment alternative for the over 7 million cy of PCB-contaminated sediments[13]. That process, developed by the Minergy Corporation of Wisconsin, is discussed in more detail in Section 10.3.4 of this CTM.

Within EPA Region 10, there are 20 completed or ongoing sediment cleanups under Superfund. Of those, only one project implemented treatment: the Occidental Chemical site at the Hylebos Waterway. Treatment was selected for that site because the volatile chlorinated hydrocarbons in the sediments were highly toxic, concentrated, and mobile. Post-treatment sediments still required disposal in an engineered confined disposal facility.

10.1.4 Ports of New York and New Jersey Sediment Treatment Technology Development Programs

The nation's ports and waterways annually dredge millions of cubic yards of sediments to maintain navigational depths (NRC 1997). The Ports of New York and New Jersey manage up to 5 million cy annually, with over 70 percent unsuitable for open-water disposal because of the presence of contaminants at unacceptable concentrations. As a

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[13] The selected remedies in the RODs for Operable Units 1, 3 and 4 of the Lower Fox River selected dredging and landfilling of contaminated sediments as the preferred alternative. These RODs also noted the during the remedial design phase, vitrification of dredged contaminated sediment may be used where practicable and cost effective, as an alternative to off-site disposal at a licensed facility.

result, the Port, along with EPA and the USACE New York District, has been involved in developing sediment decontamination and treatment technologies (EPA et al. 1999).

The emphasis of this program was *ex situ* treatment, with potential beneficial use. As discussed above, the 11 processes evaluated under the MUDS program were originally sponsored under this Port program. To date, pilot-scale tests have been planned and executed for the Biogenesis^{SM} soil washing, Westinghouse's plasma vitrification, Cement-Lock's$^{®}$ combined thermal-cement treatment process, addition of pozzolan for stabilization and solidification, and a proprietary process developed by Metcalf and Eddy for chemical treatment followed by solidification (Wargo 2002). With one exception (pozzolan stabilization), the treated materials from all of the treatment technologies generally met residential soil cleanup standards for both New York and New Jersey, including for PCBs and dioxins (e.g., 1 ppm PCBs).

Of the technologies developed under the Ports of New York and New Jersey sediment technology development program, only the Cement-Lock$^{®}$ Technology has progressed to full-scale demonstration in New Jersey, although a Biogenesis^{SM} demonstration is planned for 2005. Full-scale treatment and cost data are anticipated to be generated in time for use in the LDW FS for both of the technologies.

10.2 *In Situ* Treatment Technologies

In situ treatment of sediments refers to chemical, physical, or biological techniques for reducing COPC concentrations while leaving the contaminated sediment mass in place. *In situ* treatment technologies are commonly employed for cleanup of contaminated soil and groundwater. No successful adaptations of these and other technologies to full-scale sediment cleanup involving LDW COPCs have been reported in the literature. Table 4-1 presented the 14 identified *in situ* treatment technologies. None of the treatment technologies identified had either: (1) been demonstrated beyond bench-scale studies, or (2) were not successfully applied as a pilot project, or (3) had not been successfully demonstrated in a fully implemented field effort with documented monitoring.

Two *in situ* sediment field trials included a proprietary stabilization technology and a electro-oxidation process. The Aqua MecTool™ stabilization process was implemented as part of a pilot application for a project in Wisconsin to treat coal tar-contaminated sediments. The pilot application was not successful because trials with this technology created water treatment problems inside the caisson. An *in situ* pilot test of an electro-chemical remediation technology was conducted in the Georgia-Pacific log pond in Bellingham, Washington. The treatment pilot team included Ecology, the EPA's SITE program, the technology developer Electrochemical Process LLC of Germany and their U.S. license holders Weiss and Associates, the Georgia Pacific Corporation, King County, and the Bellingham Bay stakeholders. The *in situ* process tested utilizes electrodes placed in the sediments, and runs an electrical current that is intended to break down organic contaminants and migrate metals to plate on the cathode. The pilot test ran for approximately 5.5 months, but because of various technical problems, had an effective run time of only 2.5 months. The electrodes placed in the sediment showed corrosion throughout the study, and at the end of the test period, the target contaminants of mercury, PAHs, and phenols showed no significant changes over baseline concentrations.

Because of these reasons and more detailed information provided in Table 10-2, *in situ* treatment technologies are not considered feasible for implementation in the LDW.

10.3 *Ex Situ* Treatment Technologies

Ex situ treatment refers to the processing of dredged sediments to transform or destroy COPCs. General treatment processes may be classified as biological, chemical, physical, or thermal. *Ex situ* thermal treatment includes four subcategories: incineration, high-temperature thermal desorption, low-temperature thermal desorption, and vitrification. Each of these is discussed below.

10.3.1 Biological

Biological treatment methods involve amendments of nutrients, enzymes, oxygen, or other additives to enhance and encourage biological breakdown of contaminants. Although low molecular weight PAHs and some semivolatile organic compounds are amenable to biological treatment, metals, PCBs, dioxins and TBT are not well-suited to biological treatment techniques. Table 10-2 reports the results of the evaluation of five biological treatment process options including landfarming, biopiles, fungal degradation, slurry-phase biological treatments, and enhanced biodegradation.

There are no proven and effective biological techniques for treating PCBs full-scale, and no reports in the literature of PCB-contaminated sediments biotreated *ex situ*. Reviews conducted for both the Hudson River (EPA 2001a), and for the Fox River (RETEC 2002) demonstrated that dechlorination of PCBs by biological processes can at best result in partial reduction, but that complete destruction of PCBs through these natural or enhanced processes is not possible. A pilot-scale biological treatment study was conducted on PCB-contaminated sediments from the Sheboygan River, Wisconsin and the Hudson River, New York, but neither aerobic nor anaerobic treatment had a significant effect (BBL 1995).

10.3.2 Physical/Chemical

Chemical treatment methods involve either adding oxidants that extract contaminants, or adding oxidizing agents that encourage the contaminants to convert to less-hazardous compounds. To date, chemical methods for treating contaminated sediments have not been effective. Acid extraction is ineffective for treatment of PCB-contaminated sediments. Solvent extraction is specific to soluble organics and some organic complexed metals. Other inorganics remain in the sediments, requiring some other form of treatment or disposal. Further, additional treatment is required for the concentrated extract.

The range of chemical treatment process options is presented in Table 10-2. Those options that were evaluated, but not considered practicable for the LDW included acid extraction, solvent extraction, slurry oxidation, reduction/oxidation, and iron injection. Although potentially applicable and, in some cases, demonstrated in bench-scale studies, those specific options have not been demonstrated in field efforts, or are not considered to be implementable at this time.

Chemical process options in Table 10-2 that are potentially applicable include the Dechlorination Solvated Electron Technology (SET), a combined peroxide and ferrous iron treatment system, and high-energy electron beam irradiation. In addition, the chemical/physical separation BioGenesis^{SM} process, the proprietary process developed by Metcalf-Eddy, and the dehalogenation process developed by APEG have shown at least pilot-scale effectiveness in dechlorination of PCBs. However, it should be noted that the literature provides no reports of chemical technologies implemented full-scale for the treatment of sediments.

Full-scale implementation of the BioGenesis^{SM} Advanced Sediment Washing system is planned for the Ports of New York/New Jersey during 2005. This technology has displayed pilot-scale effectiveness in treating COPCs including PAHs, PCBs, dioxins and furans, and is potentially applicable and implementable for the LDW. A summary of this technology is discussed below.

The BioGenesis process is an *ex situ*, on-site extraction technology for treating sediments containing both organic pollutants and metals and can be used on all types of gravel, sand, silt, and clay (Wargo 2002). In this process, mechanically-dredged sediments[14] are screened to remove oversized material and debris before transfer to holding tanks. The process does not require a permanent facility and uses equipment including but not limited to: truck mounted washing units, sediment processor, sediment washing unit, hydrocyclones, shaker screens, water treatment equipment, tanks, water blasters, compressors, and earth moving equipment. In this process, dredged sediment is screened to remove oversized material and debris before transfer to holding tanks. High-pressure water, proprietary solvent and physical agitation combine to separate COPCs from the solids. Treated sediment is dewatered in the next step using a hydrocyclone and centrifuge. Some effluent water may be recycled through the system, but significant quantities of wastewater are generated requiring treatment and disposal (Wargo 2002). The process results in residual waste products including sludge and organic material that requires disposal at regulated landfill (Wargo 2002). Depending on the nature of the sediment and cleanup levels required, the sediment washing process may need to be repeated through multiple cycles.

The important BioGenesis process planning factors to be considered are contaminant type, volume of sediment to be treated, sediment geotechnical properties (fines, sands), cleanup target, and the contaminant concentrations. Each of these factors influences the

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[14] The BioGenesis process requires a mechanically-dredged sediment of approximately 32 percent solids as input delivered to the treatment facility (C. Wilde, BioGenesis Corporation, personal communication). All bench-scale and pilot-scale testing to date, and full-scale implementation systems have been based upon high-solids, mechanically-dredged sediments.

economics of implementing this technology. How those costs could be affected for a one-time, smaller-volume dredging event has not yet been considered.

10.3.3 Physical

Physical separation or soil washing refers to the process of separating sediment into fractions according to their particle size or density. Separation may be accomplished by screening, gravity settling, floatation, or hydraulic classification using devices such as hydrocyclones (USACE-DOER 2000a). Equipment for physical separation is widely available, and the concept has been demonstrated for sediments in both the United States and Europe (USACE-DOER 2000a). Physical separation of the larger sand and gravel fraction from finer-grained sediment may or may not reduce the residual contaminated sediment mass or volume, and would require testing to determine suitability.

Physical treatment can also refer to the solidification/stabilization of dredged material to reduce the mobility of constituents through the use of immobilization additives. Many additives commercially available can immobilize both organic and inorganic constituents. Solidification reagents often include Type I Portland cement, pozzolan, cement kiln dust, lime kiln dust, lime fines, and other proprietary agents. Both separation and stabilization are considered to be viable for the LDW.

10.3.4 Thermal

Thermal treatment technologies desorb and subsequently destroy organic compounds by combustion. Thermal process options may be grouped into the categories of pyrolysis, high-pressure oxidation, incineration, thermal desorption (both high and low temperature), and vitrification. Neither pyrolysis nor high-pressure oxidation has been demonstrated for sediments, and thus these technologies are not considered viable for the LDW. Incineration and thermal desorption are widely practiced technologies for treatment of soil containing PCBs and other organics. Vitrification was developed initially for use in treating radioactive mixed wastes and is receiving attention as a cost-competitive thermal option for treating soils and sediments high in sand content. Regardless of the specific technology option, thermal treatment requires that sediments first be dewatered to reduce water content and therefore the amount of heating energy required.

Thermal destruction processes also require monitoring and management of air releases of hazardous constituents, such as dioxins and furans. Dioxins and furans can be created and/or released in air emissions from some thermal treatment processes. Fulfilling all substantive permit requirements for managing these air emissions can be difficult and can affect implementability of on-site thermal treatment. These administrative implementability concerns are fewer for off-site thermal treatment at fixed facilities with established permits. If thermal treatment processes are incorporated into FS alternatives, additional assessment of air emissions from the processes would occur in the FS. Different types of thermal treatment process options are discussed below.

Incineration

Incineration is a full-scale commercial technology where temperatures typically between 1,400 and 2,200 degrees Fahrenheit (°F) are sufficient to volatilize and combust organic chemicals. A common incinerator design is the rotary kiln equipped with an afterburner, a solids quench (to reduce the temperature of the treated material), and an air pollution control system. Incinerator off-gases require treatment to remove particulates and neutralize and remove acid gases. Baghouses, venturi scrubbers, and wet electrostatic precipitators remove particulates; packed bed scrubbers and spray driers remove acid gases. Incineration facilities are generally fixed based, but mobile incinerators are available for movement to a fixed location in close proximity to the contaminated sediments.

Incineration is especially effective at destruction of PAHs, semivolatile organic compounds, PCBs and dioxins, but costs are typically very high. Metals are not affected. Incineration of PAH-contaminated sediment was successfully conducted at the Bayou Bonfouca Superfund site, Louisiana, but at a high unit cost. Residual incinerator ash was placed in an on-site landfill. Incineration is implementable and effective, and thus should be retained and considered further for the LDW.

High-Temperature Thermal Desorption

High-temperature thermal desorption (HTTD) is also a full-scale technology in which temperatures in the range of 600 to 1,200 °F volatilize organic chemicals. HTTD desorption efficiencies for removing PAHs and PCBs from sediment range between 90 and 99 percent. A carrier gas or vacuum system transports volatilized water and organics to a condenser or a gas treatment system. After sediment desorption in the HTTD unit, volatilized organics are destroyed in an afterburner operating at approximately 2,000 °F. HTTD is not generally effective for metals.

HTTD is a treatment technique that has been used successfully at several other sites with similar contamination. HTTD systems can be both fixed based and transportable and typically use a rotary kiln. HTTD is a commonly used technology for soils and is readily adapted to sediments. Capacities on the order of 100 tons per hour are available in transportable models.

An example of an anaerobic thermal processor (ATP) extraction system is operated by Soil Tech. PCB-contaminated sediment from the Waukegan Harbor site in Illinois was successfully treated. The ATP system treated sediments with greater than 500 ppm PCBs with an average PCB removal efficiency of 99.98 percent (Appendix B). Air emissions met the 99.9999 percent destruction removal efficiency (DRE) stack emission requirement for final destruction of PCBs.

Low-Temperature Thermal Desorption

Low-temperature thermal desorption (LTTD) is a readily available commercial technology in Washington that can include mobile units for the treatment of soils, and potentially dried sediments. LTTD is applicable to PAHs and semivolatile organic compounds. However, PCBs and dioxins are not readily destroyed by this process and metals are unaffected. LTTD may also not be effective against high-molecular weight semivolatile organic compounds and TBT. Thus the technology may have limited application for the LDW.

Vitrification

Vitrification is a process in which high temperatures (2,500 to 3,000 °F) are used to destroy organic chemicals by melting the contaminated soil and sediments into a glass aggregate product. Vitrification units can be operated to achieve 99.9999 percent destruction and removal efficiency requirement for PCBs and dioxin. Trace metals are trapped within the leach-resistant inert glass matrix. PAHs and semivolatile organic compounds are also destroyed. Various types of vitrification units exist that utilize different techniques to melt the sediments, including electricity and natural gas, and are discussed in detail below.

Vitrification is one process that has been recently developed into a full-scale operation that is effective in PCB and dioxin destruction (McLaughlin et al. 1999; Minergy 1999, 2002a, 2002b; GTI 2003). Three specific sub-process options are discussed below.

Plasma Vitrification Process. This process involves superheating air by passing it through electrodes of the plasma torch. Partially screened and dewatered sediment is injected into the plume of the torch and heated rapidly. After dredging, sediment must be dewatered to approximately 50 percent solids. Additional drying is required to further reduce moisture. Rotary steam tube dryers or other indirectly heated drying systems are used for this purpose. The high temperature combusts and destroys all the organic contaminants and the mineral phase melts into a glass matrix. Fluxing agents such as calcium carbonate, aluminum oxide, and silica oxide are blended with the sediment, as needed, to obtain the desired viscosity of the molten glass. The molten glass is quickly quenched, resulting in a product suitable for a wide range of applications, such as roof shingle granules, industrial abrasives, ceramic floor tile, cement pozzolan and construction fill. The Westinghouse Plasma vitrification process described above is an example of this specific process, and a similar facility is currently being constructed at the Hanford Nuclear Reservation. Because of the high cost of treatment relative to the two other processes below, plasma vitrification is not retained for further evaluation.

Glass Furnace Technology. This process uses a state-of-the-art oxy-fuel-fired glass furnace to vitrify sediment into an inert glass aggregate product. Sediment is dewatered and partially dried before being fed into the glass furnace. The high temperature melts the sediments, resulting in a homogenous glassy liquid. Additives such as calcium carbonate, aluminum oxide, and silica oxide are added to obtain the desired viscosity of molten glass. The molten glass is collected and cooled quickly in a water quench to form glass aggregate product. The final glass product has a wide range of industrial applications, such as roof shingle granules, industrial abrasives, ceramic floor tile, cement pozzolan and construction fill. The glass furnace vitrification process developed by Minergy under the SITE program for the Lower Fox River RI/FS, is an example of this specific process. The sediments treatment demonstration project was completed in 2001 under the EPA's Superfund Innovative Technology Evaluation (SITE) program.

Cement-Lock® Technology. This process involves vitrification of sediment and proprietary modifiers in a natural gas-fired melter to form a matrix melt. Organic and volatile compounds in the sediment are destroyed as a result of high temperature in the melter. The melt, which contains heavy metals present in the contaminated sediment, is quickly quenched. The metals are trapped in the matrix of the melt and are immobilized. The solidified melt is crushed, pulverized and mixed with appropriate additives to yield construction-grade cement as a product for beneficial use. As mentioned earlier, full-scale demonstration of this vitrification process is underway for the Ports of New York and New Jersey under the SITE program, although technical difficulties have prevented start-up (E. Stern, personal communication).

Although the volumes of material expected to be dredged from the LDW are substantially less than those used to justify melters for the Port of New York and Lower Fox River, these innovative technologies are retained for further evaluation during the FS process.

10.4 Retained Treatment Technologies

The effectiveness and implementability evaluations of the treatment technologies discussed in this section are summarized in Tables 10-2 and 10-3. The retained technologies may be applicable to all or portions of the areas within the LDW. The basis for retaining the technologies is provided below.

10.4.1 Effectiveness

All the retained technologies have been effective to some degree based on full-scale testing and pilot-scale testing in treating LDW COPCs. Potential disadvantages of incineration and both high- and low-temperature thermal desorption include difficulty in treating fine-grained and high moisture content sediments, as well as the concern for potential air releases of dioxins and furans during combustion. Vitrification has the ability to treat fine-grained sediments effectively but high moisture content adversely affects the treatment process. Soil washing and separation may be very effective for high solids/sandy sediments, but are less effective treating low solids content and fine-grained sediments. High contaminant concentrations and organic content reduce the effectiveness of treatment by separation. High contaminant concentrations and high water content increase the project costs for treatment by solidification.

10.4.2 Implementability

All the retained technologies are technically implementable. Of the technologies retained, mobile units are available for separation, soil washing, incineration, and both high- and low-temperature thermal desorption. Incineration, high- and low-temperature thermal desorption, separation and solidification have been demonstrated as full-scale applications, while soil washing and vitrification have not been demonstrated as full-scale technologies. Vitrification may receive further consideration later in the LDW FS process as data become available from the plasma vitrification facility under construction at the Hanford site. Potential disadvantages for soil washing, separation and solidification include disposal of by-product waste streams in regulated landfill. Both the BioGenesis and Cement-Lock® processes are retained as innovative technologies.

10.4.3 Cost

With the exception of incineration, costs for other retained technologies are low to moderate relative to incineration, which is considered to be a high-cost technology. As noted in Ecology's evaluation of treatment technologies in the MUDS program (Ecology 2001b), the volume/long-term supply of sediments to be treated, and local market for beneficial use products, determine the unit cost for treatment. For the LDW FS, re-sale of treated sediments for a beneficial use should not be factored into the costs of a treatment alternative. There are no demonstrated market-uses for treated dredged sediments, and no reliable data on which to base re-sale estimates. In-water beneficial use for sediments below the Dredged Material Management Program (DMMP) guidelines would not be characterized as re-sale but would save costs compared to landfill disposal. Potential costs savings for upland use could be evaluated only if a specific use option can be arranged. If use cannot be successfully arranged, or if treatment cannot attain use standards, treated sediments still must be landfilled and that cost must be considered.

Table 10-1 Documents and Publications

Documents and Publications	Source
Remediation of Contaminated Sediments Handbook	EPA Center for Environmental Research Information, Cincinnati, Ohio, EPA 625/6-91/028
Sediment Remediation Techniques for Contaminated Sediment	EPA Office of Water and Office of Research and Development, EPA-823-B93-001, June 1993
National Conference on Management and Treatment of Contaminated Sediments	EPA Office of Research and Development, EPA/625/R-98/001, August 1998
In-Situ Treatment of Contaminated Sediments	Renholds, J., 1988, EPA Office of Solid Waste and Emergency Response, Technology Innovation Office, Washington, D.C., http://clu-in.org
Assessment and Remediation of Contaminated Sediments (ARCS) Program, Remediation Guidance Document	EPA, Great Lakes National Program Office, EPA 905-B94-002, October 1994
Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes	Averett, D. E., B. D. Perry and E. J. Torrey, 1990, USACE Miscellaneous Paper EL-90-25, USACE Waterways Experiment Station, Vicksburg, Mississippi, http://www.epa.gov/glnpo/arcs/EL-90-25/EL-90-25.html
Dredging, Remediation, and Containment of Contaminated Sediments	Demars, K. R., G. N. Richardson, R. Young and R. Chaney, 1995, American Society for Testing and Materials Publication STP 1293
Innovative Dredged Sediment Decontamination and Treatment Technologies	USACE, ERDC TN-DOER-T2, December 2000
Remediation Technologies Screening Matrix and Reference Guide, Second Edition	DOD Environmental Technology Transfer Committee, NTIS PB95-104782
Contaminated Sediments in Ports and Waterways – Cleanup Strategies and Technologies	Committee on Contaminated Marine Sediments, Marine Board, Commission on Engineering and Technical Systems, National Research Council, National Academy Press, Washington D.C., 1997, Electronic version also available via internet at http://www.nap.edu/books/0309054931/html/index.html
SEDTEC: A Directory of Contaminated Sediment Removal and Treatment Technologies	Environment Canada Remediation Technologies Program, Ontario Region, Canada
Feasibility of a Large-Scale Facility for Treatment of Contaminated Sediments in Puget Sound	Report prepared by Science Applications International Corporation for the Washington Department of Ecology, Olympia, Washington, March 2001
Final Report, Contaminated Sediment Treatment Alternatives Analysis	Report prepared by Hart-Crowser for the Washington Department of Natural Resources, Olympia, Washington, June 2001
Fast Track Dredged Material Demonstration for the Port of New York and New Jersey	EPA, USACE New York District and the US Department of Energy Brookhaven National Laboratory, 1999, *Report to Congress on the Water Resources and Development Acts of 1990 (Section 412), 1992 (Section 405C) and 1996 (Section 226)*, EPA 000-0-99-000, December 1999

Table 10-1 Documents and Publications

Documents and Publications	Source
CERCLA Feasibility Studies	
Hudson River PCBs Reassessment Feasibility Study	EPA Region 2 and the USACE Kansas City District, 2001, Prepared by TAMS, Inc., Feasibility Study available on the web at http://www.epa.gov/hudson/feasibility.htm#study
Lower Fox River and Green Bay, Wisconsin Feasibility Study	RETEC, 2002, Prepared for the Wisconsin Department of Natural Resources, Madison, Wisconsin, Feasibility Study available on the web at http://www.dnr.state.wi.us/org/water/wm/foxriver/feasabilitystudy.html
Websites and Databases	
Assessment and Remediation of Contaminated Sediments (ARCS) Program Publications	http://www.epa.gov/glnpo/sediment/reports.html
Superfund Innovative Technologies Evaluation (SITE)	http://www.epa.gov/ORD/SITE
Hazardous Waste Clean-Up Information (CLU-IN)	http://clu-in.org
USACE Center for Contaminated Sediments	http://el.erdc.usace.army.mil/dots/ccs/

Table 10–2 Effectiveness and Implementability Evaluation of Treatment Process Options

GRA	Technology Type	Process Option	Effectiveness				Implementability		
			Applicable to Site COCs				Applicable to Site Conditions	Commercially Demonstrated at Similar Scale	Innovative Technology
			Metals	PCBs	Semivolatile Organics	TBT			
In Situ Treatment	Biological	*In Situ* Slurry Biodegradation	–	±	±	±	—	—	—
		In Situ Aerobic Biodegradation	–	±	+	±	—	—	—
		In Situ Anaerobic Biodegradation	–	±	+	±	—	—	—
		Aqua MecTool™ Oxidation	–	+	+	+	√	—	—
		In Situ Oxidation	–	–	–	–	—	—	—
		Electrochemical Oxidation	–	–	–	–	—	—	—
	Physical Extractive Processes	Sediment Flushing	+	+	+	+	—	—	—
		Air Sparging	–	–	–	–	—	—	—
		In Situ Slurry Oxidation	–	±	–	±	—	—	—
	Physical Immobilization	Aqua MecTool™ Stabilization	+	+	+	–	√	—	—
		Vitrification	+	+	+	+	—	—	—
		Imbiber Beads™	–	+	+	–	—	—	—
		Ground Freezing	–	–	–	–	—	—	—
Ex–Situ Treatment	Biological	Landfarming/Composting	–	±	+	±	—	—	—
		Biopiles	–	±	+	±	—	—	—
		Fungal Biodegradation	–	±	+	±	—	—	—
		Slurry-phase Biological Treatment	–	±	+	±	—	—	—
		Enhanced Biodegradation	–	±	–	±	—	—	—
	Chemical	Acid Extraction	+	–	+	not reported in FRTR	—	—	—
		Solvent Extraction	–	+	+	not reported in FRTR	—	—	—
		Dechlorination Solvated Electron Technology (SET™)	–	+	+	not reported in FRTR	√	—	—
		Peroxide and Ferrous Iron Treatment	–	+	+	not reported in FRTR	√	—	—
		High Energy Electron Beam Irradiation	–	+	+	not reported in FRTR	√	—	—
	Chemical/Physical	Dehalogenation	–	+	–	–	√	—	—
		BioGenesis℠ Advanced Sediment Washing	+	+	+	–	√	—	√
		Sediment Washing/Fractionation	–	–	–	not reported in FRTR	—	—	—
		Radiolytic Dechlorination	–	–	–	–	—	—	—
		Slurry Oxidation	–	–	+	not reported in FRTR	—	—	—
		Reduction/Oxidation	–	–	+	not reported in FRTR	—	—	—
	Physical	Separation	+	+	+	+	√	√	—
		Solar Detoxification	+	–	+	–	√	—	—
		Solidification	+	+	+	+	√	√	—
	Thermal	Incineration	–	+	+	+	√	√	—
		High Temperature Thermal Desorption	–	+	+	+	√	√	—
		Pyrolysis	–	+	+	+	—	—	—
		Low Temperature Thermal Desorption	–	+	+	+	√	√	—
		Vitrification	+	+	+	+	√	—	√

Notes:

Federal Remediation Technologies Roundtable (FRTR) – Remediation Technologies Screening Matrix and Reference Guide, Version 4.0 used as reference to determine effectiveness of technology for Site COCs

+ Potentially effective and applicable to LDW COPCs

– Not effective or applicable to LDW COPCs

± Potentially effective, but not within an acceptable time frame for LDW COPCs

Table 10-3 Effectiveness, Implementability, and Cost Considerations for Treatment Process Options

GRA	Technology Type	Process Option	Effectiveness		Final Screening				
			LDW COPC	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	Cost[1]
In Situ Treatment	Biological	*In Situ* Slurry Biodegradation	Biodegradation has not been demonstrated to effectively remediate metals, PCBs, or TBT within a reasonable time frame.	Eliminated	—-	—-	—-	—-	—-
		In Situ Aerobic Biodegradation	Biodegradation has not been demonstrated to effectively remediate metals, PCBs, or TBT within a reasonable time frame.	Eliminated	—-	—-	—-	—-	—-
		In Situ Anaerobic Biodegradation	Biodegradation has not been demonstrated to effectively remediate metals, PCBs, or TBT within a reasonable time frame.	Eliminated	—-	—-	—-	—-	—-
		Aqua MecTool™ Oxidation	Technology is effective for PCBs, SVOCs in soils. Process should be effective for TBT, but not metals.	Retained for further consideration	Could be applicable to conditions in LDW. Requires treating sediments in place using caisson and proprietary injectors.	Not demonstrated in pilot- or full-scale sediment projects. Technical difficulties in field trials injecting high air flows into caisson with standing water while preventing generation of TSS.	Not considered innovative or available during LDW FS	Eliminated	—-
		In Situ Oxidation	Has not been demonstrated to be effective for LDW COPCs in sediments.	Eliminated	—-	—-	—-	—-	—-
		Electro-chemical Oxidation	Applicability for use in water is not known. No demonstrated sediment application.	Eliminated	—-	—-	—-	—-	—-
	Physical-Extractive Processes	Sediment Flushing	Bench scale effectiveness for all LDW COPCs	Retained for further consideration	Potentially applicable to LDW. Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles.	No known pilot or full-scale applications.	Not considered innovative or available during LDW FS	Eliminated	—-
		In Situ Slurry Oxidation	Not demonstrated in full scale applications effective for LDW COPCs. Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles.	Eliminated	—-	—-	—-	—-	—-
		SVE/Thermally Enhanced SVE/ Bioventing	Technology is applicable to vadose zone soil or dewatered soil.	Eliminated	—-	—-	—-	—-	—-
		Air Sparging	Targets VOCs and other readily degradable organics. Not effective for PCBs, TBT or metals. Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. Possible generation of water quality exceedances through leakage from sheet pile.	Eliminated	—-	—-	—-	—-	—-
	Physical-Immobilization	Aqua MecTool™ Stabilization	Proprietary technology that has been effective in stabilizing metals, PCBs and SVOCs in soil. No data available on TBT, but physical process likely to be effective on butyltins.	Retained for further consideration	Could be applicable to conditions in LDW. Requires treating sediments in place using caisson and proprietary injectors.	Proprietary technology that was tested in a pilot-scale application in Wisconsin with coal tar-contaminated sediments, and found to be not implementable. Previous trials with this technology created water treatment problems inside the caisson.	Not considered innovative or available during LDW FS	Eliminated	—-
		Vitrification	Effective at stabilizing COPCs in soil applications, but requires less than 60% water content. Remaining sediment surface may not provide suitable habitat. No known sediment applications.	Eliminated	—-	—-	—-	—-	—-
		Imbiber Beads™	Potentially applicable to PCBs and SVOCs, not metals. No data on effectiveness with TBT. Not demonstrated for remediation of sediments. Removal and disposal of the blanket is not demonstrated.	Eliminated	—-	—-	—-	—-	—-
		Ground Freezing	Not permanently effective for LDW COPCs. Long term effectiveness in presence of standing water has not been demonstrated. Standing water likely provides a significant sink for cold temperatures and would substantially increase cost.	Eliminated	—-	—-	—-	—-	—-
Ex Situ Treatment	Biological	Landfarming/ Composting	Not effective for metals, PCBs, dioxin or TBT. PAHs and some SVOCs are amenable to aerobic degradation.	Eliminated	—-	—-	—-	—-	—-
		Biopiles	Not effective for metals, PCBs, dioxin or TBT. Used for reducing concentrations of petroleum constituents in soils. Applied to treatment of nonhalogenated VOCs and fuel hydrocarbons. Requires large upland area.	Eliminated	—-	—-	—-	—-	—-
		Fungal Biodegradation	Not effective for metals, PCBs, dioxins or TBT. No known full-scale applications. High concentrations of contaminants may inhibit growth. The technology has been tested only at bench scale.	Eliminated	—-	—-	—-	—-	—-
		Slurry-phase Biological Treatment	Not effective for metals, PCBs, dioxin or TBT. PAHs and some SVOCs are amenable to aerobic degradation. Large volume of tankage required. No known full-scale applications.	Eliminated	—-	—-	—-	—-	—-
		Enhanced Biodegradation	Not effective for metals, PCBs, dioxin or TBT. PAHs and some SVOCs are amenable to aerobic degradation.	Eliminated	—-	—-	—-	—-	—-

Table 10-3 Effectiveness, Implementability, and Cost Considerations for Treatment Process Options

GRA	Technology Type	Process Option	Effectiveness		Final Screening				
			LDW COPC	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	Cost^{1}
Ex Situ Treatment (continued)	Chemical	Acid Extraction	Suitable for sediments contaminated with metals, but not applicable to PCBs or SVOCs. No data on TBT.	Eliminated	—-	—-	—-	—-	—-
		Solvent Extraction	Potentially effective for treating sediments containing PCBs, dioxins, or SVOCs. Not applicable to metals. No data on TBT. Extraction of organically-bound metals and organic contaminants creating residuals with special handling requirements. At least one commercial unit available.	Retained for further consideration	Potentially applicable to dewatered (dry) sediments on the LDW containing primarily organic contaminants such as PCBs. Extracted organic contaminants from the process will need to be treated or disposed. Requires pre-treatment that involves screening of sediments.	Equipment is commercially available, but has not been demonstrated on a project of similar scope and scale.	This technology has been used to demonstrate under the EPA SITE program, but there are no data for similar implementation of this technology for large-scale PCB-impacted sediment. No current or planned projects.	Eliminated	—-
		Solvent Electron Technology (SET™)	Effective for SVOCs and PCBs, but not metals. No data on TBT. Full scale system commercially available for treatment. Mobile units can be set up to meet project requirements. Nationwide TSCA treatment permit for SET™ issued by US EPA for mobile PCB chemical destruction in soils.	Retained for further consideration	Potentially applicable to dewatered (dry) sediments on the LDW. This technology results in destruction of PCBs and other organic contaminants. Operates on a closed loop system and does not produce secondary hazardous waste or off-gas.	Not demonstrated in pilot- or full-scale sediment projects.	—-	Eliminated	—-
		Peroxide and Ferrous Iron Treatment	Oxidation using liquid hydrogen peroxide (H_2O_2) in the presence of native or supplemental ferrous iron (Fe^{+2}) produces Fenton's Reagent which yields free hydroxyl radicals (OH^{-}). These strong, nonspecific oxidants can rapidly degrade a variety of organic contaminants, including SVOCs, PCBs, dioxin and TBT. Not effective for metals.	Retained for further consideration	Potentially applicable to LDW.	Technology is not commercially available nor demonstrated on a project of similar size and scope.	This technology has been used for pilot studies for treating PAH-impacted sediment from Utica Harbor, but there are no data for similar implementation of this technology for PCB-impacted sediment. No current or planned projects.	Eliminated	—-
		High Energy Electron Beam Irradiation	Full scale system commercially available for treatment of PCBs and SVOCs, and process is limited to slurried soils, sediments and sludges. Slurrying is a required pre-treatment for this technology. Not demonstrated to be effective in sediments. Pilot-scale testing has been performed to treat wastewaters with organic compounds. Metals are not amenable to treatment. No data on TBT.	Retained for further consideration	Potentially applicable to slurried sediments in the LDW consisting primarily of organic contaminants such as PBCs.	Equipment is commercially available, but has not been demonstrated on a project of similar scope and scale.	This technology has been used to demonstrate under the EPA SITE program to treat wastewater with organic compounds, but there are no data for similar implementation of this technology for PCB-impacted sediment. No current or planned projects.	Eliminated	—-
	Chemical/ Physical	Dehalogenation	PCB and dioxin-specific technology. Generates secondary waste streams of air, water, and sludge. Similar to thermal desorption, but more expensive. Solids content above 80% is preferred. Technology is not applicable to metals	Eliminated	—-	—-	—-	—-	—-
		Slurry Oxidation	Applicable to SVOCs, but not PCBs or metals. TBT treatment unknown. Large volume of tankage required. No known full-scale applications. High organic carbon content in sediment will increase volume of reagent and cost.	Eliminated	—-	—-	—-	—-	—-
		Reduction/ Oxidation	Target contaminant group for chemical redox is inorganics. Less effective for nonhalogenated VOCs, SVOCs, fuel hydrocarbons, and pesticides. Not cost-effective for high contaminant concentrations because of large amounts of oxidizing agent required.	Eliminated	—-	—-	—-	—-	—-
		BioGenesis^{SM} Advanced Sediment Washing	Pilot-scale testing showed demonstrated effectiveness for metals, SVOCs and PCBs in sediments. Limited data suggests not effective for TBT. High recalcitrant (e.g. PCB) contaminant concentration, increased percentage of fines, and high organic content increases overall treatment costs	Retained for further consideration	Potentially applicable to dewatered sediments on the LDW. Would require upland processing space, storage capacity for dredged sediments, wastewater treatment and discharge. Treated residuals would still require disposal.	Equipment is commercially available, but has not been demonstrated on a project of similar scope and scale. Pilot tests to date have been on less than 1000 cy.	Pilot-scale testing has been performed and full-scale facility in planning stages. Mobile units available for quick setup and takedown time. Continuous flow process designed to process up to 40 cy of sediments per hour for the proposed full-scale system.	Retained as innovative technology for further consideration in the FS	Moderate to High
	Chemical/ Physical	Sediment Washing/ Fractionation	May be effective for metals and SVOCs, but not effective for PCBs. Not an easily-accessible commercial process (limited use in the United States). Process has difficulty with fine-grained sediment.	Eliminated	—-	—-	—-	—-	—-
		Radiolytic Dechlorination	Only bench-scale testing has been performed. Difficult and expensive to create inert atmosphere for full-scale project.	Eliminated	—-	—-	—-	—-	—-
	Physical	Separation	Reduces volumes of COPCs by separating sand from fine-grained sediments. Some bench scale testing has suggested that at high PCB concentrations, the sand fraction retains levels that still require landfilling.	Retained for further consideration	Potentially applicable dredged sediments in the LDW	Separation technologies available and have been used in several programs of similar size and scope.	—-	Retained for further consideration in the FS.	Low
		Solar Detoxification	The target contaminant group is VOCs, SVOCs, solvents, pesticides, and dyes. Not effective for PCBs, dioxins or TBT. Some heavy metals may be removed. Only effective during daytime with normal intensity of sunlight. The process has been successfully demonstrated at pilot scale.	Eliminated	—-	—-	—-	—-	—-

Table 10-3 Effectiveness, Implementability, and Cost Considerations for Treatment Process Options

GRA	Technology Type	Process Option	Effectiveness		Final Screening				
			LDW COPC	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	Cost[1]
Ex-situ Treatment (continued)	Physical (continued)	Solidification	Bench-scale studies have added immobilizing reagents ranging from Portland cement to lime cement, kiln dust, pozzolan, and proprietary	Retained for further	Potentially applicable to LDW.	Lime has been successfully added to dredged material at other projects. Considered for use during	—-	Retained for further consideration in the	Moderate
	Thermal	Incineration	High temperatures result in generally complete decomposition of PCBs and other organic chemicals. Effective across wide range of sediment characteristics. Not effective for metals.	Retained for further consideration	Technically applicable to LDW site conditions. Especially effective and potentially required where COPCs exceed TSCA limits (e.g., PCB > 50 ppm)	Only one off-site fixed facility incinerator is permitted to burn PCBs and dioxins. Metals not amenable to incineration. No data on TBT, but should be effective. Mobile incinerators are available for movement to a fixed location in close proximity to the contaminated sediments.	—-	Retained as high-cost alternative	Very High
		High-temperature Thermal Desorption (HTTD) then Destruction	Target contaminants for HTTD are SVOCs, PAHs, PCBs, TBT and pesticides. Metals not destroyed.	Retained for further consideration	Technically applicable to LDW site conditions. Especially effective and potentially required where COPCs exceed TSCA limits (e.g., PCB > 50 ppm)	Technology readily available as mobile units that would need to be set up at a fixed location in close proximity to the contaminated sediments.	—-	Retained for further consideration in the FS.	High
		Pyrolysis	High moisture content increases treatment cost. Generates air and coke waste streams. Target contaminant groups are SVOCs and pesticides. It is not effective in either destroying or physically separating inorganics from the contaminated medium.	Eliminated	—-	—-	—-	—-	—-
		Low-temperature Thermal Desorption	Target contaminants for LTTD are SVOCs and PAHs. May have limited effectiveness for PCBs. Metals not destroyed. Fine-grained sediment and high moisture content will increase retention times. Widely-available commercial technology for both on-site and off-site applications. Acid scrubber will be added to treat off-gas.	Retained for further consideration	Potentially applicable to LDW	Demonstrated effectiveness at several other sediment remediation sites. Vaporized organic contaminants that are captured and condensed need to be destroyed by another technology. The resulting water stream from the condensation process may require further treatment.	—-	Retained for further consideration in the FS.	Low
		Vitrification	Thermally treats PCBs, SVOCs, TBT, and stabilizes metals. Successful bench-scale application to treating contaminated sediments in Lower Fox River, and in Passaic River.	Retained for further consideration	Potentially applicable to LDW	Not commercially available or applied on similar site and scale.	No known pilot or full-scale applications in sediments planned.	Eliminated	—-
		High-pressure Oxidation	Predominantly for aqueous-phase contaminants. Wet air oxidation is a commercially-proven technology for municipal wastewater sludges and destruction of PCBs is poor. Supercritical water oxidation has demonstrated success for PCB destruction in bench- an	Eliminated	—-	—-	—-	—-	—-

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[1] Costs indicated here are relative to incineration costs.

11 Disposal

Disposal technologies are coupled with removal and/or treatment actions, and may include on-site, off-site, and beneficial use[15] options for sediments removed from the LDW. On-site disposal options can include contained aquatic disposal, a confined disposal facility, or an on-site upland disposal facility. Off-site technologies include construction of an upland containment facility, transport to regional landfills, or potentially beneficial use such as industrial/commercial fill. An additional potential option includes disposal of sediments at the DMMP open-water disposal site in Elliott Bay if the sediments have been treated to concentrations that are at or below the DMMP disposal criteria. Regional landfill and disposal options are discussed below.

11.1 Resources for Evaluating Sediment Disposal

Disposal facilities and alternatives were comprehensively evaluated as part of the MUDS program. Key documents that are relevant to disposal options available for the LDW include:

- *Standards for Confined Disposal of Contaminated Sediments Development* (Ecology 1990)
- *Multi-User Sites for the Confined Disposal of Contaminated Sediments from Puget Sound* (Ecology 1991a)
- *Multi-User Disposal Sites (MUDS) for Contaminated Sediments from Puget Sound – Subaqueous Capping and Confined Disposal Alternatives* (USACE 1997)
- *Puget Sound Confined Disposal Study Programmatic Environmental Impact Statement* (USACE et al. 1999)
- *Multi-User Disposal Site Investigation* (Ecology 2001a)
- *Puget Sound Confined Disposal Site Study, Washington* (USACE 2003).

11.2 On-Site Disposal

On-site disposal options include level-bottom capping, contained aquatic disposal, and confined disposal facilities. Examples of each of these are shown in Figure 7-1. In addition, an on-site landfill could be constructed along the LDW.

Level bottom capping involves the mounding of contaminated sediment in an area of a water body that has a relatively flat bottom. Capping material is then placed on top of the mounded sediments to isolate contaminants. The cap must be designed to prevent scour and erosion. Level bottom caps have typically been constructed in large water

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[15] Beneficial use may be more accurately considered as an alternative to disposal options. It is included in this section as a consideration for final placement of dredged material.

bodies such as oceans or lakes. Applications in river systems are uncommon because of water depth requirements for navigation and recreation, as well as the potential scouring that can occur during high flow periods. Level bottom caps are more commonly used on the east coast, and in particular Long Island Sound. There are no level bottom caps in Puget Sound.

Contained aquatic disposal is similar to level-bottom capping, with the exception that the contaminated sediments have lateral sidewall containment from an engineered berm or as a result of excavating a depression at the disposal site (Figure 7-1). As with level-bottom capping, the cap must be designed to prevent scour, erosion, and bioturbation. Contained aquatic disposal applications in river systems are less common because of water depth requirements for navigation and recreation, as well as the potential scouring that can occur during high-flow periods. One of the first examples of a CAD site occurred in 1984, when contaminated fine-grained sediment dredged from the LDW navigation channel between Kellogg Island and the Duwamish Diagonal CSO and storm drain was disposed of in a borrow pit in the West Waterway; that material was capped with clean sand dredged from the LDW's upper turning basin (Sumeri 1984, 1989; USACE 1994). As recently as 1995, monitoring demonstrated that the capped contaminated sediment remained effectively isolated (USACE et al. 1999). In addition, contained aquatic disposal was recently used for contaminated sediments dredged from a combined CERCLA cleanup action and navigation dredge project at the Puget Sound Naval Shipyard in Bremerton, Washington.

A **confined disposal facility** is an engineered containment structure that provides for dewatering and permanent storage of dredged sediments. In essence, confined disposal facilities feature both solids separation and landfill capabilities (EPA 1994a). Containment of contaminated sediments in confined disposal facilities is generally viewed as a cost-effective remedial option at Superfund sites (EPA 1996b). Interest in confined disposal facilities for disposal of contaminated dredged sediment has led both the USACE and the EPA to develop detailed guidance documents for their construction and management (USACE 1987, 2000; EPA 1994, 1996; Averett et al 1988; Brannon et al 1990).

Confined disposal facilities for contaminated sediments have an excellent track record in Washington State. These include the Milwaukee Waterway in Tacoma, the Eagle Harbor East Operable Unit in Winslow, Terminal 90-91 in Elliott Bay, Pier 1-3 in Everett, and the recent Blair Waterway Slip 1 nearshore confined disposal facility.

An **on-site** landfill for dewatered contaminated sediments could be constructed within the LDW Superfund site boundaries. Under CERCLA, an on-site landfill would not be required to obtain permits, but would have to meet the substantive requirements for either a Subtitle D or Subtitle C landfill, as described in Section 11.3, below.

11.3 Regional Upland Disposal Alternatives

A key conclusion of the MUDS Feasibility Study Phase Final Report (USACE 2003) was that there is ample capacity for environmentally acceptable and cost-effective management of contaminated marine sediment at existing solid waste landfills within the region. Unique to EPA Region 10 is the existence of facilities that are licensed to take not only de-watered sediments, but also wet sediments. These are discussed below.

11.3.1 Subtitle D Landfills

There are several off-site Subtitle D solid waste landfills in the region that are licensed to accept non-dangerous sediments as long as they are not classified as dangerous wastes. Nearby facilities include the Olympic View Landfill in Kitsap County, the Greater Wenatchee Regional Landfill in Wenatchee, the Columbia Ridge Landfill in Arlington, Oregon operated by Waste Management, and the Roosevelt Regional Landfill in Klickitat County operated by Allied/Rabanco.

Solid waste landfills in the State of Washington are regulated primarily by local health departments under the authority and requirements of the Minimum Functional Standards for Solid Waste Handling (WAC 173-304), the Solid Waste Handling Standards (WAC 173-350), Criteria for Municipal Solid Waste Landfills (WAC 173-351), and the Resource Conservation and Recovery Act (Subtitle D). WAC 173-304(100) identifies “dredge spoils resulting from the dredging of surface waters in the state where contaminants are present in the dredge spoils at concentrations not suitable for open water disposal and the dredge spoils are not dangerous wastes…” as problem wastes. It further defines problem wastes as being a category of waste that is accepted at solid waste landfills. Dangerous wastes in the State of Washington are defined in WAC 173-303, Dangerous Waste Regulations. In general, sediment that is not eligible for open-water disposal and will pass the Toxicity Characteristic Leaching Procedure (TCLP) test as defined in WAC 173-303, can be disposed of in a solid waste landfill.

Subtitle D Landfills Licensed to Take Dewatered Sediments

Generally, disposal of sediments at most Subtitle D landfills (see following section) requires that the sediment be dewatered so that it will pass the paint filter test for free water. This is true for both the Olympic View Landfill and the Greater Wenatchee Regional Landfill. Dewatering of the sediments is required for both transport and disposal of the dredged material so a dewatering facility needs to be present at the point where the wet sediments are offloaded from the haul barge to the shore. The most economical dewatering facility is an area along the shoreline where the sediments can be stored for some period of time while free water drains from the sediments and is collected. Perimeter berms are common as well as a low-permeability liner or pavement to prevent water from leaching outside of the collection area.

Subtitle D Landfills Licensed to Take Wet Sediments

There are two solid waste landfills in the region that are licensed to accept sediments that have excess water, or wet sediments. The Roosevelt Regional Landfill operated by Allied/Rabanco and the Columbia Ridge Landfill operated by Waste Management both have received exemptions from state, federal, and county requirements to accept sediments with free water. The amount of free water that is acceptable over a certain time period is written into the operating permit of the landfills. The free water is utilized to enhance the moisture condition of the landfill, providing greater compaction ratios and increasing methane production in the landfill. Transport of the wet sediment is required to be by closed-container rail only, with local trucking permitted only on the landfill property.

Handling wet sediments requires that a sediment offloading/transfer facility be available for use to directly transfer wet sediments from the haul barge to a lined rail car. Until recently, Allied/Rabanco had an active sediment offloading facility at Terminal 25 (T-25) along the East Waterway at the mouth of the Duwamish River, but that lease expired in 2005. They are actively pursuing an alternative location in the local area, and are currently in negotiation on at least one site. They expect to be able to fulfill their contracted acceptance of dredged material for the '05-'06 dredging season, and are intending to remain operational after that. Waste Management is currently operating a temporary barge offloading and rail loading facility on Harbor Island through 2005. They have indicated that their intention is to have a facility present in the future.

Barge offloading/rail loading facilities have also been constructed for specific projects if a facility is not available or not economical. Such a facility was constructed for dredging work on the Hylebos Waterway in Tacoma. The facility consists of a dock with either a ramp so that a loader can be driven onto the barge, or a crane with a dredge bucket for offloading the wet sediments. Sediment storage is provided by a lined bermed area, and rail access is extended to the facility to move rail cars in position to load the wet sediments.

11.3.2 Subtitle C and TSCA Landfills

There are several possible waste designations that have special landfilling requirements: Washington State Dangerous Waste, TSCA remediation waste, and Resource Conservation and Recovery Act (RCRA) listed or characteristic waste. Sediments containing PCBs at concentrations greater than 50 ppm are considered hazardous wastes under TSCA, and are by law required to be either disposed of in an approved TSCA landfill or destroyed. However, if EPA approves of a risk-based option (40 CFR 761.61(c)) for PCB remediation waste, solid waste landfills or RCRA Subtitle C hazardous waste landfills may also be used, if consistent with the disposal facility's permit and state regulations. Sediments that meet the definition of RCRA hazardous waste must meet the RCRA land ban requirements prior to disposal, which may require treatment of the sediment prior to disposal. Chem-Waste Management operates a Subtitle C and TSCA-approved landfill in Arlington, OR, that is adjacent to its Subtitle D Columbia Ridge Facility. Unlike the Subtitle D facility, the sediments must pass the paint-filter test in order to enter the TSCA-permitted facility.

11.4 Post-Treatment Disposal Alternatives

Sediments that have undergone *ex situ* treatment that do not pass DMMP criteria for open-water disposal still require disposal in an acceptable facility or must have a beneficial use for the volumes of material generated. Sediments that pass DMMP criteria for open-water disposal are not currently regulated as solid waste under state regulations but are subject to other requirements. Upland uses identified by treatment vendors during the MUDS program included use as sand, top soil, cement, lightweight aggregate, fill, landfill cover, and glass (Ecology, 2001a). That same document also indicated that sand, topsoil, cement, and lightweight aggregate are the most regionally acceptable beneficial uses.

To date, beneficial uses of dredged sediments have not been thoroughly investigated or implemented. Regulation and permitting of beneficial use of treated dredged sediments may include federal, state, and local county/city regulations, depending upon the designated beneficial end use. The primary considerations include:

- Whether the treated dredged material (DM) is defined as a solid waste under Washington State law
- Whether it would be used within the LDW CERCLA site boundaries
- Whether the intended use is in-water (e.g., habitat creation, capping material)
- Whether it would be used in an upland setting (e.g., fill, road construction, cement, composting).

In all cases, federal, state and local laws are clear in stating that any beneficial use of treated dredged sediments must not result in an unacceptable risk to human health or the environment, and must not be used in a manner that results in the degradation of application-site conditions (i.e., soil, surface water, groundwater, and air).

11.4.1 Solid Waste Determination for Treated Dredged Material

The first determination for beneficial use is whether treated dredged material is classified as a solid waste. Under Washington State law, a dredged material is defined as a solid waste if it has been designated as unsuitable for open-water disposal (WAC 173-350-040 of the Solid Waste Handling Standards). For evaluating potential treatment technologies, the DMMP Screening Levels (SL)[16] would be used to define whether the material is a solid waste. Treated material that meets these screening levels may be a candidate for in-water beneficial use, if the material can also be shown to meet the Washington State Sediment Management Standards (WAC 173-204). Treated sediment that exceeds the DMMP SL may qualify for upland use, but would require a more stringent set of permit requirements.

11.4.2 In-Water Beneficial Use

Beneficial in-water use of treated dredged material could potentially include its use as capping material, cover material to enhance natural recovery, habitat creation (elevating bathymetry), or simply used to fill and cover the dredge prism to restore the pre-removal contours. The physical properties of the treated material may limit its applicability to some of these potential use options. For in-water beneficial use, the

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[16] While under the DMMP guidelines, a material that exceeds the SL but passes the toxicity tests could be suitable for open-water disposal, and thus also not be considered a solid waste.

treated sediments would need to be below both the DMMP guidelines, and the Washington Sediment Management Standards.

In-water beneficial use would also require that the treated sediments have not been altered in a way that rendered them unsuitable for biological re-colonization (Stephanie Stirling, USACE; personal communication). How this would be applied has yet to be determined by DMMP. All treatment methods would result in changing at a minimum the physical condition of the sediment, reducing or destroying its organic carbon content. In addition, chemical treatment processes used in enhanced sediment washing technologies may result in residual surfactants and oxidants in the treated sediments. In this latter case, Ecology and EPA would need to determine if the chemical treatment residuals would still allow for in-water use. Chemical and/or biological testing of the treated material would likely be required.

Permits required would depend upon whether the treated dredged material was returned to within the LDW CERCLA site boundaries (no permits required), or whether the material would be applied off-site. While the latter case is unlikely, permit requirements would include a Clean Water Act (CWA) 404(b)(1) permit from the Corps, a CWA 401 Water Quality Certification from Ecology, a Hydraulic Permit Approval from the Washington Department of Fish and Wildlife, and an Endangered Species Act Consultation with the USFWS. Application of the material back into the CERCLA Site boundaries of the LDW would not require permitting however, the substantive requirements of each of the permits listed above would still need to be addressed and reviewed by the DMMP.

If an on-site use application could not be identified, treated material that passes PSDDA suitability criteria could be disposed of at the open-water disposal site in Elliott Bay (requiring permitting), provided that the material met the DMMP disposal criteria. Although technically feasible, whether it is administratively feasible will be determined in later evaluations.

11.4.3 Upland Beneficial Use

Uplands beneficial use could potentially include using the treated material as structural fill, incorporating it into cement or asphalt, composting it, or blending it with other humic materials and selling it as a commercial soil mixture. As with in-water use, the physical properties of the treated material may limit its applicability to some of these potential use options. The Washington State Solid Waste Management Reduction and Recycling Act, (RCW 70.95) assigns Ecology the responsibility for overseeing solid waste regulations, but under state rule, the county health departments are assigned the permitting and oversight responsibilities.

There are no defined treatment standards for beneficial use for sediments. The state’s Solid Waste Management policy simply states that the material must be protective of human health and the environment, and meet the requirements of the Anti-Degradation Policy for surface water and groundwater (RCW 90.48 and 90.54). While the state’s rule does not contain any cross-reference to the Model Toxics Control Act cleanup standards, both King County and Pierce County incorporate the Model Toxics Control

Act (WAC 173-340) by reference into their respective management plans and permit processes.

MTCA Method B would be used to establish treatment standards that would be protective of human health and the environment. Human health treatment standards for unrestricted use would need to be based upon a lifetime cancer risk of less than 1 in 1,000,000, and a hazard index of less than 1. Treatment standards protective of wildlife would follow WAC 173-340-7490 and 7494. Finally, any treatment standards would need to meet the Anti-Degradation Policy for Surface Water and Groundwater (RCW 90.48 and 90.54) and the treated residual would at a minimum need to meet soil cleanup levels protective of groundwater.

Permitting would require at a minimum the local county health department permit issued pursuant to RCW 70.94.1. Additional permits would depend upon the use and placement of the treated dredged material. For example, treated dredged material that might be used at a composting facility or blended into a commercial soil product would require only the local county permit if not defined as a solid waste, but may require an additional state permit. Material to be used as fill that was defined as a solid waste under the Washington State rule would require the county permit, as well as a Washington State Limited Purpose Landfill Permit (WAC 173-350-400). In addition, if the intended fill use was in the vicinity of, or drained to a wetland or designated water of the United States, a federal 404(b)(1) permit and the 401 Water Quality Certification would be required.

11.5 Retained Disposal Technologies

All of the disposal technologies discussed are retained for potential consideration.

11.5.1 Effectiveness

The effectiveness of a disposal technology depends upon the residual concentrations of COPCs in the dredged or treated sediments. Subtitle D landfills are suitable for all contaminants that do not designate as State dangerous waste, RCRA hazardous waste, or TSCA remediation waste, as described in Sections 11.3.1 and 11.3.2. Two regional landfills accept wet sediments, but the effectiveness (and implementability) of this disposal option will depend upon the availability of transfer facilities operating on the LDW. Subtitle C landfills are reserved for sediments exceeding TSCA limits. Beneficial use would be a potential application for treated materials. These would need to meet MTCA or DMMP guidelines. Contained aquatic disposals must be designed, built and managed for reliable placement and monitoring, and to prevent potential bioturbation, advection of contaminants into the clean contained aquatic disposal cover by groundwater, and from scour by propeller wash or other hydraulic forces in the LDW. DMMP disposal in Elliott Bay would only be applicable for treated sediments that met the DMMP disposal guidelines. In addition, the DMMP would determine suitability of treated material for beneficial use at in-water locations other than the Elliott Bay open-water disposal site (e.g., as capping material or habitat enhancements).

11.5.2 Implementability

All disposal technologies are technically implementable. Confined disposal facilities and contained aquatic disposals may be limited by the lack of suitable sites along and within the LDW.

11.5.3 Costs

Costs range from low where beneficial use can be found for treated sediments or where disposal at the DMMP Elliott Bay site is feasible, too high for sediments disposed of at a Subtitle C landfill. If a beneficial use cannot be found for treated sediments, the cost of disposing treated materials into a Subtitle D landfill would be moderate to high. Of the disposal options, Subtitle C disposal would have the highest cost.

12 Summary of Retained Technologies and Next Steps

The intent of this CTM was to identify remedial technologies and process options that could be carried forward for consideration in the LDW FS. As discussed in Sections 1 and 2, this technology screen is based on site conditions and COPCs identified in the Phase 1 RI. For each of the remedial technologies and process options reviewed in Sections 5 through 11, the evaluation was conducted using the effectiveness and implementability criteria consistent with EPA guidance (1988), and defined in Section 1.4. Effectiveness referred to consideration of whether the technology can contain, reduce, or eliminate the COPCs found in the LDW sediments. Technical implementability referred to whether the technology was implementable to conditions known to occur within the LDW, and is both commercially available and has been used on sites similar in scale and scope to the LDW. Finally, innovative technologies were carried forward if they are beginning demonstration-scale programs that are expected to produce useable data within the time frame of the LDW FS.

12.1 Retained Technologies

Based on the analysis presented in this CTM, a list of retained remedial technologies is provided in Table 12-1. The technologies are grouped by GRA and include related process options. A brief summary of each of these by GRA follows:

- **No Action** is retained as a technology, as required by CERCLA and the NCP. No Action could only be selected where site conditions as identified in the RI posed no unacceptable risks to human health or the environment. A No Further Action alternative would be possible only where remedial actions already undertaken at the site have achieved the risk-based RAOs (OSWER 2005), and the site poses no further risks to human health or the environment. Source control will be an important implementability consideration after the residual risk assessment.

- **Institutional Controls** are retained principally as a companion technology for an implemented engineering control alternative, but are not expected to occur as a sole alternative. These would include potential seafood consumption advisories, access/deed restrictions, and LDW use restrictions. Although applicable throughout the LDW, any use restriction can only be made with careful consideration of the current and future industrial and commercial uses of the LDW. Tribal usual and accustomed harvest areas or areas of cultural importance may preclude consideration of institutional controls in some areas of the LDW. These are implementable through local government ordinances, and require resource commitment by those agencies to the selected controls until risk reductions are met and use controls can be lifted. Institutional controls have limited effectiveness, as they are dependent upon education and enforcement.

- **Monitored Natural Recovery**, including the natural processes of burial, transport, physical/chemical degradation, and some expected biological degradation of semivolatile organic compounds, is a retained technology. Expected remedial action goals, time to achieve those goals, and the monitoring requirements for implementation will need to be identified and developed. MNR may need to be combined at a minimum with institutional controls until the risk-reduction goals to be identified in the overall LDW FS process are achieved. MNR may also be combined with more active alternatives such as removal or containment.

- **Enhanced Natural Recovery** is retained as a potential option; both as a component of an alternative, but also for post-dredge residuals management.

- **Containment** (e.g., an *in situ* cap) is retained for further evaluation. The options include a conventional sand cap, sediment cap, armored cap, or composite capping. Reactive caps are retained as an innovative technology. All are considered implementable and effective technologies for the LDW. Factors that will be considered for identifying the type and appropriateness of a cap include the type and concentrations of COPCs, current, depth, vessel traffic, site use (i.e., commercial, recreational, or traditional Native American use), and ecological value of the current habitat.

- **Removal** technologies (i.e., mechanical, hydraulic, excavators and specialty dredging) are all considered implementable and effective, and are potentially applicable to the LDW. Selection of the appropriate dredge technology will be based in part on the physical conditions of the in-place sediments (e.g., presence of debris/rocks, grain size, bulk density), depth of dredging, potential for resuspension of sediments, and environmental impacts. However, the dredging technology selected will be based principally on the type of potential treatment or disposal technology selected. In all cases, the selected dredging technology must be coupled with adequate site characterization, skilled and experienced dredging contractors, and appropriate best management practices and oversight to ensure project success.

- ***In situ*** treatment technologies are not considered implementable or effective for use in the LDW at this time. Although some *in situ* technologies have been shown to be effective for immobilization and reduction of certain chemicals in lab-scale bench tests, there have been no field-demonstrated *in situ* treatment tests that have achieved long-term effectiveness.

- ***Ex situ*** treatment technologies that are potentially applicable to the LDW include sediment washing and separation, physical separation methods, solidification, and thermal options including incineration, high-temperature thermal desorption, and low temperature thermal desorption. All of the retained technologies have been shown to be effective in reducing or immobilizing many of the LDW COPCs, and all are either past the pilot-scale or are in full-scale production at this time (i.e., implementable). However, few of the retained technologies are applicable to all of the COPCs identified within the LDW sediments, but some may be applicable to portions of the site depending on COPC concentrations and clean-to treatment criteria. As noted in Section 2, most of the sediments within the LDW contain a mix of metals, TBT, phthalates, PCBs and PAHs, which will be difficult for any single technology to treat.

- **Disposal** technologies include both on-site and off-site options. On-site alternatives considered effective and implementable include capping, contained aquatic disposal, confined disposal facility, and upland confined fill, as appropriate. The off-site options include existing upland Subtitle C and D landfills for either de-watered or water-loaded sediments, respectively; upland confined fill; or DMMP open-water disposal. Provided contaminated sediments are treated *ex situ* to the appropriate soil standards, sediments may have beneficial commercial/industrial use, as long as they can meet the anti-degradation principle.

The evaluation criteria for the retained technologies are summarized in Table 12-2. These evaluation criteria again include the applicability of the technology or process option, the advantages and disadvantages relative to the technical implementability, the advantages and disadvantages relative to effectiveness, and the relative costs.

12.2 Next Steps

12.2.1 FS Documentation

The identification of candidate technologies and the subsequent list of retained technologies in this memorandum is only the first step in the development of alternatives for consideration in the LDW FS. Following EPA and Ecology approval of this CTM, a more rigorous screening of these retained technologies will be conducted and presented in a *Preliminary Screening of Alternatives Memorandum*. This screening memo will be based upon the results of the continuing Phase 2 RI investigations, including the surface sediment data report, the sediment transport analysis report, and other RI data as they become available. These site-specific data and information will be used to assemble a series of alternatives out of the technologies retained by the CTM. Although a technology may have been screened out during the CTM, this does not preclude reconsideration of a screened technology in subsequent documents, where site-specific information can support reconsideration of that technology. Finally, newer technologies, or technologies overlooked in this evaluation, may be appropriate to evaluate during the *Preliminary Screening of Alternatives Memorandum* or the subsequent LDW FS.

12.2.2 Early Actions

Concurrent with the development of the FS, early actions are being planned and implemented at several other sites in the LDW. Planning for the EAAs, which is documented either in Engineering Evaluation/Cost Analysis reports (EE/CAs) for the actions being conducted under Superfund, or in a Corrective Measures Study (CMS) for the actions being conducted under RCRA will consider the information in this CTM. However, the EAAs need to be cleaned up under accelerated timeframes and involve comparatively small volumes of materials for treatment and/or disposal. When evaluating the effectiveness, implementability, and cost of alternatives at EAAs, additional site-specific information will be considered.

Table 12-1 Summary of Technologies Reviewed and Potentially Applicable to the LDW

General Response Action	Remedial Technology	Process Option
No Action	None	Not Applicable
Institutional Controls	Physical, Engineering or Legislative Restrictions	Fish or Shellfish Consumption Advisories Waterway Use Restrictions Access/Deed Restrictions
Monitored Natural Recovery	Physical Transport	Desorption, Diffusion, Dilution, Volatilization, Resuspension, and Transport
	Chemical and Biological Degradation	Dechlorination or degradation (aerobic and anaerobic)
	Physical Burial Processes	Sedimentation
Enhanced Natural Recovery	Enhanced Physical Burial	Thin-layer sand/sediment placement to augment natural sedimentation rate
Containment	Capping	Conventional Sand Cap Sediment Cap Armored Cap Composite Cap Reactive Cap
Removal	Dredging	Hydraulic Dredging Mechanical Dredging
	Dry Excavation	Excavator (for specific conditions)
Ex Situ Treatment	Chemical/Physical	Sediment Washing
	Physical	Separation Solidification
	Thermal	Incineration High-temperature Thermal Desorption Low-temperature Thermal Desorption
Disposal	On Site	Contained Aquatic Disposal Confined Disposal Facility On-site Confined Fill In-water Beneficial Use
	Off Site	Existing Upland Landfills (C or D) TSCA Landfill Upland Confined Fill (MTCA commercial/industrial) Upland Beneficial Use DMMP Open-Water Disposal

Table 12-2 Review Criteria for Technologies Retained for the LDW

GRA	Technology Type	Process Option	Effectiveness			Implementability			Cost (1)
			COPCs	Advantages	Disadvantages	Site Conditions	Advantages	Disadvantages	
No Action	None	Required by NCP	Applicable to all LDW COPCs.	Applicable to all COPCs. Effective where risk assessment demonstrates low to no risk to human health and environment.	COPCs remain in place.	Applicable throughout LDW where COPC concentrations are low.	(1) Readily implemented with no construction or monitoring requirements; (2) Minimal impact on industrial and shipping uses of waterway.	(1) Requires source controls to be in place.	Low
Institutional Controls	Physical, Engineering, or Legislative Restrictions	Fish and Shellfish Consumption Advisories	Applicable principally to bioaccumulative COPCs such as PCBs and arsenic that pose human health risks through fish or shellfish consumption.	Experience at other sites has shown that consumption advisories can be effective for well-educated public.	(1) Less effective for subsistence ethnic groups who harvest fish or shellfish as a source of protein; (2) Not effective for ecological receptors because COPCs remain in-place.	Applicable to all areas of the LDW.	(1) Implemented through continuing health advisories, sign postings, regular and continued public notices, and enforcement; (2) Minimal impact on industrial and shipping uses of waterway.	(1) Sign postings subject to theft and vandalism. Must also be printed in multiple languages to account for different ethnic uses of aquatic environment; (2) Requires long-term financial commitment to ensure continuing enforcement. (3) May conflict with Tribal ~~usual and accustomed fish~~ treaty rights to harvest fish and shellfish in the LDW.	Low
		Access/Deed Restrictions	Applicable to all LDW COPCs.	Can be effective for protecting human health in smaller tidal and subtidal areas where longer-term natural recovery is expected to occur, or where industrial waterway activities are expected to continue (e.g., under docks, active berths). Land use restrictions can be effective in maintaining the integrity of engineered structures such as caps or CAD sites.	(1) Short-term impacts to human health may continue, and require use in conjunction with consumption advisories and/or other site restrictions; (2) Potentially low levels of short-term effectiveness for ecological receptors because COPCs remain in-place, but can provide adequate long-term protection.	Applicable to all areas of the LDW.	(1) Implemented through laws, zoning restrictions, and/or deed restrictions for upland and in-water uses; (2) Compatible with minimal impact on industrial and shipping uses of waterway; (3) Can be combined with other alternatives (e.g., MNR, ENR) as an interim measure until human health standards are achieved.	(1) Deed restrictions may limit future development of water-related uses, or require removal of COPCs by future developers. (2) May conflict with Tribal historical and cultural uses.	Low
		Waterway Use Restrictions	Applicable to all LDW COPCs.	Can be effective for protecting human health in smaller tidal and subtidal areas where longer-term natural recovery is expected to occur, or where industrial waterway activities are expected to continue (e.g., under docks, active berths).	(1) Short-term impacts to human health may continue, and require use in conjunction with consumption advisories and/or other site restrictions; (2) Not effective for ecological receptors because COPCs remain in-place.	Applicable to all subtidal areas of LDW.	(1) Implemented through laws, zoning restrictions, and/or deed restrictions for in-water uses; (2) Can be combined with other alternatives (e.g., MNR, ENR) as an interim measure until human health and ecological standards are achieved.	(1) Waterway use restrictions for boating, marinas, anchoring, or other waterway-dependent activities for sub-tidal state lands may require Washington legislative action; (2) Waterway use restrictions could negatively impact current and future industrial waterway activities, prevent future development of water-related uses, or require removal of COPCs by future developers.	Low
Monitored Natural Recovery	Chemical/ Physical Degradation	Combination of natural desorption, diffusion, dilution, volatilization, resuspension, and transport	Effective principally to LDW organic COPCs including SVOCs and PCBs. Inorganics not subject to degradation.	Effective where chemical and/or physical degradation of COPCs are demonstrated to occur in the short- and long-term.	(1) Effective where risk assessment demonstrates low to no risk to human health and environment; (2) Physical/chemical degradation demonstrated for SVOCs, but less effective for metals, PCBs, TBT and pesticides; (3) Short-term impacts to human health may continue, and require use in conjunction with consumption advisories and/or other site restrictions; (4) Potentially low level of short-term effectiveness for ecological receptors because COPCs remain in-place, but can provide adequate long-term protection; (5) Requires implementation of long-term monitoring study and risk attainment objectives.	Applicable to all areas of the LDW.	(1) Readily implemented with no construction requirements; (2) Minimal impact on current or future industrial and shipping uses of waterway; (3) May be used in conjunction with other technologies in a combined alternative.	(1) Must be implemented in conjunction with a well-designed, long-term monitoring program; (2) May require future active remediation where MNR risk-expectations are not achieved.	Low
	Biological-Degradation	COPC Metabolization (aerobic and anaerobic)	Effective principally to SVOCs. PCBs and TBT will degrade, but not within an acceptable time frame. Metals will not degrade.	Biodegradation is a demonstrated and proven remedial technology for volatiles and SVOCs. Effective where degradation of COPCs are demonstrated to occur in the short- and long-term.	(1) Biological degradation less effective for PCBs and TBT; (2) Short-term impacts to human health may continue, and require use in conjunction with consumption advisories and/or other site restrictions; (3) Less effective for ecological receptors because COPCs remain in place; (4) Requires implementation of long-term monitoring study and risk attainment objectives.	Applicable in areas with low concentrations of SVOCs in well-mixed sediments.	(1) Readily implemented with no construction requirements; (2) Minimal impact on current or future industrial and shipping uses of waterway; (3) May be used in conjunction with other technologies in a combined alternative; (4) Implemented in areas with biodegradable COPCs.	(1) Must be implemented in conjunction with a well-designed long-term monitoring program; (2) May require future active remediation where MNR risk-expectations are not achieved.	Low

Table 12-2 Review Criteria for Technologies Retained for the LDW

GRA	Technology Type	Process Option	Effectiveness			Implementability			Cost (1)
			COPCs	Advantages	Disadvantages	Site Conditions	Advantages	Disadvantages	
Monitored Natural Recovery (continued)	Physical Burial Processes	Sedimentation/Burial	Effective for all LDW COPCs where concentrations are low.	(1) Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants; (2) Effective for contaminants with low solubility and high sorption where the main concern is resuspension and direct contact.	(1) Requires implementation of long-term monitoring study and risk attainment objectives; (2) Short-term impacts to human health may continue, and require use in conjunction with consumption advisories and/or other site restrictions; (3) Less effective for ecological receptors because COPCs remain in-place; (4) COPCs not actively removed and remain in place.	Applicable where geochronological studies and hydrodynamic modeling demonstrate long-term sedimentation and burial processes are in-place.	(1) Readily applied and demonstrated process; (2) Can be combined with institutional controls until long-term risk-objectives are demonstrated; (3) Minimal impact on industrial and shipping uses of waterway.	(1) Requires long-term monitoring and continuing financial commitment until risk-objectives are achieved; (2) Associated institutional controls may limit future uses of waterway.	Low
		Resuspension and Transport	Effective for all LDW COPCs where concentrations are low.	May result in the reduction of COPCs to concentrations that no longer pose risks to human health or the environment.	(1) Requires implementation of long-term monitoring study and risk attainment objectives; (2) Can result in downstream buildup of COPCs to elevated risk levels; (3) Requires implementation of long-term monitoring study and risk attainment objectives; (4) Short-term impacts to human health may continue, and require consumption advisories and/or institutional controls; (5) Less effective for ecological receptors because COPCs remain in-place; (6) COPCs not actively removed or destroyed.	Applicable where geochronological studies and hydrodynamic modeling demonstrate transport processes are in-place.	(1) Readily applied and demonstrated process; (2) Can be combined with institutional controls until long-term risk-objectives are demonstrated; (3) Minimal impact on industrial and shipping uses of waterway.	(1) Requires long-term monitoring, institutional controls, and continuing financial commitment until risk-objectives are achieved; (2) Associated institutional controls may limit future uses of waterway.	Low
Enhanced Natural Recovery	Enhanced Physical Buria	Thin-layer placement to augment natural sedimentation	Effective for all LDW COPCs where MNR processes are demonstrated.	ENR dilutes COPC concentrations while not resulting in the resuspension and transport of contaminants that occurs with dredging.	(1) Requires implementation of long-term monitoring study and risk attainment objectives; (2) Short-term impacts to human and ecological health may continue, and require use in conjunction with consumption advisories and/or other site restrictions; (3) COPCs not actively removed, but attenuated by addition of clean sediments.	Applies where data and modeling indicate placement of a thin-layer of material, combined with natural recovery processes will result in achievement of risk-based sediment objectives. Particularly useful for critical habitat areas, and/or shallow intertidal areas where active remedial methods could result in unwanted habitat loss. Potentially suitable for management of dredge residuals.	(1) Puget Sound-demonstrated technology with local construction knowledge; (2) Sediment for thin-layer placement readily available.	(1) Requires long-term monitoring, institutional controls and continuing financial commitment until RAOs are achieved; (2) Institutional controls may limit future uses of waterway.	Low
Containment	Capping	Conventional Sand Cap	Applicable principally to PAHs, other SVOCs, metals, and PCBs; Limited applicability to VOCs.	(1) Demonstrated effectiveness for isolating contaminants in the LDW; (2) Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants; (3) Capping does not result in the resuspension and transport of contaminants that occurs with dredging.	(1) Sand cap may be subject to bioturbation and release of buried COPCs; (2) Sand caps may be susceptible to propeller and/or flooding scour, methane generation, and earthquakes; (3) Changes in bed elevation may result in unacceptable ecological impacts to salmonid habitat.	Applicable to subtidal areas where sediments have sufficient bearing strength to support cap, and have low erosive potential. Not suitable for areas where groundwater can advect COPCs into the clean cap surface.	(1) Readily applied and demonstrated technology. Local construction experience; (2) Capping materials readily available from navigation dredging at the Upper Turning Basin.	(1) Requires long-term maintenance and financial commitment; (2) May not be implementable for shallow, intertidal areas where elevation changes would result in unacceptable ecological impacts; (3) May require permanent institutional controls and limit future uses of waterway; (4) Impacts to flooding, stream bank erosion, navigation, and recreation must be addressed in design.	Low to Moderate
		Conventional Sediment/Clay Cap	Applicable principally to COPCs with potentially higher solubilities and lower sorption.	(1) Sediment with high fines (silt and clay) and/or TOC is effective in limiting diffusion of contaminants. Sediment caps are generally more effective than sand caps for containment of contaminants with high solubility and low sorption; (2) Natural TOC present in conventional sediments more effective at adsorbing COPCs such as PCBs.	(1) Clay liners in caps are potentially more susceptible to breaches caused by methane generation through the cap; (2) Caps may be susceptible to propeller and/or flooding scour, methane generation, and earthquakes; (3) Changes in bed elevation may result in unacceptable ecological impacts to salmonid habitat.	Applicable in sections of LDW with low erosion potential and where placement of finer-grained material can be managed. May be useful in nearshore, or intertidal applications where thinner caps with higher sorbtive capacities are required. Sediments must still have sufficient bearing strength to support cap, and have low erosive potential. Not suitable for areas where groundwater can advect COPCs into the clean cap surface.	(1) Readily applied and demonstrated technology; (2) Placement of high TOC and/or high fine sediments minimizes thickness of cap in areas with shallow water depth; (3) Materials readily available through upland sources or from navigation dredging at other systems.	(1) Requires long-term maintenance and financial commitment; (2) May not be implementable for shallow, intertidal areas where elevation changes would result in unacceptable ecological impacts; (3) May require permanent institutional controls and limit future uses of waterway; (4) Impacts to flooding, stream bank erosion, navigation, and recreation must be addressed in design; (5) Utilization of navigation dredged material for capping has potential logistical issues.	Low to Moderate

Table 12-2 Review Criteria for Technologies Retained for the LDW

GRA	Technology Type	Process Option	Effectiveness			Implementability			Cost (1)
			COPCs	Advantages	Disadvantages	Site Conditions	Advantages	Disadvantages	
Containment (continued)	Capping (continued)	Armored Cap	Applicable to all LDW COPCs as described for sand and/or conventional caps.	Effective in combination with conventional caps to isolate contaminants and protect cap against physical erosion and/or bioturbation.	(1) Changes in bed elevation may result in unacceptable ecological impacts to salmonid habitat; (2) Armor rock may be less productive habitat for benthic organisms.	Applicable in conjunction with other cap configurations in areas of LDW, but can be applied where erosion potentials are higher.	(1) Readily applied and demonstrated technology; (2) Armor placement can be used to minimizes thickness of cap in areas with shallow water depth; (3) Armor materials can be combined with habitat-enhancing materials (e.g., "Fish Mix").	(1) Requires long-term maintenance and financial commitment; (2) May not be implementable for shallow, intertidal areas where elevation changes would result in unacceptable ecological impacts; (3) May require permanent institutional controls and limit future uses of waterway.	Low to Moderate
		Composite Cap	Applicable to all LDW COPCs as described for sand and/or conventional caps.	(1) Provides physical isolation of COPCs from the overlying water column; (2) Assists in preventing bioturbation breaches of caps and prevents direct contact between aquatic biota and contaminants; (3) Rigid HDPE layers used in small areas to assist in NAPL containment, control hydraulic gradient, and methane containment and diffusion.	(1) Composite caps at other sites have resulted in catastrophic breaches due to methane generation under the cap; (2) Rigid HDPE layers do not have long-term demonstrated effectiveness; (3) Use of geotextiles may not be necessary for contaminants with low solubility and high sorption where the main concern is resuspension and direct contact; (4) Geotextiles by themselves do not limit advective or diffusive flux of COPCs; (5) Requires long-term monitoring and financial commitment.	Composite caps with impermeable layers such as HDPE are generally applicable where control of NAPL or groundwater movement is needed in a limited area. Composite caps may also be potentially applicable in intertidal areas where physical separation between receptors and COPCs are required, but where minimal change to the slope or bathymetric configuration is needed.	(1) Increasingly applied technology; (2) Placement of geotextile or rigid HDPE can be used to minimize thickness of cap in areas with shallow water depth.	(1) Requires specialty equipment for placement, sinking, and securing to the sediment floor; (2) Tidal ranges in the LDW can affect ability to place materials; (3) Requires long-term monitoring and financial commitment.	Low to Moderate
		Reactive Caps	Potentially applicable to all LDW COPCs as described for conventional sand and/or conventional sediment caps.	Similar to advantages described for other caps. Provides an additional level of contaminant-sorbing materials to caps.	Long-term effectiveness not demonstrated. Retained as innovative technology. Requires long-term monitoring and financial commitment.	Applicable in conjunction with other cap configurations in areas of LDW.	Adds an additional level of environmental protection with contaminant sorbing materials. May allow for construction of thinner caps	(1) Requires specialty equipment for placement, sinking, and securing to the sediment floor; (2) Tidal ranges in the LDW can affect ability to place materials. (3) Requires long-term monitoring and financial commitment; (4) Long-term implementability not demonstrated. Retained as innovative technology.	Low to Moderate
Removal	Dredging	Hydraulic Dredging	Applicable to all LDW COPCs at higher concentrations that either pose unacceptable risks to human health and the environment, and/or serve as sources for downstream recontamination.	(1) Effective removal with lower resuspension and recontamination/residual rate relative to mechanical dredging; (2) Can be readily incorporated into treatment trains such as chemical and/or physical separation.	Requires management of contaminant residuals after dredging.	Applicable in areas with high volumes of low solid sediments, generally less than 20 ft. of water depth and low levels of debris.	(1) Various hydraulic dredges readily available on the West Coast and at least one dredging contractor has equipment on the LDW; (2) More effective lateral and vertical cut control may be achieved, relative to mechanical dredges; (3) High utility when used in conjunction with CDFs; (4) Local experience of use for the Sitcum and Blair Waterway projects.	(1) Hydraulic dredges limited in heavy-debris environments; (2) Environmental hydraulic dredges are depth limited, and difficult to size to accommodate steady solids flow under varying tidal regimes; (3) Requires separation of solids from water, resulting in large volumes of water that may require treatment prior to discharge back to LDW; (4) Treatment facilities must be located near-waterway with enough land space to accommodate retention basins, mechanical dewatering equipment, sand and carbon filtration, and transfer of dewatered material to trucks or trains for transfer to regional landfill; (5) Limited regional construction experience with mechanical dewatering and water treatment facilities.	Moderate to High
		Mechanical Dredging	Applicable to all LDW COPCs at concentrations that either pose unacceptable risks to human health and the environment, and/or serve as sources for downstream recontamination.	Effective for removal in areas with high debris and sediments with high sand or heavy clay content that require digging buckets.	Requires management of contaminant residuals after dredging.	Applicable in areas with high volumes of high percentage solids sediments, including areas with heavy debris, sand and clay. Mechanical dredging is not depth restricted, and not affected by tidal exchange.	(1) Various mechanical dredges, including environmental buckets and clamshells readily available on the LDW and in Puget Sound; (2) Recent construction experience in LDW and Puget Sound with skilled operators; (3) Environmental buckets useful in softer, unconsolidated materials with low debris; (4) Digging buckets (e.g., clamshells) useful in harder clays or compacted sediments, or where debris is high; (5) Existing infrastructure for barge transport, off-loading, and transfer to railcars for transport to regional landfills; (6) Depth and tidal limitations within the LDW do not restrict use of mechanical buckets.	(1) Not all river segments may be accessible to a barge-operated mechanical dredge; (2) Can result in potentially higher resuspension and residual rates than hydraulic dredges; (3) Lower vertical and horizontal operational control relative to hydraulic dredges.	Low to Moderate
	Excavating	Dry Excavating	Applicable to all LDW COPCs. Effective for nearshore and/or intertidal areas where depths limit conventional dredging equipment	(1) Contaminated sediments removed; (2) Residuals can be minimized or eliminated by dry excavation.	Effective only in relatively small and narrow shoreline areas of limited intertidal bands. Requires either only working during low tides, or using coffer dams or sheet pile walls to create a contained, dry area.	Limited in application to nearshore shallow and/or intertidal areas that can be reached from shore or by specialty equipment designed to work on soft, unconsolidated sediments.	Equipment and construction experience in Puget Sound.	(1) Construction costs may involve contingencies to address potential spills and leaks; (2) Runoff water may contain high concentrations of TSS and COPCs.	Low to Moderate

Table 12-2 Review Criteria for Technologies Retained for the LDW

GRA	Technology Type	Process Option	Effectiveness			Implementability			Cost (1)
			COPCs	Advantages	Disadvantages	Site Conditions	Advantages	Disadvantages	
Ex-situ Treatment	Physical	Separation	Applicable to all concentrations of LDW COPCs. Offers greatest utility and cost saving benefits where concentrations of COPCs would otherwise require incineration or Subtitle C disposal. Only applicable to adsorptive COPCs that would adhere to the fine-grained soil.	(1) Demonstrated effectiveness for reduction in volume of highly contaminated sediments with a high percentage of sand-content; (2) Used to increase effectiveness of dewatering dredged material.	(1) Not effective for contaminants with high concentrations and high organic content; (2) Previous work at other sites with PCB-contaminated sediments has shown that PCBs are retained on sand particles (as emulsion), requiring Subtitle D disposal.	Applicable to potential dredge areas containing higher sand content.	(1) Readily implementable, resulting in reduced contaminated sediment volume; (2) Can be combined with soil washing to improve contaminant separation and/or destruction; (3) Mobile units available for quick setup and takedown time; (4) Separated sand may be available for potential beneficial reuse.	If beneficial reuse not identified, will require disposal of separated waste stream at a Subtitle D landfill. Separated fine materials could also require Subtitle C disposal or incineration.	Moderate
	Physical/Chemical	Soil Washing	Applicable to all LDW COPCs. Principal application would be for high volumes of organic-contaminated sediments.	(1) Pilot-scale testing demonstrated ability to take high concentrations of COPCs and treat to equivalent of MTCA soil standards; (2) Potential beneficial reuse for residuals.	(1) Has not been demonstrated at a full-scale production level; (2) Pilot tests to date have treated hazardous waste-level materials. No data on treatment of lower concentrations of contaminants; (3) Effective treatment when starting with high sands materials -- lower effectiveness when treating low solids and high fine-grained sediments; (4) Solid-waste classification in Washington state unclear, which may require disposal of treated materials at a Subtitle D landfill.	Applicable to potential dredge areas containing organic and coarse-grained sediment.	(1) Readily implementable, resulting in reduced contaminated sediment volume; (2) System could be coupled with hydraulic dredging for continuous treatment train; (3) Mobile units available for quick set up and take-down time; (4) Continuous flow process designed to process up to 40 cy of sediments per hour for the proposed full-scale system. (5) May be available for potential beneficial reuse	(1) Not a demonstrated full-scale technology. Only bench and pilot-scale testing done to date; (2) Waste streams include hydraulic-dredge decant water, reagents used in soil washing, and the treated residuals; (3) Water will require filtration and treatment prior to discharge; (4) Treated residuals may require off-site disposal; (5) Volume/long-term supply of sediments to be treated and local market for beneficial use products affect the economics of implementing this technology.	Moderate
		Solidification	Applicable to all LDW COPCs. Principal application would be for high volumes of PCB-contaminated sediments that exceed hazardous waste criteria and would otherwise require incineration or Subtitle C disposal.	(1) Lime has been successfully added to dredged material at other projects; (2) Effective during the dewatering operation to remove excess water and prepare material for disposal.	High contaminant concentration and high water content results in higher project costs.	Applicable to all dredge areas of LDW.	(1) Readily implementable; (2) Reagent materials readily available.	(1) Immobilizing reagents, ranging from Portland cement to lime cement, kiln dust, pozzolan, and proprietary agents, have been applied with varying success. Dependent on sediment characteristics and water content; (2) Contaminants remain in place. Stabilized product requires disposal in regulated landfill.	Moderate
	Thermal	Incineration	Applicable to all LDW organic COPCs where concentrations exceed the hazardous waste designation; principally PCBs > 50 ppm. Would also be effective at destruction of PAHs and SVOCs, but not metals. Principal application would be for low volumes of TSCA-contaminated sediments.	(1) Complete and permanent destruction of organic COPCs; (2) Effective across wide range of sediment characteristics.	(1) Fine-grained sediment difficult to treat; (2) Not effective for treating metals; (3) Dewatering required prior to treatment; (4) Potential for creation of dioxins and furans during incineration.	All LDW sediments above hazardous waste designation.	Readily implementable.	(1) Only one off-site fixed facility incinerator is permitted to burn PCBs and dioxins; (2) Mobile incinerators are available for movement to a fixed location in close proximity to the contaminated sediments; (3) May require an acid gas scrubber for treatment of air emissions.	Very High
		High-temperature Thermal Desorption (HTTD) then Destruction	Applicable to all organic LDW COPCs. Not effective for metals	Thermal desorption and combustion is effective with a range of SVOCs. Target contaminants for HTTD are SVOCs, PAHs, PCBs and pesticides. Destruction of organic compounds occurs within an off-gas chamber or unit that is integrated into the thermal desorption system.	Fine-grained sediment and high moisture content will increase retention times.	Low volumes of dredged sediments that are dewatered to low water content.	Technology readily available as mobile units which would need to be set up at a fixed location in close proximity to the contaminated sediments.	Set-up time may be high depending on the size of the project.	High
		Low Temperature Thermal Desorption	Applicable to all organic LDW COPCs. May be less effective for PCBs. Not effective for metals.	(1) Demonstrated effectiveness at several other sediment remediation sites; (2) Dioxins and furans are not produced as byproducts as heating process is conducted in the absence of oxygen. Acid scrubber will be added to treat off-gas.	(1) Fine-grained sediment and high moisture content will increase retention times; (2) Vaporized organic contaminants that are captured and condensed need to be destroyed by another technology. The resulting water stream from the condensation process may require further treatment as well; (3) Not effective for metals.	Low volumes of dredged sediments that are dewatered to low water content.	Widely-available commercial technology for both on-site and off-site applications.	Set-up time may be high depending on the size of the project.	Low

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Appendix A

RI/FS Integration Memo

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MEMORANDUM

TO: Allison Hiltner, EPA
Rick Huey, WDOE
FROM: John Ryan, Tim Thompson
DATE: May 31, 2005

CLIENT: Lower Duwamish Waterway Group
TASK:
RE: Remedial Investigation/Feasibility Study Integration Memorandum

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Purpose

This Remedial Investigation/Feasibility Study (RI/FS) Integration Memorandum provides a “road map” to the Lower Duwamish Waterway (LDW) FS process and demonstrates how specific activities, memoranda, and decision points associated with the RI, the FS Work Plan, and the FS will be conducted. This memorandum identifies where the FS process can be advanced while data collection and analyses for the RI are on-going. The purpose of identifying and initiating these FS activities at this point in the RI/FS process is to inform the RI while data are being collected, in order to minimize any potential FS data gaps later in the process. In addition, the FS process allows for an expedited evaluation of potential cleanup technologies for the Early Actions and the overall LDW. Given the complexity of the overall LDW project and the high level of public interest regarding cleanup technologies, this memorandum describes a process that allows for advance discussion and consensus building to meet the RI/FS schedule.

The following activities will be conducted in concurrence with the RI, and in advance of the FS Work Plan:

- Review and provide input to the germane Quality Assurance Project Plans (QAPPs) for the RI
- Produce a Candidate Technologies Memorandum
- Produce a Preliminary Screening of Alternatives Memorandum.

The RI/FS integration process is shown in Figure 1, and is discussed below. The rationale for conducting these activities, and early completion of technical memoranda, is to ensure: (1) that data needed to complete the FS are collected during the RI to the extent possible, (2) that any additional data needs be identified in the FS Work Plan, and (3) that the FS is completed within the overall schedule established for the LDW RI/FS. In addition, the integration process identifies where memoranda required by the Administrative Order on Consent (AOC) can be combined to increase efficiency and meet the overall program schedule. The intent of these memoranda is to provide a useful forum to exchange ideas between the Lower Duwamish Waterway Group (LDWG), the United States Environmental Protection Agency (EPA) and the Washington Department of Ecology (Ecology). It is acknowledged that decisions reached in early memoranda may need to be modified as new information becomes available through the RI process.

Background

In December 2000, the City of Seattle, King County, the Port of Seattle, and the Boeing Company [collectively LDWG], signed an Administrative Order on Consent (AOC) with EPA and Ecology to conduct an RI/FS for the LDW. The RI, which includes human health and ecological risk assessments (HHRA and ERA, respectively), and a sediment transport study, is currently underway. The AOC also specifies the content of the FS.

Guidance for the Feasibility Study

The RI/FS work required by the AOC is being conducted under the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the associated National Contingency Plan, and the Washington State Model Toxics Control Act (MTCA). Any identified potential response action in the FS must comply with both laws. The specific documents defining the conduct of the overall FS process include the following:

- Administrative Order on Consent for the LDW
- Clarification of Feasibility Study Requirements (Clarification Letter from LDWG to EPA and Ecology, December 4, 2003)
- *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (USEPA 1988)
- Model Toxics Control Act (MTCA) guidance and criteria for the selection of cleanup actions and content of an FS (Washington Administrative Code [WAC] 173-340-350 through 360).

Additional documents relevant to the conduct of the FS are:

- *A Guide for Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents* (USEPA 1999)
- *A Guide for Developing and Documenting Cost Estimates During the Feasibility Study* (USEPA 2000)
- *A Risk Management Strategy for PCB-Contaminated Sediments* (NRC 2001)
- *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (USEPA 2002)
- *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (OSWER, January 2005, Draft).

The FS will address the LDW as a whole, i.e., on a river-wide basis as defined in the December 4, 2003 clarification letter. The FS will identify and screen remedial alternatives based on the general range of LDW sediment characteristics, waterway conditions, and the chemicals of concern (COCs) identified in the Phase 2 risk assessments (Clarification Letter, December 2003). The detailed analysis of alternatives will provide the information necessary to formulate the Record of Decision (ROD).

Road Map to the FS Process

The general steps in the FS process include (USEPA 1988):

- Establishing remedial action objectives (RAOs)
- Identifying and screening general response actions (GRAs) and remedial technologies that address the GRAs
- Developing and conducting a detailed analysis of remedial alternatives.

Many of the important work products needed to complete the required technical memoranda and the FS are described in the RI/FS Statement of Work (LDWG 2000) and the Phase 2 RI Work Plan (Windward 2003). Although GRAs and candidate remedial technologies to address the GRAs can be identified before the RI is completed, the development and detailed analysis of remedial alternatives cannot occur until the Phase 2 RI and risk assessments are completed, and RAOs are formulated.

The LDW FS framework is presented in Figure 1, which shows the linkages between work being conducted under the RI, the FS technical memoranda and other reports required under the AOC, and proposed Sections 1 through 9 of the FS report. The framework has been constructed to complete FS activities as data, memoranda, and reports become available from the RI. Figure 1 also shows the expected timeline for draft Phase 2 HHRA, ERA, and RI deliverables, as well as the sequencing of the draft FS technical products.

Input to the RI

To ensure that to the degree practicable all data needs for the FS are addressed in the RI, LDWG retained the FS contractor (RETEC) to be an active part of sediment-related information and data generation activities in the RI. To that end, RETEC is providing input to the following QAPPs: Sediment Transport, Surface Sediment Sampling, and Subsurface Sediment Sampling. In addition, RETEC is reviewing relevant RI work, including the Phase 1 RI report, the current database, the bathymetric survey, and shoreline surveys, for adequacy to the FS. In addition, as Early Action reports, plans, or specifications become available on the LDW, these will also be reviewed by RETEC for consideration in development of the FS.

Pre-FS Work Plan Memoranda

Two memoranda will be produced prior to the FS Work Plan:

- Candidate Technologies Memorandum
- Preliminary Screening of Alternatives Memorandum.

Production of these memoranda before the FS Work Plan will fulfill three functions: (1) meet requirements of the AOC; (2) identify data needed for the FS that can be collected during the RI in order to incorporate any additional data needs or processes beyond what is planned for the RI into the FS Work Plan; and (3) identify and preliminarily screen candidate technologies. This series of memoranda is similar to the process undertaken with the RI, in which historical data reviews, site characterization technical memoranda, the Phase 1 RI report, and identification of data needs culminated in the Phase 2 RI Work Plan. The specific memoranda proposed for completion in advance of the FS Work Plan are discussed below.

Candidate Technologies Memorandum

Both *in situ* and *ex situ* remedial technologies will be compiled and evaluated in the Candidate Technologies Memorandum. This memorandum will begin with a discussion of GRAs and then focus on specific technologies applicable to meet the GRAs. Technologies represent specific components or processes that are part of a potential cleanup. Mechanical dredging with a clamshell bucket, capping, treatment using thermal desorption, are examples of specific candidate technologies.

The candidate technologies memorandum will reflect a wide range of preliminary sediment cleanup technologies that are consistent with both CERCLA and MTCA guidance. This is an initial evaluation of technologies, and the applicability to the LDW will be based on the criteria of implementability and effectiveness. Preliminary candidate *in situ* technologies include isolation capping, reactive caps, partial dredging and capping, and enhanced natural recovery. Potential candidate *ex situ* treatment technologies include solidification, stabilization, high-temperature thermal desorption, vitrification, solvent extraction, and/or segregation/separation/consolidation technologies. Two specific clean-up technologies the public has expressed the most interest in are dredging and treatment/disposal technologies, and thus the memorandum will include a detailed evaluation of applicable technologies in these areas.

Preliminary Screening of Alternatives Memorandum

Results from the Candidate Technologies Memorandum will be incorporated into the Preliminary Screening of Alternatives (PSA) Memorandum. This memorandum will use the existing sediment chemical data to further screen technologies and assemble combinations of those into alternatives, to evaluate for use under site-specific conditions. Examples of assembled alternatives could include mechanical dredging with barge transport, followed by physical separation as a treatment and Subtitle D landfill disposal, or capping combined with monitored natural recovery.

The preliminary screening will include evaluation of the applicability of technologies and alternatives to site conditions, including the general physical, biological, and chemical properties, as well as site use (e.g., shipping, navigational dredging, fishing). This memorandum will acknowledge that site conditions vary, particularly in intertidal versus subtidal areas, and that different technologies or alternatives may be more or less appropriate at specific areas of the site. This memorandum will be an initial filter of FS process options to carry forward into the later evaluations when all sediment data are available.

In addition, this memorandum will examine technical aspects of remediation activities at the Early Action areas, evaluate past sediment remediation projects and technologies applied in EPA Region 10, and evaluate both monitored natural recovery and enhanced natural recovery for applicability to the LDW. The memorandum will document which technologies have been applied, which have resulted in successful environmental cleanup/restoration, and what factors affected outcomes at other sites. Long-term effectiveness achieved at other sites (when that information is available) will be discussed in terms of habitat quality, reduced exposure and risks to biota, protection of human health, the lifting of fish consumption advisories, and reduced bioaccumulation of COCs up the food chain.

This memorandum will also specify whether there are additional FS data needs or a need to conduct bench-scale treatability studies to evaluate the preliminary alternatives.

FS Work Plan

The FS Work Plan will establish the approach and procedures for execution of the FS. The concepts and data from the pre-FS Work Plan memoranda are part of the process for identifying and understanding the issues, and will help guide the development of the FS Work Plan.

The FS Work Plan establishes the scope and nature of the FS, and will be definitive about how each of the technical sections of the FS will be executed. The Work Plan will include a discussion of how the Applicable or Relevant and Appropriate Requirements (ARARs), Remedial Action Objectives (RAOs), and Preliminary Remediation Goals (PRGs) will be developed. In addition, the metrics for identification and screening of technologies, as well as for conducting the detailed evaluation of alternatives will be specified.

The FS Work Plan will integrate information and data generated for the RI, HHRA, ERA, and pre-FS Work Plan technical memoranda, and will serve to evaluate the adequacy of the data for the FS and to identify any additional FS data needs. In addition, the FS Work Plan will confirm the findings regarding the need for treatability studies noted in the PSA Memorandum. If required, a treatability study work plan will be submitted at the same time, but under a separate cover with the FS Work Plan. In addition, the plan will define the evaluation process for the AOC-required memoranda, including the assembly of alternatives, and how the detailed and comparative analysis of alternatives will be conducted. The FS Work Plan is scheduled to be developed after submittal of the draft Phase 2 HHRA and ERA, approximately one year before the draft FS will be submitted to EPA and Ecology.

The FS Work Plan will also define a series of forthcoming memoranda and/or sections of the FS that will be written as information from the RI and risk assessments becomes available. These include:

- RAO Memorandum
- Development, Screening, and Final Assembled Alternatives Memorandum

- Detailed Evaluation of Alternatives (as a section submitted in the FS)
- Comparative Analysis of Alternatives (as a section submitted in the FS)
- Treatability Study Evaluation Report (if required).

As noted above, the AOC-required Detailed Evaluation of Alternatives and Comparative Analysis of Alternatives will be developed and submitted with the draft FS. This will allow the overall RI/FS schedule to be achieved, while meeting the AOC requirements and allowing the agencies adequate time to review all of the proposed, detailed and comparative evaluations of alternatives.

These memoranda, unless already specified above as a section of the FS, will form the basis for individual FS chapters, as described below.

Feasibility Study

Following an introduction (Section 1), the eight major technical sections of the FS will be:

- Section 2: Summary of the Remedial Investigation
- Section 3: Summary of the Baseline and Residual Risk Assessments
- Section 4: Remedial Action Objectives and General Response Actions
- Section 5: Identification and Preliminary Screening of Technologies
- Section 6: Remedial Action Levels and Potential Actionable Areas
- Section 7: Source Control on the Lower Duwamish Waterway
- Section 8: Assembly of Alternatives
- Section 9: Detailed Analysis of Alternatives
- Section 10: Comparative Analysis of Alternatives.

The following discussion outlines the content of each FS section and describes how information developed in the pre-, and post-FS Work Plan memoranda will be integrated to fill critical data needs.

- **Section 2: Summary of the RI –** This section will include descriptions of the site, hydrologic conditions, bathymetric contours, results of the sediment transport study, area uses (commercial and recreational), and the sediment COC distributions.

- **Section 3: Summary of the Baseline and Residual Risk Assessments –** This section will include information related to human cancer and non-cancer risks from exposure to sediments or consumption of seafood, as well as information on risks to ecological receptors from both the baseline, and the residual risk assessments.

- **Section 4: Remedial Action Objectives and General Response Actions –** This section will draw on results from the RI, risk assessments, and from the two pre-FS Work Plan memoranda (the Candidate Technologies Memorandum and the Preliminary Screening of Alternatives Memorandum). A separate, technical memorandum on

RAOs will be completed after submittal of the HHRA and ERA, and will build off of the ARAR section completed as part of the Phase 1 RI. In accordance with EPA CERCLA RI/FS guidance, ARARs are directly applicable to the development of a set of RAOs. RAOs establish the expectations against which progress toward the RAOs will be measured, including the time frame and specific metrics applicable to the FS for determining feasibility, implementability, and potential public acceptance of remedial alternatives. The memorandum will outline how the RAOs were derived and how they have been applied elsewhere in Region 10 and Washington state and at other regional or national CERCLA sites. PRGs follow directly from the RAOs, and relate to the ARARs. GRAs will be developed as part of the Candidate Technologies Memorandum, and refined in the Preliminary Screening of Alternatives Memorandum.

- **Section 5: Identification and Preliminary Screening of Technologies and Alternatives –** This section will draw on two technical memoranda proposed for the pre-FS Work Plan period: (1) the Candidate Technologies Memorandum; (2) the Preliminary Screening of Alternatives Memorandum. The Candidate Technologies Memorandum will have evaluated a comprehensive range of potential technologies, including enhanced and monitored natural recovery, institutional controls, removal, capping, treatment, and disposal. These technologies will then have been initially screened per CERCLA and MTCA requirements as to implementability, effectiveness, and cost, in the Preliminary Screening of Alternatives Memorandum, leading to a list of retained technologies.

- **Section 6: Remedial Action Levels and Potential Actionable Areas –** This section will be derived principally from documents and information produced in the RI and risk assessments, including the distribution of COCs, potential remedial areas, depths, and volumes; residual risks following Early Actions in relation to the overall assessment of risks within the LDW; and the potential for erosion and sediment transport in the LDW.

- **Section 7: Source Control on the Lower Duwamish Waterway –** This section will discuss the status of on-going source identification and source control activities on the LDW. It will also summarize the status of source control work, and assess the compatibility of remedial alternatives with completed and planned future source control actions.

- **Section 8: Assembly of Alternatives –** This section will use the final identified “actionable areas,” the preliminary volume and mass estimates, as well as information from the Preliminary Screening of Alternatives Memorandum, to construct specific alternatives, develop process flow diagrams, and make an initial estimate of costs. These mass, volume, and cost estimates will be constructed so as to meet the CERCLA FS cost estimating goals of -30% to +50% accuracy. Detailed cost estimates will be conducted after the ROD, in conjunction with remedial designs for specific areas by the responsible party (or parties). These assembled alternatives will then be evaluated against EPA and Ecology's threshold criteria of overall protection of human health and the environment, for compliance with the ARARs, and for ability to meet RAOs. The alternatives will also be screened for effectiveness, implementability and costs in the LDW. The retained alternatives will be carried forward into the Detailed Analysis of Alternatives section.

- **Section 9: Detailed Analysis of Alternatives –** This section will evaluate the retained set of alternatives against EPA's nine criteria (in the categories of threshold, balancing, state acceptance, and community acceptance), and appropriate criteria under MTCA. This section will also incorporate source control information from the RI and any LDW source control reports in an evaluation of the proposed remedies against the long-term effectiveness and permanence criteria.
- **Section 10: Comparative Analysis of Alternatives –** This section will compare the retained alternatives using a specific methodology for the final evaluation that will be developed in the FS Work Plan.

Summary

The RI/FS process for the LDW is envisioned as a collaborative and iterative process in which many technical elements will converge in the FS to achieve a well-supported recommended alternative or combination of alternatives for remedial action. Throughout this process, a key goal is to meet critical interim deadlines and complete the FS on schedule. To that end, it is proposed that technical memoranda regarding candidate technologies and preliminary screening of alternatives be executed in advance of the FS Work Plan, allowing for the integration of FS data needs with RI activities. The rationale is three-fold:

- To streamline data collection by identifying the data needed to complete the FS that can be collected during the RI
- To inform the FS Work Plan
- To meet the schedule for completion of the FS to allow a ROD to be issued on schedule.

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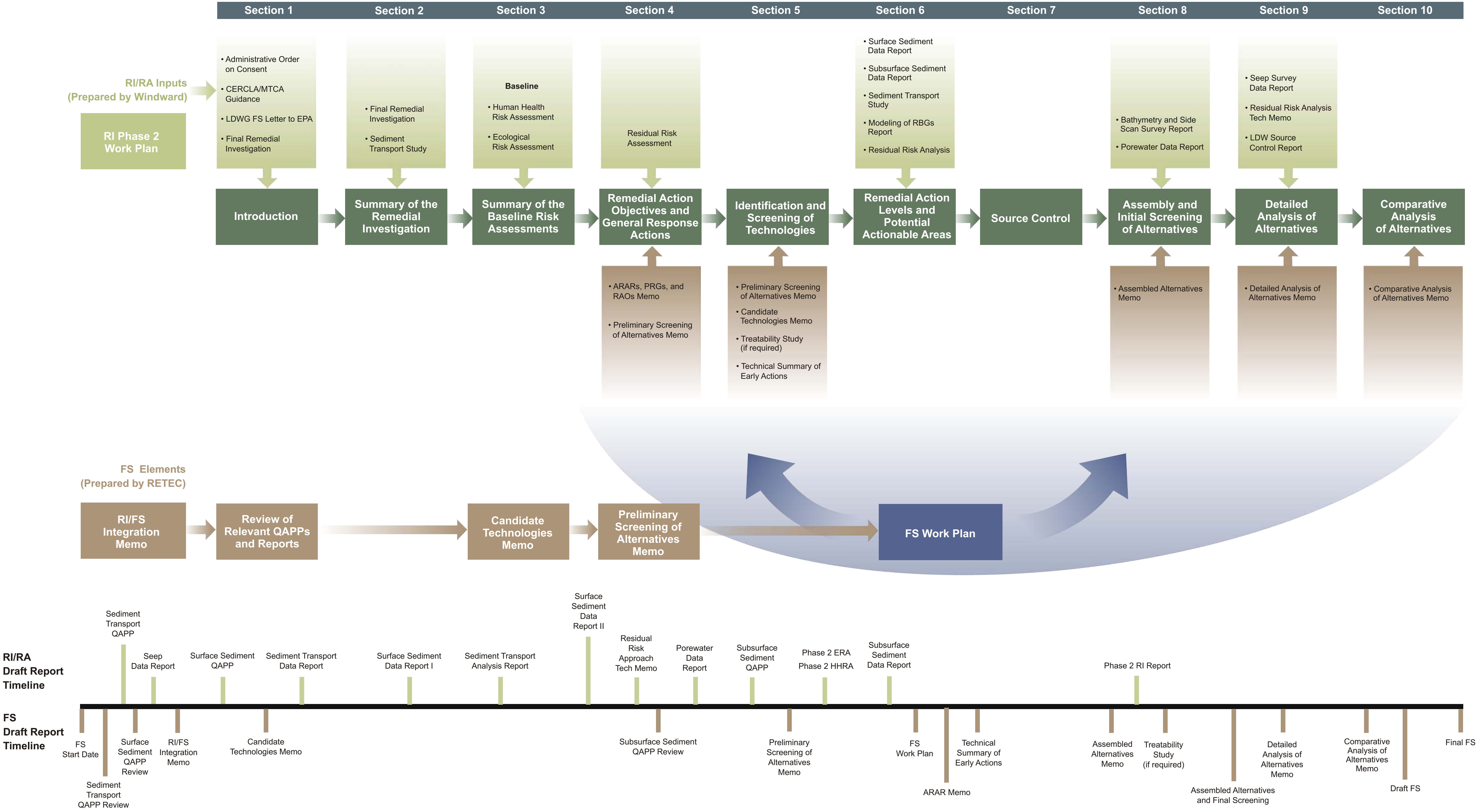
Figure 1 Feasibility Study Outline, Scope of Work, and Schedule



Schedule is currently under discussion among LDWG, EPA and Ecology