PORTLAND HARBOR RI/FS

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TREATABILITY STUDY LITERATURE SURVEY TECHNICAL MEMORANDUM

October 20, 2007

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List of Acronyms

% HEM	percent hexane extractable material
APEG	potassium polyethylene glycol
ARCS	Assessment and Remediation of Contaminated Sediments
B.E.S.T.	Basic Extractive Sludge Treatment
BCD	sodium bicarbonate
BTEX	benzene, toluene, ethylbenzene, and xylene
CDF	confined disposal facility
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLU-IN	Hazardous Waste Clean-up Information
DDT	dichloro-diphenyltrichloroethane
delta-BHC	delta-hexachlorocyclohexane
DNAPL	dense, non-aqueous phase liquid
DOER	Dredging Operations and Environmental Research
DOTS	Dredging Operations Technical Support
GRA	General Response Action
GTI	Gas Technology Institute
iAOPCs	initial areas of potential concern
iCOC	initial chemicals of concern
ISV	In situ vitrification
LWG	Lower Willamette Group
mg/kg	milligrams per kilogram
NAPL	non-aqueous phase liquid
NY/NJ	New York/New Jersey
OAR	Oregon Administrative Rule
ODEQ	Oregon Department of Environmental Quality
PAH	Polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
pg/g	picograms per gram
PRG	preliminary remediation goals
RBC	risk-based concentrations

RBDM	risk-based decision making process
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
S/S	Stabilization/solidification
SET™	Solvated Electron Technology
SITE	Superfund Innovative Technology Evaluation
SVOCs	semivolatile organic compounds
TPH	total petroleum hydrocarbons
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
VOC	volatile organic compound
WRDA	Water Resources Development Act

1.0 Introduction

The purpose of this technical memorandum is to provide information on the potential suitability of various technologies for the treatment of sediments associated with the Portland Harbor Superfund Site (Site). For this memorandum, treatment technologies consist of those processes or methods that either reduce or eliminate the concentrations of initial chemicals of concern (iCOCs) in sediment, or prepare sediment so that it is amenable to treatment. Generally, these technologies may be implemented either in situ or ex situ and generally use biological, chemical, physical, and thermal processes.

This document was produced in accordance with the *Portland Harbor Remedial Investigation/Feasibility Study (RI/FS) Programmatic Work Plan* (Integral et al. 2004). Specifically, this document summarizes the results of a comprehensive literature survey on demonstrated and emerging sediment treatment methods with respect to applicability to Site conditions, technology performance (i.e., removal efficiency), relative cost, operational and maintenance requirements, and overall implementability. The document also provides a preliminary screening of technology alternatives applicable to the project and notes which technologies would require bench- or pilot-scale testing prior to FS evaluation. Finally, the document provides an initial assessment of beneficial use feasibility (i.e., in situ sediment concentrations are compared to various upland land use criteria) to gauge the practical volume of sediment potentially amenable to ex situ treatment. Treatment methods are then screened based on these evaluation criteria, resulting in a recommendation to carry viable technologies forward into the FS process.

The remainder of this document is organized as follows:

- Section 2 – Sediment Characteristics – a brief, preliminary description of the physical and chemical sediment characteristics at the Site pertinent to the treatment technology evaluation based on results of the *Comprehensive Round 2 Site Characterization Summary and Data Gaps Analysis Report* (Integral et al. 2007).

- Section 3 – Literature Review Sources – documentation of the various resources reviewed to develop this memorandum.

- Section 4 – Treatment Technology Overview – a general summary of the definitions and evaluation criteria used throughout the remainder of the memorandum.

- Section 5 – Ex Situ Treatment – descriptions and preliminary evaluation of technologies that could be considered for implementation subsequent to a primary removal General Response Action (GRA).

- Section 6 – In Situ Treatment – descriptions and preliminary evaluation of technologies that could be considered for implementation in place in support of a non-removal GRA.

- Section 7 – Treatment Technology Evaluation – preliminary screening of treatment technologies by general Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) criteria and as related to potential beneficial upland uses.

- Section 8 – Final Evaluation and Recommendations – a discussion of applicable treatment technologies that are viable candidates to be further investigated during the RI/FS process and recommendations for treatability studies, as well as a preliminary evaluation of beneficial use options for sediment addressed by a removal GRA scenario.

It should be noted that the final evaluation summarized here should be viewed as a preliminary recommendation by the Lower Willamette Group (LWG). As such, the LWG is interested in discussing with the U.S. Environmental Protection Agency (USEPA) and its partners any treatment technologies that they wish to consider further and the rationale for further evaluating those technologies in comparison to the information provided here. Through this ongoing discussion, the LWG hopes to work collaboratively with USEPA and its partners to identify a reasonable subset of treatment technologies (and any associated necessary treatability studies) to evaluate in the FS.

2.0 Sediment Characteristics

An RI has not yet been completed for the Site; however, data are available from the Comprehensive Round 2 Site Characterization Summary Report (Round 2 Report; Integral et al. 2007) to identify Site-wide and area-specific iCOCs for the project. To determine the suitability of a specific treatment technology for sediments, it is necessary to identify a range of target iCOCs. The physical properties of the sediments, such as grain size, organic carbon content, and other characteristics, are also pertinent as they can also impact the effectiveness of a given technology.

2.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

For the purpose of this treatability literature survey technical memorandum, it is assumed the candidate sediment for remediation is comprised of a balanced (average 50 percent) mixture of sand and low plasticity, fine-grained sediment, with relatively low organic matter content (less than 10 percent total organic carbon). Analyses from the Round 2 Report indicate that sediments are on average comprised of 54 percent fine-grained sediment and total organic carbon is less than 4 percent at the 95th percentile. In portions of the river where sandier material exists (with sand contents much greater than 50 percent), sediments tend to be less impacted by iCOCs.

Based on initial risk screening evaluations presented in the Round 2 Report, the iCOCs for sediment that may drive a cleanup action include polychlorinated biphenyls (PCBs), dioxins/furans, and dichloro-diphenyltrichloroethane (DDT) compounds. These iCOCs were preliminarily identified as primary risk drivers within the study area, with PCBs accounting for the largest contributions overall to human health and ecological risk. Additional iCOCs for human and ecological risk include metals (e.g., arsenic, cadmium, mercury, lead, zinc, and silver), pesticides, in addition to DDx (e.g., endrin ketone and delta-BHC [delta-hexachlorocyclohexane]), individual and total polycyclic aromatic hydrocarbons (PAH), phthalates, and total petroleum hydrocarbons (TPH). The above key contaminants exist in various combinations at some locations. Therefore, the ability of a given treatment technology to treat multiple organic and inorganic chemicals in sediment is an evaluation criterion considered later in Section 8. Technologies that selectively treat compounds may be considered in the FS to address isolated areas affected by iCOCs at concentrations that are orders of magnitude above potential target cleanup levels.

2.2 INITIAL AREAS OF POTENTIAL CONCERN

The Round 2 Report identified 29 initial areas of potential concern (iAOPCs) throughout the study area based on initial human health and ecological risk assessments. Twenty-eight of these areas are noted as individual iAOPCs, while the remaining iAOPC was designated to address the elevated PCBs on a Site-wide basis. While these iAOPCs have not been approved at this point in the RI/FS process, they are used here as a basis for assessing technologies that may be used for remediation at the Site as they contain the range of iCOCs and range widely in aerial extent. Terminal 4, designated as iAOPC T4, is an early action project that will commence prior to the initiation of the overall Portland Harbor remediation and therefore is not considered in the context of this memo. Other potential early action areas include the Arkema site and the NW Natural Gasco site, although there are no pre-selected remedies for these potential early actions.

The iAOPCs range in size from under 0.2 acres, to just over 40 acres. Five of the iAOPCs are less than 1 acre; 10 of the iAOPCs are between 1 and 10 acres; and 12 of the iAOPCs are between 10 and 40 acres. The iCOCs associated with iAOPC vary by location and may include the one or more of the key target contaminants listed. Figure 1 illustrates the location and size of the various iAOPCs. Outside of the iAOPCs, additional risk primarily associated with human health exposure to elevated PCBs through fish consumption may exist. Additional iAOPCs may also be identified in addition to the iAOPCs identified in the Round 2 Report and/or identified iAOPCs may be modified or eliminated in the final RI. The treatment technologies discussed in the following sections were selected based on their demonstrated ability to address one or more of the iCOCs identified in the Round 2 Report.

3.0 Literature Review Sources

Many documents and informational resources were reviewed. Generally, documents were selected from various databases, websites, local and federal guidance documents, engineering sediment design studies, reports and presentations on current sediment treatment programs, and proceedings from technical conferences. In addition, documents prepared for other CERCLA sites with multiple sediment iCOCs were also reviewed.

The primary sources of information include:

- USEPA Office of Solid Waste and Emergency Response (http://www.epa.gov/swerrims/)
- USEPA Great Lakes National Program Office – Assessment and Remediation of Contaminated Sediments (ARCS) Program (http://www.epa.gov/glnpo/arcs/)
- U.S. Army Corps of Engineers (USACE) Center for Contaminated Sediments (http://www.wes.army.mil/el/dots/ccs/)
- USEPA National Risk Management Research Laboratory (http://www.epa.gov/ORD/NRMRL/)
- USEPA Superfund Innovative Technology Evaluation (SITE) Program (http://www.epa.gov/ORD/SITE/)
- Hazardous Waste Clean-up Information (CLU-IN) Technology Innovation Program (http://clu-in.org/)
- USACE Dredging Operations and Environmental Research (DOER) Program (http://el.erdc.usace.army.mil/dots/doer/)
- USACE Dredging Operations Technical Support (DOTS) Program (http://el.erdc.usace.army.mil/dots/dots.html)
- Sediment Management Work Group (http://www.smwg.org/)
- Remediation Technologies Development Forum (http://www.rtdf.org/)
- Federal Remediation Technologies Roundtable (http://www.frtr.gov/)
- Major Contaminated Sediment Sites Database (http://www.hudsoninformation.com/mcss/)
- Interstate Technology and Regulatory Council (http://www.itrcweb.org/)

- Los Angeles Region Contaminated Sediments Task Force (http://www.coastal.ca.gov/sediment/sdindex.html)

- Puget Sound Multi-User Disposal Site Project (http://www.ecy.wa.gov/programs/tcp/smu/muds.htm

- Water Resources Development Act (WRDA) Sediment Decontamination Technologies Demonstration Program – NY/NJ Harbor (http://www.bnl.gov/wrdadcon/)

- Strategic Environmental Research and Development Program (http://www.SERDP.org)

- U.S. Department of Defense Environmental Security Technology Certification Program (http://www.estcp.org/)

Section 9 provides a comprehensive list of the various documents reviewed, in addition to the general sources listed above.

4.0 Treatment Technology Overview

The treatment types considered in this literature review can be broken down into the following four descriptive categories:

- Pre-treatment processes, such as dewatering, to facilitate transport and disposal or to amend the raw material prior to treatment by a more sophisticated process.
- Physical processes, such as separation.
- Treatment processes to reduce mobility, contaminant levels, or toxicity.
- Treatment processes to provide complete contaminant sequestration or destruction.

The appropriateness of a given treatment technology may depend upon the other GRAs selected for the Site. If capping is the selected GRA, the cap matrix may be amended with enhancing materials when traditional capping isolation alone is an inadequate long-term remedy. A removal GRA is typically implemented through hydraulic or mechanical dredging. Selection of a dredging method will affect the logistics of any ex situ process selected. Some processes are more compatible with some dredging methodologies than others because of factors such as water content that differ between dredging methods.

The various treatment technologies are organized into two main groups: ex situ and in situ treatment, which are presented in Sections 5 and 6, respectively. Some treatment technologies may be implemented either ex situ or in situ and are therefore discussed in both sections. Each section provides information regarding the types of contaminants treated by the technology and the status of field- and laboratory-scale demonstration testing. At the end of each section, a general discussion of the advantages and disadvantages of the various treatment technologies is provided. Additional evaluation criteria are discussed in Section 7 while Section 8 summarizes the likelihood of further FS evaluation of each technology, building upon the information provided in the previous sections, including the need for and timing of treatability studies. Information pertinent to the assessment of the technologies described in the text below is summarized in Tables 1 and 2.

5.0 Ex Situ Treatment

Ex situ treatment technology options are often selected to complement GRAs when beneficial uses of the treated sediment exist or an amendment is required for dredged material prior to transport and disposal. Ex situ options are organized and discussed in the following technical categories:

- Pre-treatment
- Biological
- Chemical
- Physical
- Thermal

In some cases, combinations of the technical categories may be implemented. For example, sediment washing is a chemical/physical process in which chemicals, such as surfactants, are added to the sediment slurry as the mixture is passed through a series of collision chambers and centrifuges.

5.1 PRE-TREATMENT METHODS

When removal and subsequent disposal is selected as a GRA, oftentimes the material must be pre-treated (i.e., dewatered or stabilized) prior to material handling and transport. Several factors must be considered when selecting an appropriate pre-treatment technology including sediment characteristics, selected dredging method, and the required moisture content of the pre-treated material.

Three primary categories of pre-treatment that are regularly implemented include: passive dewatering, mechanical dewatering, and reagent enhanced dewatering/stabilizing methods.

5.1.1 Passive Dewatering

Passive dewatering (also referred to as gravity dewatering) is facilitated through natural evaporation, consolidation, and drainage of porewater. The method is capable of dealing with large volumes of sediment at variable flow rates and the process is fairly simple. However, significant amounts of land and time are required for sufficient water content reduction. Passive dewatering is most often facilitated through the use of a dewatering lagoon or temporary settling basin, although in-barge settling and subsequent decanting is effective when pre-treating coarse sediments. Air quality impacts associated with volatilizing contaminants (where such volatile chemicals exist) may be of concern in implementing this open air process for some types of highly contaminated sediments.

An innovative technology using geotextile tubes to confine sludge and sediment during passive dewatering has been implemented at several sites. This method has proven effective for sites primarily comprised of coarse sediments and has had varied success at sites with fine-grained and plastic sediments. In addition, sediments contaminated with dense, non-aqueous phase liquid (DNAPL) and other oily substances typically have not been dewatered as effectively because the geotextile often becomes blinded (clogged), hindering the process. The required time for completion of this process option is a function of the target water content and the percentage of fine-grained particles in the sediment matrix. Plastic fine-grained sediments will take additional time to dewater in comparison to non-plastic sands that freely allow water to flow through pore spaces without prematurely blinding the geotextile. An innovative modification to geotextile tube dewatering has been developed by Turner Specialty Services, L.L.C., which encapsulates the geotextile tube within a sealed geomembrane and then applies a vacuum to assist in the process. The system has been used to dewater sludge materials. However, a demonstration project has not been completed on fine-grained sediments. Because of these uncertainties, at a minimum, both geotextile tube methods would require bench-scale testing before they could be fully implemented. Normal passive dewatering would likely require little or no treatability testing, although characteristics of the sediment such as grain size, plasticity, and non-aqueous phase liquid (NAPL) content would need to be understood in order to determine whether passive dewatering is appropriate and the timeframe required for implementation.

5.1.2 Mechanical Dewatering

Mechanical dewatering involves the use of equipment such as centrifuges, hydrocyclones, belt presses, and plate-and-frame filter presses to squeeze, press, or draw out water from sediment pore spaces. The process can handle large volumes of sediment, but requires operator attention, consistent favorable flow rates, and consistent sediment feed quality. In some cases, the material must first be screened to remove debris, and chemicals may also be added to enhance the physical properties of the material. In comparison to passive dewatering, the process is fairly expedited and requires relatively little space for operations. Air quality issues can be more readily managed in comparison to open air dewatering in that temporary housing can be constructed to contain the process and address emissions. Bench-scale tests are not typically required at the FS stage, but may be performed by the contractor prior to implementation to refine the equipment selection.

5.1.3 Reagent Enhancement Dewatering

Reagent enhancement dewatering is an offshoot of stabilization/solidification methods in that cementitious or pozzolanic materials are added to sediment to dewater the material via dehydration caused by chemical reactions. For situations where dewatering is the single goal, the most economic, procurable, and effective reagent would be used (typically, a product such as quicklime). Oftentimes, the reagent mixtures will be optimized to provide enhanced strength or leachate retardation. This process is discussed below in Section 5.3.3 Stabilization/Solidification.

Dewatering by the addition of reagents is regularly used and has similar space and operational requirements as mechanical dewatering. Additional permitting and air quality monitoring may be necessary due to the regulated use of some of the common reagents (such as fly ash). Bench-scale testing is required to determine the optimum reagent mixture prior to construction. However, general information is available from other sites on the amount of material needed for sediments of various water contents and this information would be sufficient for any FS evaluations.

5.2 BIOLOGICAL METHODS

Biological treatment (bioremediation) of sediment involves the use of microorganisms to degrade organic contaminants. The process stimulates the activity of naturally occurring microbes that biologically degrade or metabolize organic contaminants and, to a lesser extent, immobilize inorganic contaminants. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials. The bioremediation process can occur under aerobic or anaerobic conditions, resulting in by-products ranging from carbon dioxide and water to methane and sulfur. The anaerobic process typically requires the injection of nutrients and control of the oxygen, temperature, and pH levels. In some cases, intermediate products are created as the biological processes break down the original contaminants. The intermediate products may be less, equally, or more toxic than the original contaminants. However, these by-products are generally isolated from the environment within the ex situ treatment unit.

The most widely used and effective biological treatment options include land treatment, composting, biopiles, and slurry-phase treatment. The former three technologies are similar processes in that they are generally implemented in open air environments requiring large plots of land. They require high solids contents to avoid excessive water management and therefore, are most compatible with mechanical dredging operations. In contrast, slurry-phase treatments are more compatible with hydraulic dredging, as the process requires low solids content on the intake. Dewatering is a necessary component of the post-processing of slurry-phase treated sediments.

Ex situ bioremediation is typically reserved for treating heavier organic contaminants (e.g., TPHs), as volatile compounds are more effectively treated by processes such as in situ vapor extraction. Air quality issues may also arise when treating sediment with high concentrations of volatiles. In general, slurry-phase treatment is a more controllable method for remediating these contaminants in comparison to the other biological methods because emissions are contained within the treatment unit and further treated (e.g., vapor-phase bioreactor) prior to discharge to the atmosphere.

Demonstrations have shown that properly designed ex situ bioremediation systems can treat petroleum hydrocarbons, solvents, pesticides, and wood preservatives on relatively small scales. However, there are several limitations that are associated with the selection of bioremediation as a treatment option for multi-contaminant sediments (e.g., different organisms may be required to metabolize the range of iCOCs present; some iCOCs may be efficiently reduced under aerobic, while others under anaerobic conditions). While bioremediation (or any other remediation technology) cannot degrade inorganic contaminants, bioremediation can be used to change the valence state of inorganics and cause adsorption, immobilization onto soil particulates, precipitation, uptake, accumulation, and concentration of inorganics in micro or macroorganisms. Although there is promising data on PCB biodegradation, it is in the early phases of research and no sediment demonstration projects have been completed (Adrieans et al. 2006). Because of the differing biodegradation processes for differing iCOCs, design of a biological treatment system to remediate combinations of iCOCs where they exist at the Site could be difficult. For all process options, bench- and field-scale treatability studies would be required to identify and design the most effective bioremediation system.

5.3 PHYSICAL/CHEMICAL METHODS

Physical/chemical treatment methods result in the destruction, dilution, separation, or immobilization of contaminants from the sediment matrix. Process options potentially applicable to the Site are described below.

5.3.1 Particle Separation

Particle separation is a procedure where, through a series of mechanical processes, sediment particles are separated into fractions according to their particle size or density. Several techniques are available to facilitate separation including: gravity settling, sieving, and hydraulic separation through the use of hydrocyclones. Because contaminants are typically bound, either chemically or physically, to fine-grained sediment, the coarse-grained particles generated by the separation process generally meet cleanup standards and subsequently can be beneficially used without further treatment. Ex situ separation can be performed by many processes. Gravity separation, sieving/physical separation, and hydrocyclone separation are well-developed processes that have been implemented to segregate particles by size, while providing a dewatering mechanism. Gravity separation is also effective in removing immiscible oil phases from the sediment matrix.

The separation methods found in this review are well-established technologies. Particle separation methods would be applicable for the Site if a large deposit of coarse sediment were identified within the study area that could be beneficially used either as upland fill or as habitat restoration material. However, an additional survey of the potential uses of the beneficial use product (i.e., clean sand) would be required to support the economic viability of the process. Another benefit of implementing particle separation is the reduction of waste material that would otherwise be disposed of or treated with a more sophisticated (i.e., destructive or immobilization) technology. Literature information is likely sufficient to gauge the feasibility and approximate range of potential costs should these types of contaminated sediment be found.

5.3.2 Sediment Blending

Sediment blending involves blending the contaminated dredged sediment with borrowed clean aggregate to reduce contamination concentrations. One of the primary issues of concern with sediment blending is the cost of obtaining large quantities of the clean material required to achieve the treatment objective. In addition, although effective, dilution has not been considered an environmentally accepted method of treatment, thus limiting potential beneficial uses.

5.3.3 Stabilization/Solidification

Stabilization/solidification (S/S) is a treatment process that provides three types of treatment benefits: dewatering of dredged sediment, immobilization of leachable contaminants, and enhancement of geotechnical properties. The S/S process occurs through the addition of Portland cement, fly ash, lime, or other pozzolanic reagents that immobilize and/or bind contaminants in the sediment into a solid matrix or chemically stable form, thus resulting in a less soluble, less mobile, and/or less toxic material. Depending upon the proportion of reagents, the end product may take on the form of a quasi-soil/concrete material that could later be used as bulk fill or a solid mass that could be used as building blocks or tiles.

The S/S process is generally implemented at sites with metals contamination; uncertainties remain as to the effectiveness of pozzolanic-based stabilization to treat sediments predominantly contaminated by organics. The Portland Cement Association and various government agencies continue to investigate the effects of organics on the S/S process. Current research indicates that pozzolanic-based stabilization is effective for sediments primarily contaminated by organics in cases when the organic contaminants are generally highly sorbed to soil particles and exhibit low relative mobility in air and water (e.g., PCBs; Wiles and Barth 1992).

Laboratory-scale testing to support the New Bedford Harbor project indicated that Portland cement, sorbent clay, and other proprietary reagent mixtures were not effective in preventing contaminant leaching of PCBs and semivolatile organic compounds (SVOCs). Although not investigated, S/S for metals stabilization was considered to be a viable treatment method; however, additional testing was recommended to confirm the proper reagent type and recipe. Stabilization of sediment with low to moderate contaminant levels in New York/New Jersey (NY/NJ) Harbor is regularly implemented and incorporated into Brownfield projects as bulk fill. Stabilized sediment meeting industrial soil cleanup criteria is also used as daily cover for landfills.

In addition to the S/S methods described above, other innovative processes continue to emerge. United Retek (Medway, Massachusetts) has developed a process utilizing specially formulated asphalt emulsions for the stabilization and beneficial use of petroleum-contaminated soil. An asphalt emulsion is a liquid mixture of asphalt binder, water, and an emulsifying agent. When mixed with an aggregate (e.g., contaminated sediment), the emulsion sets, porewater is released, and the organic phase forms a continuous matrix of asphalt around the sediment. The resulting product can then be used beneficially as a pavement layer or mixed with Portland cement to serve as bulk fill. Asphalt emulsion stabilization is commercially available and proven for upland soils. Application of the technology to contaminated sediments is promising; however, bench-scale testing would be required prior to selection as a treatment option in the FS.

Innovative applications of sorbent materials, such as granular activated carbon and organoclay, are also being evaluated to assist in the process of immobilizing organic contaminants. Long-term performance may be an issue because in situ solidification may not change the toxicity of some chemicals within the sediments. In other instances it may alter chemicals, resulting in changes in toxicity.

Because S/S processes do not permanently destroy chemical contaminants, the permanence (e.g., long-term durability) of the stabilized matrix would need to be investigated through bench-scale testing for both traditional and innovative S/S methods before a design could be completed. Because the effectiveness of these technologies is dependent upon the concentration levels of chemicals of concern in the sediments, further information regarding remediation goals is needed before treatability tests could be devised to determine if this technology is applicable to Site iCOCs.

5.3.4 Sediment Washing

In general, sediment washing is a process that uses physical and/or chemical techniques to separate contaminants from sediments. In some cases the technology application may be as simple as salt removal (where applicable) or particle separation (see Section 5.3.1). Sediment washing as a treatment technology for contaminated sediments typically refers to a process that involves slurrying the contaminated sediment and subjecting the slurry to physical collision and abrasive actions and aeration, cavitation, and oxidation processes while reacting with chemical additives such as chelating agents, surfactants, and peroxides. Through these processes, the organic contaminants are destroyed and inorganic contaminants are transferred from the sediments to the water phase in the process. The washed material is then dewatered and stockpiled for future beneficial uses or further amendment for use as manufactured topsoil.

A number of process options exist for sediment washing, but few have transitioned to full-scale applications. The BioGenesis^{SM} Advanced Sediment Washing system has been demonstrated as part of the WRDA Sediment Decontamination Program and internationally through the Port of Venice, Italy. It is one of the treatment technologies selected as part of the NY/NJ Harbor regional decontamination facility in Bayshore, New Jersey. Upon fulfillment of final demonstration requirements under WRDA, the process will be available commercially to the NY/NJ Harbor region.

Application of sediment washing for this project would not require a full-scale demonstration, as data from the Bayshore full-scale facility could be used to preliminarily assess the efficiency of the process with respect to Site iCOCs. However, a bench-scale testing program would be warranted to design the process for the site-specific iCOCs and ultimately to develop accurate unit costs for treatment.

The cost of sediment washing is impacted by the percentages of fine-grained and organic constituents within the sediment matrix, as increased particle surface areas may require additional treatments. In addition, complex mixtures of contaminants and heterogeneous contaminant compositions throughout the waste stream increase the difficulties associated with designing a suitable washing solution that will consistently and reliably remove the various contaminant groups. For these cases, sequential washing, using different wash formulations and/or different sediment to wash fluid ratios, may be required. Bench-scale treatability tests would be needed to complete a site-specific design for this technology.

5.3.5 Chemical Extraction

Chemical extraction is a treatment method that utilizes extractants to separate contaminants from sediments, but does not completely destroy them. The technology differs from soil washing in that chemicals are used, rather than water or additive-enhanced water. The extraction process is facilitated through the use of acid or organic solvents as the extractant. For both types of solvents, post-treatment dewatering and residuals handling is required. These residuals may have increased toxicity or may require acid neutralization. In order to avoid disposal of the residuals, it is common to use chemical extraction methods in combination with other technologies, such as S/S, incineration, or sediment washing, depending upon site-specific conditions.

An example of solvent extraction is the Basic Extractive Sludge Treatment (B.E.S.T.®) process. The extractant used in this process is triethylamine, which differs from other solvents in that it is inversely miscible (i.e., miscible in colder temperatures). The process can also be used to simultaneously treat oil and water in that they are similarly soluble in cold triethylamine. Under the ARCS Program, this process was bench-scale tested using sediment from the Buffalo (New York), Saginaw (Michigan), and Grand Calumet (Indiana) Rivers and later pilot-scale demonstrated on the Grand Calumet River in Gary, Indiana. Primary contaminants at these sites were PAHs and PCBs, and all tests indicated removal recoveries of 96 percent or greater, leaving behind a significantly smaller volume of contaminated particulates and water/oil. The B.E.S.T.® process was also successfully pilot-demonstrated at New Bedford Harbor in separating PCBs contamination from the sediment grains. Bench-scale treatability tests would be needed during design for this technology.

5.3.6 Chemical Oxidation

Ex situ chemical oxidation can be broken down into two categories: reduction/oxidation (redox) and slurry oxidation. Both methods involve the conversion of contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. Redox chemical oxidation is primarily used to address inorganic contaminants while slurry methods target organics, although both may have some additional remedial effects on other contaminant groups. The main advantage of implementing chemical oxidation technologies in the ex situ environment rather than in situ is that sufficient time for oxidation to occur is allowed and the treatment can take place in a controlled environment.

The technology is commercially available to treat drinking water and waste water. Its use to remediate contaminants in soils and sediments is still emerging. Bench- and pilot-scale treatability studies would be required during design.

5.3.7 Dehalogenation

Dehalogenation is the process of removing the halogen molecules (e.g., chlorine) from a contaminant in the sediment. In this process, dewatered contaminated sediment is screened, pulverized, and mixed with reagents prior to being heated in a reactor. Reagents used in the process consist of sodium bicarbonate (BCD) or potassium polyethylene glycol (APEG). The dehalogenation process is achieved by either the replacement of the halogen molecules or the decomposition and partial volatilization of the contaminants. The technology targets a relatively small range of contaminants (i.e., PCBs, dioxins, furans, and other halogenated compounds).

An example of a dehalogenation process option is the Solvated Electron Technology (SET™) process, which uses an alkali metal dissolved in liquid anhydrous ammonia to generate a solvated electron solution. This solution is a strong reducing agent that treats PCBs, dioxins, and furans through dechlorination. This technology was pilot-demonstrated at the New Bedford Harbor site following B.E.S.T.® treatment application. The analytical results of the testing were inconclusive and attributed to equipment problems encountered during processing. Treatability studies would be needed for this technology during remedial design.

5.4 THERMAL METHODS

Thermal processes use heat to increase the volatility (separation), burn or decompose (destruction), or melt (immobilization) the contaminants within the sediment matrix. Process options potentially applicable to the Site are described below.

5.4.1 Incineration

Incineration uses high temperatures, between 1,400 and 2,200°F, to volatilize and combust (in the presence of oxygen) halogenated and other refractory organics in hazardous wastes. Although it destroys a range of chemicals, such as PCBs, solvents, and pesticides, incineration does not destroy metals. The efficiency of the process depends on three main parameters: temperature of the combustion chamber, residence time of the sediment in the combustion chamber, and turbulent mixing of the sediment. Turbulent mixing is important because the waste and fuel must contact the combustion gases if complete combustion is to occur. Sufficient oxygen must be present and is supplied as ambient air or as pure oxygen through an injection system. Process options include circulating bed combustors, fluidized beds, liquid injection, and rotary kilns.

Although incineration was successfully permitted and implemented at the Bayou Bonfouca Superfund Site in Slidell, Louisiana, the technology has been abandoned at other sites, including New Bedford Harbor in Massachusetts and Reynolds Metals in New York, due to general public perception and other community issues, including concerns over emissions to ambient air. In addition, unit costs of treatment at the Bayou Bonfouca site were approximately $650/cubic yard, significantly higher than landfill disposal fees. Based on past performance at more than 100 CERCLA sites, treatability studies are generally not required for this technology.

5.4.2 Pyrolysis

Pyrolysis is similar to incineration in that organic materials are destroyed by heat; however, the process is conducted in the absence of oxygen. In practice, since it is not possible to achieve a completely oxygen-free atmosphere, some oxygen will be present in any pyrolytic system and nominal oxidation will occur. If volatile or semivolatile materials are present in the waste, thermal desorption will also occur. The concerns over cost, general public acceptance, and emissions control that are associated with incineration also apply to pyrolysis. Unlike incineration, pyrolysis has not been as widely applied to waste remediation and has only been demonstrated at the pilot scale for sediments. Consequently, treatability studies would be needed, at least during design, if this technology were to be used.

5.4.3 Thermal Desorption

Thermal desorption systems separate contaminants from sediment by applying direct and indirect heat. It is a thermal-induced physical process and is not designed to destroy contaminants. Contaminants and water are vaporized from a solid matrix and transported to a gas treatment system. The bed temperatures and residence times designed into these systems will volatilize selected contaminants but will typically not oxidize them. Two common thermal desorption designs are the rotary dryer and thermal screw. Rotary dryers are horizontal cylinders that can be indirect- or direct-fired. For the thermal screw units, screw conveyors or hollow augers are used to transport the medium through an enclosed trough. All thermal desorption systems require treatment of the off-gas to remove particulates and contaminants.

Based on the operating temperature of the desorber, thermal desorption processes can be categorized into two groups: high temperature thermal desorption, which operates at temperatures between 600 and 1,000°F; and low temperature thermal desorption, which operates at temperatures between 200 to 600°F. Exhaust gases produced by the process are typically combusted. Thermal desorption systems can be designed to operate without producing liquid or solid secondary wastes, to meet clean air standards, and to achieve very low levels of residual contaminants in soil. Limitations include high energy requirements for treating wet sediments, difficulty in completely treating sediments containing high levels of organics, and the extensive permitting requirements for on-site thermal desorption systems. Thermal desorption may be accomplished on site with a mobile treatment unit or off site at a permanent treatment facility. Compared to off-site landfill disposal, thermal desorption is typically more expensive, but has the advantage of providing treatment and destruction of contaminants, rather than containment.

The thermal desorption process has been pilot-scale demonstrated through the WRDA Sediment Decontamination Program. The UPCYCLE process is a resident technology at the NY/NJ Harbor regional decontamination facility in Bayshore, New Jersey, that produces a lightweight aggregate that can be beneficially used in concrete mixes. Post-treatment analytical testing on leachate indicated that all metals and inorganic compounds were below locally-established regulatory limits. Similar results have been observed in other demonstrations targeting PCB contamination including the Outboard Marine Corporation Superfund Site in Waukegan, Illinois and the New Bedford Harbor Superfund Site in New Bedford, Massachusetts. Treatability studies would likely be needed during design if this technology were to be used.

5.4.4 Vitrification

Vitrification is a thermal solidification process, conducted at temperatures greater than 1,500°C to melt the sediment particles, that results in the formation of a glass aggregate. The high temperatures destroy any organic constituents with very few by-products and metals are incorporated into a glass structure that is resistant to leaching. Three main process options exist for vitrification: the Westinghouse Plasma Vitrification process, the Minergy Glass Furnace Technology, and the Gas Technology Institute (GTI) Cement-Lock™ Technology. The former two processes result in a beneficial use product that may be used as roofing granules for shingles, roadbed materials, fiberglass insulation, decorative aggregate, or construction block. The GTI process produces construction-grade cement. Vendors for each of the technology variations have completed full-scale demonstrations indicating that remediation efficiencies of greater than 99 percent are regularly achievable. Plans to integrate the GTI process into the NY/NJ Harbor regional decontamination facility in Bayshore, New Jersey, are ongoing.

The downside to this technology is that the process requires significant electrical energy to generate extremely high heat, and thus costs significantly more than many of the other non-thermal treatment alternatives. An economic analysis would be required for the Portland Harbor area to determine the marketability of the vitrification beneficial use products within the region. Thereafter, more accurate treatment costs could be estimated. No additional treatability studies would be required to implement this technology at the Site.

5.5 SUMMARY

The main advantage of ex situ treatment methods over in situ treatment (discussed in the next section) is that they generally require shorter time periods to achieve similar remedial goals. There is also more certainty about the uniformity of treatment applications because of the ability to homogenize, screen, and continuously mix the sediment. In addition, ex situ treatment products can have secondary beneficial uses that can reduce the overall costs of the technology as a whole. However, implementation of ex situ treatment options can have some drawbacks. Because dredging, handling, and application of large amounts of other agents or energy is required, this can increase the overall costs of the process. Also, there are possible permitting issues associated with the final destination of the material in a beneficial use scenario, as well as additional worker exposures associated with the treatment process.

For this project, likely disposal options include placement at the Waste Management facilities in Arlington, Oregon or an equivalent permitted facility. At a minimum, these options would require dewatering prior to handling/transport.

Table 1 summarizes the treatment technologies discussed in this section and provides a preliminary evaluation of each technology’s applicability to this project based on the level of demonstration, effectiveness, resources required, cost, and overall implementability.

6.0 In Situ Treatment

In situ treatment of contaminated sediments involves applying chemical reagents, binding agents, or physical modifications directly to the in-place sediments. The intent of the treatment is to modify the physical and chemical properties of the sediment in such a way as to potentially reduce the concentration, mobility, and/or toxicity of iCOCs. The disadvantage of many in situ treatment technologies is that their effectiveness is often limited by subsurface conditions (e.g., heterogeneous layers, saturation, and ambient temperature) that create inefficiencies in the treatment processes. In addition to demonstrated in situ technologies, there are a number of innovative treatment technologies at various levels of development that are potentially applicable to Site sediments. In situ treatment options can be divided into two primary categories: contaminant destruction/reduction technologies (biological and chemical processes) and contaminant sequestration technologies (S/S and electrochemical remediation).

6.1 BIOLOGICAL/CHEMICAL METHODS

In situ biological and chemical methods are often paired together as they are sometimes implemented in series to enhance the other process or to address a wider range of iCOCs. For both technologies, pilot-scale studies provide the necessary information required to perform a full-scale design, including determining appropriate injection well/point spacing and determining appropriate injection flow rates for liquid delivery and to compare various biological/chemical approaches. Descriptions of candidate technologies are provided below.

6.1.1 Enhanced Bioremediation

Similar to ex situ bioremediation methods, in situ biological treatment refers to the microbial degradation of contaminants by organisms. In situ enhanced bioremediation involves injecting chemicals into sediment to accelerate the destruction of contaminants by biological mechanisms, such as microorganisms. Recent trends have advocated the application of innovative sediment stabilization strategies through the placement of reactive capping material to allow long-term biodegradation of contaminants in the complex biogeochemical sediment environment (Adrieans et al. 2006).

The effectiveness of bioremediation is limited, as are other treatment technologies that rely on subsurface distribution of chemicals, when applied to heterogeneous, low-permeability sediments. In addition, large amounts of organic matter that often exist in sediments compete with contaminants as a carbon source, making treatment less efficient. However, depending on the desired biologic process, organic carbon can enhance reduction reactions such as the dechlorination of PCBs and dioxins and aromatic ring destabilization of PAHs (Adrieans et al. 1999). Low temperature environments also work to slow the remediation process. In field-scale case studies described by Renholds (1998), degradation rates were on the order of 50 to 80 percent for sediments contaminated with various organic compounds. The results are likely indicative of physical conditions adverse to optimal biodegradation, which often exist at sediment sites. Enhanced bioremediation may also be classified as a long-term technology as cleanups often require several years for completion.

Methane-enhanced bioremediation was demonstrated in 1992/1993 at the Savannah River Site located in Aiken, South Carolina. The site was contaminated with DNAPL (primarily as tetrachloroethylene and trichloroethene). After 384 days of operation, concentrations of tetrachloroethylene and trichloroethene in vadose zone sediments were reduced to below detectable limits. Although these results are favorable, the demonstration on Lake Ontario at Hamilton Harbor (Dofasco Boatslip), Canada, indicated degradation rates of PAHs of 15 percent, 48 percent, and 68 percent, respectively, after three discrete injections. Other organic compounds at the Dofasco Boatslip showed more promising degradation rates (approximately 85 percent); however, upon the 1992 injection, naphthalene concentrations increased by 195 percent. Given the wide variety of results, bench- and pilot-scale treatability studies of this technology would be required prior to completing a design.

6.1.2 Phytoremediation

Phytoremediation is an emerging technology that involves the direct use of living plants for in situ remediation of contaminated sediments through contaminant removal, degradation, or containment. Phytoremediation occurs via five main mechanisms:

- Enhanced rhizosphere biodegradation – biological degradation taking place in sediment or porewater immediately surrounding plant roots
- Phytoextraction (or phytoaccumulation) – uptake and accumulation of contaminants into plant stems and leaves
- Phytodegradation – metabolism of contaminants within plant tissues
- Phytostabilization – production of chemical compounds by plants to immobilize contaminants at the interface of roots and sediment
- Phytovolatilization – uptake of volatile contaminant by the plant and volatilization through the foliage via photodegradation

Phytoremediation can be used to clean up metals; benzene, toluene, ethylbenzene, and xylenes (BTEX); TPH; pesticides; chlorinated solvents; crude oil; PAHs; PCBs; radionuclides; and landfill leachates (www.clu-in.org; and ITRC 2005). Phytoremediation has been studied extensively in research and small-scale demonstrations, but full-scale applications are currently limited in number.

Planting a contaminated sediment with shallow water wetland plants or deeper water emergent plants can form a vegetative root mass that acts as a cap to prevent movement of the sediment or contaminant while bioremediation is occurring. A dense root mass not only holds existing sediments in place, it collects and gathers sediments that had been held in suspension, adding to the protective cap over the contamination. A downside to the application is that only a shallow zone of contamination is treated by the process. Although the time-frame can vary significantly depending on the vegetation used and processes involved, time to completion is generally greater than three years, which may not be feasible for an active area of the harbor. Inactive areas that are slated for enhanced natural recovery may benefit from the accelerated recovery associated with the phytoremedation process. Bench- and pilot-scale treatability studies would be required to determine the applicability of phytoremediation to the Site.

6.1.3 Chemical Oxidation

Chemical oxidation typically involves injecting chemical oxidants into the sediment matrix resulting in redox reactions that chemically convert hazardous contaminants to non-hazardous or less toxic compounds. The oxidizing agents most commonly employed are hydrogen peroxide-based Fenton’s reagent and permanganate, and less frequently, ozone. Typically, the injection points are coupled with extraction wells to control the flow and recirculate the oxidizing agent. In locations where the hydraulic gradient is strong, the need to install extraction wells increases in order to control the zone of treatment.

The chemical oxidation process has been demonstrated to produce rapid and complete destruction of several toxic organic chemicals while other organics are only amenable to partial degradation. However, chemical oxidation (the oxidant) can also aid in the subsequent bioremediation of the partially degraded organics. The effectiveness of this technology is generally limited in heterogeneous and low-permeability soils due to poor distribution of the oxidants. Additionally, high concentrations of organic matter in the subsurface consume oxidants and decrease treatment efficiency. Field applications have confirmed that matching the oxidant and in situ delivery system to the iCOCs and site conditions is the key to successful implementation and achieving performance goals. This technology has also been found to mobilize recalcitrant contaminants by enhancing solubility while providing incomplete destruction. In cases where complete destruction is not possible, chemical oxidation may be implemented as a pre-treatment for in situ bioremediation.

A field-scale demonstration using hydrogen peroxide was conducted in 1997 at the Savannah River Site in Aiken, South Carolina. Results indicate that 94 percent of the DNAPL present in the treatment area was destroyed. The inability to attain complete destruction was attributed to the process not contacting all DNAPL globules in the fine-grained sediments. Adverse effects on fish and benthic species, due to the increased temperature and chemical reactions associated with the process, were not investigated as part of the demonstration project. Bench- and pilot-scale treatability studies would be required to determine the applicability of implementing an in situ chemical oxidation process at the Site.

6.2 CONTAMINANT SEQUESTRATION

In situ contaminant sequestration is facilitated through barriers (vertical or horizontal) that isolate contaminants from adjacent sediments and porewater or via a chemical/physical reaction causing the contaminants to be more tightly bound to the sediment matrix.

6.2.1 In Situ Stabilization/Solidification

As described in Section 5.3.3, S/S involves the addition of reagents that immobilize and/or bind contaminants to the sediment in a solid matrix or chemically stable form. Depending upon the iCOCs, reagents may vary from pozzolanic materials to sorptive clays. In situ S/S techniques use auger systems or grout injection systems to apply the reagents to the subsurface. Caisson installation prior to injection has also been used to prevent migration of contaminants into the water column through sediment resuspension and also to isolate the subsurface treatment zone from adjacent sediment.

In some cases reagents have been injected to create zones of low-permeability (i.e., solidified sediment) that serve as isolation barriers. For example, bottom barriers are horizontal subsurface barriers that prevent vertical porewater migration by providing a floor of impermeable material beneath the zone of contamination. Implementation of this technology is highly dependent on the in situ geotechnical properties of the sediment.

A recent field demonstration of in situ S/S using cement based reagents was performed at the Koppers Co., Inc. Charleston Plant on the Ashley River north of Charleston, South Carolina. In this demonstration, the goal was to develop a zone of solidified material that would serve as an isolation barrier between the overlying water and sediments below. No analytical data were collected to determine the efficacy of the treatment with respect to contaminant immobilization. A positive outcome was that a nominal half-foot increase in mudline elevation was observed within the project area following treatment. During other in situ S/S demonstrations, increases in mudline elevation have been excessive. Although considered a successful project, limitations to the technology were identified over the course of the demonstration, including that cement formation was affected by the presence of certain organic and inorganic contaminants, and increased river velocities would lead to difficulties in controlling equipment and releases of reagent (prior to injection).

At another site near Menasha, Wisconsin, lead contamination was discovered during a bridge reconstruction project crossing the Fox River. The project was implemented through the use of a cofferdam system in order to control flow of surface water from the project area. The treatment process achieved reductions in lead leachate concentrations by greater than 99 percent and was deemed a success. However, because the water was completely turbid during treatment, investigators concluded that it would have been impossible to treat the sediment without the cofferdams. This could present problems in larger-scale treatments where the use of cofferdams to section off the contaminated portion is not feasible. No report of any effects on increased mudline elevation was given.

A bench- and pilot-scale treatability study would be required prior to assessment of this technology at the Portland Harbor Site. Adverse effects on fish and benthic species, due to the increased temperature and chemical reactions associated with the process, were not investigated as part of the demonstration projects above. In addition, consideration must be given to the resulting surface associated with S/S as it may not be compatible with habitat restoration goals (e.g., unacceptable habitat substrate) and/or future shoreline development. For example, if deeper draft vessels are desired for future waterfront uses, then the post-remedial monolith (or zone of high-strength material) resulting from S/S may not be easily excavated and could potentially require expensive blasting operations for removal.

6.2.2 In Situ Vitrification

In situ vitrification (ISV) involves applying a strong electrical current to the subsurface, heating sediment to temperatures above 2,400°F to fuse it into a glassy solid. Organic compounds are destroyed or volatilized by the heating process, and volatilized compounds are collected in the off-gas and treated. Inorganic compounds are immobilized within the glass/crystalline structure. The vitrification product is a chemically stable, leach-resistant, glass and crystalline material similar to obsidian or basalt rock. When properly designed, the treatment can be highly effective, although no full-scale applications of ISV have been implemented for sediment remediation. The downside to this technology is that the process requires significant electrical energy to generate extremely high heat, and thus costs significantly more than many of the other non-thermal in situ treatment alternatives.

A pilot study was conducted at the Parsons Chemical/ETM Enterprises Superfund Site in Grand Ledge, Michigan in 1993/1994. Site contaminants included heavy metals, dioxins, and pesticides. Treatment success was evaluated after the vitrified mass cooled (approximately one year). Confirmation coring samples indicated that vitrified sediments met the cleanup criteria for mercury and pesticides and were below detection limits for volatile organic compounds (VOCs) and SVOCs. As expected, the cost of the treatment process was very high at $267/cubic yard (exclusive of design, mobilization, ancillary costs, etc.). Overall, the project proved successful. Adverse effects on fish and benthic species were not investigated as part of this demonstration project.

Like other in situ S/S technologies, a bench- and pilot-scale treatability study would be required. In addition, compatibility with future Site uses (e.g., shoreline development and habitat goals) must be considered.

6.2.3 Electrochemical Remediation

Electrochemical remediation is an innovative technology for destroying organic contaminants in situ by applying an alternating current across electrodes placed in the subsurface. In theory, the applied voltage creates redox reactions that destroy contaminants. The primary advantage of this technology is that it can treat sediment (within both the unsaturated- and saturated-zones) and groundwater. The disadvantages are that it has produced mixed results at the field level, and studies indicate that treatment is less effective in soils and sediments with high organic carbon content, although the process generally performs best on clays that possess negatively charged facies. Another drawback is that other metals can affect the effectiveness of the process; therefore, the process may perform erratically in areas where unidentified debris may be buried below the mudline.

This technology has been field-scale demonstrated by Weiss Associates Electrochemical Remediation Technologies and Lynntech, Inc., at three sites in the United States: the Duluth/Superior Harbor Superfund Site in Minnesota, the Georgia Pacific Remediation Site in Bellingham, Washington, and the Naval Air Weapons Station in Point Magu, California. In spite of several successful demonstrations in Europe, the projects in the United States were unable to yield favorable results. Pilot-scale treatability studies would be needed for this technology.

6.2.4 Enhanced Cap Materials

In cases when traditional capping is found to be potentially ineffective to prevent impacts to surface water, reactive cap materials have been considered a potential modification to the design. In reactive capping, a permeable cap is placed above contaminated sediments, and a material (such as wood waste, coke, organophyllic clays, phosphate additives, zero-valent iron, biopolymers, or activated carbon) is placed within the sediment cap to sorb dissolved-phase contaminants, often facilitating further biodegradation and limiting contaminant migration into overlying sediment porewater and surface water. In certain applications, sorptive caps may lose their effectiveness when the sorptive material becomes saturated. Therefore, for continued effectiveness, a reactive cap should be designed such that one or more of the following design goals are achieved:

- A sufficient volume of sorptive material is added such that its operating lifetime is longer than the projected remediation restoration timeframe.

- A mechanism for replacement of the sorptive layer is incorporated into the design.

- The cap is designed to also biodegrade sorbed contaminants, thereby regenerating the material's sorptive capacity (reactive/sorptive capping).

Biodegradation within the cap can be enhanced by adding amendments, such as calcium nitrate, to the sorptive material. A properly designed cap that combines sorption and biodegradation to treat dissolved-phase contaminants could potentially last indefinitely and not require replacement. Activated carbon (including regenerated products) and more cost-effective coke breeze materials have been used at a number of upland sites as a sorptive barrier to hydrocarbon mobility, and several promising in situ sediment/porewater treatment technologies are currently undergoing pilot-scale testing in aquatic environments, such as the Anacostia River in Washington, D.C. Results from an 18-month monitoring program on the Anacostia River indicate various cap sections tested were effective in preventing chemicals of concern from migrating through the four individual cap areas. The caps placed for the pilot program include:
1) a coke mat placed above a sand layer to evaluate PAH retardation/sequestration;
2) Apatite placed above sand to evaluate metal sequestration/retardation;
3) AquaBlok^{TM} placed above sand to evaluate tidal seepage control; and 4) a conventional sand cap for comparison. Additional data collected between months 18 and 30 show that AquaBlok^{TM} is an effective low-permeability hydraulic barrier reducing seepage from 1 to 5 cm/day less than 1 cm/day.

Organoclay was used as enhanced capping material in the sediment cap at the McCormick & Baxter Site in the Willamette River to control the seepage of creosote NAPL into the river. A series of experiments were conducted to assess the sorption capacity, permeability, swelling characteristics, leachability, and strength of two selected organoclays when exposed to the NAPL from the McCormick & Baxter Site. Sorption capacities of the two organoclays ranged from 1.39 to 4.82 g of NAPL per g of organoclay. Both organoclays were found to provide good control of both dissolved phase and non-aqueous phase contaminants in column tests. The clay used at McCormick & Baxter resulted in a permeability comparable to silt or silty sand (Reible 2005).

Cores collected from the enhanced capping material at McCormick & Baxter two years after the sediment cap was placed were also tested by Dr. Reible. The tests were designed to evaluate the performance through October 2006 of organoclay placed in bulk layers to control potential NAPL migration during 2004 and in mats to control gas (NAPL seeps) during 2005. The following tests were conducted: available sorption capacity for NAPL, percent hexane extractable material (% HEM), permeability, and water content. Available sorption capacity and % HEM were designed to determine the extent to which the organoclay has absorbed NAPL and the potential for further NAPL retention. Permeability was used to assess the ability of NAPL to access available organoclay capacity. Water content influences NAPL capacity and assisted in interpretation of available capacity. The tests indicated that the organoclay has not been affected significantly by NAPL to date. The results from sorption capacity and % HEM tests were essentially equivalent to that expected of water-saturated fresh organoclay. The permeability of the core samples also was essentially equivalent to fresh organoclay (i.e., not NAPL-affected), suggesting that NAPL can continue to penetrate and be sorbed by fresh organoclay if any mobile residual NAPL exists. Strength tests indicated no degradation in organoclay physical integrity over time. These results indicate that the placed organoclay continues to perform as designed and that its ability to contain NAPL has not been compromised by reduction in either capacity or permeability.

Reactive Core Mats were also used effectively at the McCormick & Baxter Site to eliminate ebullition-induced sheen in areas where residual creosote is present in the sediments and there is significant methane production from biological activity.

Limitations of enhanced capping includes the difficulty of placing material in a riverine environment and the limited lifetime of the high value reagents used as enhanced capping material. The placement issues can be overcome by using Reactive Core Mats that are easily emplaced and exchanged. The use of bauxite to sequester metals is another emerging cap enhancement material. Pilot scale testing during design would likely be warranted for this technology.

6.3 SUMMARY

In situ treatment options are attractive when implementable because they generally alleviate the need for a removal GRA, thus reducing the potential impacts to surface water quality and reducing costs associated with moving and manipulating sediments. Subsurface investigations are critical to the success of these treatment processes and necessary to gain an adequate understanding of the complex geologic and hydrologic conditions that exist at many contaminated sites. Furthermore, bench-scale and pilot-scale testing is required in nearly all situations to confirm the effectiveness of the selected technology to the site-specific iCOCs and field conditions. Finally, extensive monitoring programs are necessary to assess the success of the treatment and should be considered as part of the overall remedial costs.

Table 2 summarizes the treatment technologies discussed in this section and provides a preliminary evaluation of each technology’s applicability to this project based on the same criteria used for ex situ technology evaluations.

7.0 Evaluation of Treatment Technologies

This section summarizes the preliminary screening of treatment technologies provided in Tables 1 and 2. The tables provide the overall evaluation and the following text focuses on defining the criteria and judgments used in that screening. The section also provides a preliminary estimate of the sediment volume that could be recommended for removal and subsequent ex situ treatment in the FS in order to provide an initial understanding of the practicability of implementing the treatment technologies identified in this memorandum. The section further classifies the volumes by iAOPC with respect to iCOC type and concentration level.

7.1 GENERAL EVALUATION OF TECHNOLOGIES

An FS evaluation generally ranks various alternatives with respect to three primary criteria: effectiveness, implementability, and cost. The ex situ and in situ treatment technologies discussed in Sections 5 and 6 are summarized in Tables 1 and 2, respectively. Additional details regarding the use of these criteria in the tables are discussed below. The tables also include an initial assessment of the likelihood for a particular treatment technology to be included in an FS alternative, along with other pertinent information to be considered in the technology screening (e.g., the need for pre-FS pilot testing or additional permit requirements associated with siting treatment facilities).

7.1.1 Effectiveness

The ability of a technology to be effective is primarily characterized by the range of iCOCs it is able to remediate at the Site and the level of demonstrated effectiveness it has achieved. Four scaled levels of demonstration are presented in the tables: implemented on a large project and/or commercially available (full-scale); implemented on a large project but not commonplace (limited full-scale); implemented in the field on a small scale (pilot-scale); and tested in a laboratory (bench-scale).

7.1.2 Implementability

Three main categories of information were collected to support an FS implementability ranking as discussed below.

- Resources Required. Several resources, such as the use of large staging areas for extended periods of time and multi-year maintenance and/or monitoring of a treatment installation, may be required to ensure the success of the project. For example, land treatment may prove to be an economically and technically effective method for treatment of TPH affected sediment; however, land to stage the multi-year project may not be available.

- Required Treatability Testing. Many of the treatment technologies described in this memorandum will require some level of testing either prior to implementation or during design. A few promising technologies that are either emerging or whose success is site-specific may require testing prior to the FS in order to evaluate applicability to the Portland Harbor project conditions.

- Primary GRA Compatibility. In general, ex situ technologies will be paired with removal GRAs and in situ technologies will be considered under non-removal GRA scenarios (such as capping or enhanced natural recovery). Many of the ex situ technologies require a specific sediment moisture content prior to entering the treatment train and may be more compatible with one removal method over another (i.e., mechanical or hydraulic dredging). This table column in Tables 1 and 2 notes the most probable GRA compatible with each treatment technology.

7.1.3 Cost

Cost is separated into two columns in Tables 1 and 2: the first indicates the reported range of unit costs associated with the implementing technology and the second column provides a list of pay items not often included in the unit price. The cost ranges (per cubic yard) are presented in four intervals: low (less than $40), moderate ($40 to $80), high ($80 to $160), and very high (greater than $160). These cost ranges were selected, in part, for initial comparison to the cost of transport and disposal of material from the Site to a nearby subtitle D landfill (approximately $50 per cubic yard [cy] to $65 per cy). However, it should be noted that while these implementation costs include a general mobilization fee, they do not consider costs associated with other necessary supporting tasks such as, but not limited to:

- Pre-design bench- or pilot-scale testing.

- Attainment of major permits or equivalents, such as air permits for thermal treatment and water discharge permits for soil washing.

- Long-term monitoring or maintenance associated with in situ technologies.

- Cost of dredging or preparation of sediment prior to ex situ treatment process.

In general, technologies that have estimated unit costs much higher than other effective technologies are not recommended for detailed evaluation in the FS.

7.2 TREATMENT VOLUME ESTIMATE

The FS will evaluate which iAOPCs would be best addressed by removal (rather than in situ management options such as capping) in order to meet the in-river sediment cleanup goals currently in development. An important component of the FS evaluation is the cost analysis to determine the economic viability of treatment. For example, if treatment costs are found to be significantly greater than landfill disposal costs, then it is possible that the FS would recommend disposal over a treatment alternative. However, if marketable beneficial uses of the treated end-product were identified (e.g., material treated by sediment washing is often blended with additional natural aggregate to produce a manufactured topsoil), then the net unit cost of the treatment technology may be reduced and become more competitive with the disposal alternatives. In general, the alternatives to deal with dredged sediment after dewatering include:

- Direct disposal in a Subtitle C or D landfill
- Disposal in a Subtitle C or D landfill following some pre-treatment to meet landfill requirements
- Ex situ treatment with subsequent beneficial use
- Limited beneficial use without pre-treatment (e.g., use as daily cover at a landfill, as fill at an industrial site, or as road base under an impermeable surface cap)

The beneficial use evaluation of treated and untreated dredge sediment options are not part of the scope of this memorandum and will be considered in the FS on a case-by case basis. The alternatives listed above are included for reference only. The purpose of this section is to provide a preliminary evaluation of the volumes potentially available for ex situ treatment to support the FS practicability assessment. Again, because cost is a contributing factor in determining the viability of implementing a treatment technology, an initial estimate of the total potential volume is useful in understanding how capital costs can be distributed over the length of a project, ultimately resulting in a lower net unit cost for projects with larger treatment volumes.

To further understand the sediment volume that potentially is suitable for ex situ treatment in lieu of upland disposal, the iAOPCs were grouped according to contaminant and analyzed with respect to potential upland disposal and cleanup levels to determine which sediments would require pre-treatment prior to landfill disposal under a removal GRA scenario.[1] This approach was taken as regulations that provide guidance or criteria

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[1] Note that comparison of in situ sediment concentrations to upland disposal and soil cleanup values was performed solely to understand whether or not excavated sediments would benefit from ex situ treatment or require pre-treatment prior to disposal. This comparison to upland soil disposal and soil cleanup values is not an indicator of any in situ toxicity and should not be confused with in-river sediment cleanup goals, which have not yet been determined for the Site. Also, comparison of sediment values to soil values involves the assumption that material concentrations will not change through the dredging and any dewatering process, which to some extent is untrue. However, such a comparison provides a useful initial benchmark for consideration of the need for treatment of any removed sediments. Information provided for iAOPC groups that would not likely meet these upland disposal and soil cleanup values could be refined and used in future FS evaluations focused on the specific iCOCs present in the individual iAOPC. In addition, it is expected that the iAOPC boundaries will be refined as the RI and RA are completed, allowing for the designation of additional iAOPCs or the modification or elimination of others.

for placement of upland materials are an important benchmark to evaluate the extent to which treatment is necessary for a given contaminant level. Using the upland criteria, each iAOPC was screened against potential upland disposal and soil cleanup screening levels (values) and then grouped by the primary (or driving) iCOCs present at concentrations elevated above upland values. The FS will re-evaluate this screening. Additional landfill-specific screening requirements will be researched and addressed in the FS as the need for treatment prior to disposal is further evaluated.

7.2.1 Upland Values for Screening

The iCOC concentrations were screened against Oregon Department of Environmental Quality (ODEQ) upland soil cleanup values. For this initial screening of Site iCOCs, the most restrictive ODEQ residential upland soil cleanup risk-based concentrations (RBCs) were used on the basis of protection from direct soil contact (ODEQ 2003 and 2006). The RBCs are considered to be preliminary soil cleanup screening levels and are based on a risk-based decision making process (RBDM) developed by ODEQ in 2003 guiding the evaluation of risk posed to human health and the environment at upland cleanup sites in accordance with Oregon Administrative Rule (OAR) 340-122 – Hazardous Substance Remedial Action Rules (OSOS 2006a). In 2007, the RBDM spreadsheets associated with the original guidance document (ODEQ 2003) were expanded to include generic RBCs of individual chemicals of interest to ODEQ. This guidance is included by reference to OAR 340-122 and replaces, in part, the previously promulgated numeric upland soil cleanup levels (repealed from OAR 340-122-0045).

For iCOCs without calculated RBCs, USEPA guidance was consulted. Prior to 2007, ODEQ human health risk assessment guidance allowed the use of USEPA Region 9 preliminary remediation goals (PRGs) as screening values for site investigations (ODEQ 2003). Because PRGs are no longer updated by USEPA Region 9 on a regular basis, ODEQ now consults screening values developed by USEPA Region 6 for constituents where RBCs are not available. Table 3 summarizes the ODEQ RBCs and Region 6 screening values considered in this memorandum.

For PCB-bearing sediments, additional guidance regarding the disposal and cleanup of upland soil was considered. In 2006, ODEQ proposed guidelines for the beneficial use of “clean” soil generated from upland cleanup projects (ODEQ 2006) based on risk-based screening values. No rulemaking efforts are underway at this time; however, such a process would likely result in an amendment to the solid waste regulations (OAR 340-093, OSOS 2000). The proposed total PCB upland screening value in the 2006 ODEQ draft guidelines is 0.22 milligrams per kilogram (mg/kg), equal to the existing RBC. Since upland disposal of dredged sediment in Oregon is currently governed by OAR 340-093, these regulations were consulted for further insight into acceptable concentrations of PCBs under residential and industrial upland land use scenarios. Storage, treatment, and disposal of PCBs and PCB items (e.g., PCB remediation waste such as affected environmental media) is regulated under OAR 340-110 (OSOS 2000 and 2006b) and, by reference, Title 40 Part 761 of the Code of

Federal Regulations (40CFR761, USEPA 1999c). Under 40CFR761.61(a)(4)(i)(A), the cleanup level for PCB-affected media in high occupancy areas (e.g., residences, schools, office buildings) is 1 mg/kg without further controls such as capping or deed restrictions. If PCB concentrations are present at levels greater than 1 mg/kg, but less than 10 mg/kg, then the affected media may be managed on site and capped.

In Oregon, the cleanup rule (OAR 340-122) further allows for development and use of risk-based generic remedies for "impacted media" under OAR 340-122-0047. In 1997 ODEQ developed guidance for the implementation of generic remedies to facilitate remedial actions for upland sites with PCB-affected soil (ODEQ 1997). This guidance presents protective soil concentrations that correspond to human-health risk-based concentrations derived for a lifetime excess cancer risk of 10^{-6}. The upland generic remedy soil values are 1.2 mg/kg and 7.5 mg/kg, respectively, for residential and industrial land use scenarios. Although the guidance provided in the PCB generic remedy document is not directly applicable to the upland disposal of dredged sediments; it does provide insight into acceptable PCB concentrations implemented for residential and industrial land use projects. These generic remedy cleanup levels, as well as the cleanup levels codified in 40CFR761, were used to further categorize PCB-bearing sediment into the iAOPC groups discussed in Section 7.2.2.

7.2.2 Identification of iAOPC Groups

Average concentrations of target iCOCs were evaluated for each individual iAOPC. The iCOC concentrations that posed a lesser impact to sediment quality in each iAOPC were not selected in the resulting determination of iCOC drivers. The iCOCs that were identified as primary iCOC drivers for the purpose of iAOPC grouping were PCBs, arsenic, pesticides, TPH, and PAHs. The 27 of the 29 iAOPCs identified in Section 2.2 were divided into groups by iCOC drivers upon screening with the upland criteria to determine if treatment options are viable for larger iAOPC-combined areas. As noted in Table 4, PCBs are the iCOC driver for Groups A, B, and C. The categorization of these groups was completed using ODEQ's residential RBC (0.22 mg/kg) and upland generic remedy soil protection level (1.2 mg/kg) as thresholds. For the remainder of the groups, arsenic is the iCOC driver for Group D, pesticide compounds are the iCOC drivers for Group E, and TPH and PAHs are iCOC drivers for Group F. The spatial distribution of the iAOPC groups is shown on Figure 1.

Dioxins were not considered as a primary driver in the iAOPC grouping as the remedial goals for this Site are not yet understood. The literature review indicated that for upland CERCLA and Resource Conservation and Recovery Act (RCRA) sites, the USEPA has recommended that initial soil cleanup levels for residential land use scenarios be set at 1,000 pg/g toxicity equivalents (USEPA 1998e and U.S. Congress 1991), which is consistent with the Federal land disposal restriction values (40CFR268). Although not indicative of in situ sediment toxicity or ODEQ upland remedial goals, this criterion is two orders of magnitude greater than the dioxin concentrations observed in iAOPCs with detectable dioxin (iAOPCs 13, 15, and 17), with the exception of iAOPC 14. Dioxin concentrations within iAOPC 14 averaged approximately 700 pg/g on the surface and approximately 300 pg/g in subsurface samples; therefore, pre-treatment prior to disposal is likely not required. As shown in Table 4, iAOPC 14 is primarily affected by pesticide compounds. In general, ex situ treatments applicable to pesticides are also effective in the treatment of dioxin contamination. FS evaluations of this iAOPC will need to address both iCOCs when evaluation treatment options.

7.2.3 Preliminary Treatment Volume Assessment

Volume estimates of sediment contained within each iAOPC listed in Table 4 were approximated using an iAOPC-wide depth of contamination based on available subsurface sediment analyses. It is estimated that the vertical extent of contamination is 10 feet below the mudline for most iAOPCs except for two iAOPCs with highly elevated iCOC sediment concentrations (iAOPCs 11 and 14). These iAOPCs exhibit greater depths of contamination warranting the use of a depth of 15 feet below mudline as an initial approximate depth in which to calculate a preliminary sediment volume. More detailed volume estimates will be made for the FS, but these preliminary values are sufficient for the purpose treatment technology screening.

Based on initial volume estimates, it is evident that PCBs are the primary iCOCs driving potential remedial action for approximately 69 percent of the total estimated project volume within the 29 iAOPCs identified in the Round 2 Report. Table 4 indicates that approximately 44 percent of the potential total Site sediment volume is contained within iAOPC Groups A and B at contaminant concentrations less than the more restrictive cleanup levels; therefore, this sediment would not likely require ex situ treatment prior to disposal. Although similar in characterization to Groups A and B, sediments in Group C may require additional evaluation in FS to determine if treatment is economically viable as maximum concentrations are greater than the upland criteria. The remaining iAOPC Groups D through F may require pre-treatment prior to disposal; however, the final iCOC delineation and characterization in the RI has yet to be completed. More importantly, these volumes may change as the FS evaluates the most cost-effective GRA alternatives in accordance with the CERCLA FS criteria and evaluation process. In summary, the evaluation of the potential volumes contained within the preliminary iAOPC Groups can be categorized as the following:

- Sediment not requiring pre-treatment prior to disposal – 44 percent or approximately 2,900,000 cy
- Sediment potentially benefiting from treatment – 25 percent or approximately 1,700,000 cy
- Sediment potentially requiring pre-treatment prior to disposal – 31 percent or approximately 2,100,000 cy

8.0 Final Evaluation and Treatability Study Recommendations

The primary goals of this technical memorandum are to provide information on the potential suitability of various technologies for the treatment of sediments associated with the Portland Harbor Superfund Site and to identify the need for any treatability studies. This final evaluation identifies those technologies that the LWG has judged would likely be retained as viable FS options and makes initial recommendations regarding the need for and timing of treatability studies.

It should be noted that the final evaluation summarized here should be viewed as a preliminary recommendation by the LWG. As such, the LWG is interested in discussing with USEPA and its partners any treatment technologies that they wish to consider further and the rationale for further evaluating those technologies in comparison to the information provided here. Through this ongoing discussion, the LWG hopes to work collaboratively with USEPA and its partners to identify a reasonable subset of treatment technologies (and any associated necessary treatability studies) to evaluate in the FS.

As shown in Tables 1 and 2, several of the technologies evaluated are considered likely to be carried forward through the FS process. Selections of ‘very likely’ or ‘likely’ of undergoing further evaluation in the FS process are based on the technology’s ability to remediate Site iCOCs, demonstrated level of effectiveness, relative commercial availability, cost to implement, potential for end-product beneficial uses, and overall ease of implementation. Cost and level of demonstrated effectiveness at other sites are two of the primary differentiating factors in this selection. Many of the ex situ treatment technologies considered have relatively high costs in comparison to other potential remedial alternatives (such as landfill disposal or in situ capping). Consequently, most treatment technologies rated as having even a relatively “moderate” cost (as compared to other treatment technologies) can have relatively high costs in comparison to options such as disposal or capping. On this basis, technologies that were rated as having “low” costs were most often selected as likely or very likely, as shown in Tables 1 and 2.

As a result, many of the treatment technologies likely to move forward into the FS are generally conducted in combination with other technologies (e.g., dredging and disposal in the case of dewatering) or have potential beneficial uses (such as manufactured topsoil) of the material combined with relatively low process costs. Additional costs that arise from a single technology, combination of technologies such as mobilization, facility construction, or long-term maintenance costs should be considered in the total system cost of a technology. Ex situ treatment technologies, such as some dewatering techniques requiring large staging areas, would face permitting timeframes that must be evaluated in the FS process. Lead time for permitting (or completion of equivalent regulatory processes) to site facilities would be assumed to be minimally accelerated under the CERCLA process. In situ technology operations would likely be limited to fish window construction regulations.

Technologies that are primarily in the development stage and/or have not been demonstrated at full scale at multiple sites will likely be difficult to both evaluate and implement without considerable research-level analysis and treatability tests, thus increasing the overall unit cost of the technology. Even with this level of analysis, the results of these extensive efforts can be a determination that the technologies are ‘unlikely’ or ‘very unlikely’ for various reasons. Unless there is some other potential major advantage to untested technologies, there is no compelling reason to use such technologies over better understood and tested technologies.

The technologies most likely to be carried forward in the FS evaluation and development of remedial action alternatives include:

- Pre-treatment technologies
  - In-barge dewatering
  - Mechanical dewatering
  - Reagent dewatering
  - Geotextile dewatering
- Ex situ physical/chemical technologies
  - Cement/pozzolanic-based S/S
  - Asphalt emulsion
  - Particle separation
- In situ contaminant sequestration
  - Enhanced (reactive) capping

Technologies assessed as ‘unlikely’ in Tables 1 and 2 have the potential for further consideration as additional studies related to the RI/FS are completed. For example, some of the ex situ biological methods require large staging areas. At this time no such facilities have been identified to support the technologies; however, a facility siting study is to be conducted as part of the FS process. After this study is completed, a more detailed evaluation of ex situ technologies requiring larger, long-term staging facilities could be performed. Similarly, costs associated with ex situ physical/chemical-based technologies (such as sediment washing) could be refined once actual areas of concern are designated and GRAs are selected for each area. In some cases, this memorandum assessed these technologies as ‘unlikely’ because of the high costs associated with implementing the technology on a short-term, relatively small-scale project basis (i.e., projects approximately 100,000 cy or less in volume). The preliminary volume estimate presented in Table 4 indicates that the potential project sediment yield could support a multi-year treatment operation. For example, if Group C sediments were dredged and subsequently treated, this activity would logistically occur over several years, thus spreading the capital costs, and potentially increasing the economic viability of implementing a particular technology (i.e., unit costs could be competitive with landfill disposal).

Of the technologies assessed as ‘very likely’ and ‘likely’, all will require some bench-scale testing to finalize the design of the process systems for these technologies. Because these technologies are technically proven and demonstrated, this information is not critical to the FS evaluation and would be performed during the remedial design investigation. An exception to this may be that the ‘very likely’ and ‘likely’ technologies that have not been well demonstrated at sites with very elevated contaminant concentrations (e.g., sites exceeding cleanup levels by several orders of magnitude or with free product) may require pre-FS testing in order to assess applicability to the Portland Harbor project.

Other technologies assessed as ‘unlikely,’ but that have the potential to become economically viable (e.g., ex situ biological and physical/chemical methods) would also require some pre-design bench- or pilot-scale testing. Because many of these technologies have not been fully demonstrated, pre-design testing during the FS may be warranted as noted in Tables 1 and 2. Prior to initiating pre-design studies for the less likely technologies, we recommend further investigation of the costs associated with these technologies to better determine the likelihood of being carried forward in a detailed FS evaluation. If so, treatability testing of these technologies in late 2008 (after the RI and at the start of the FS) may be warranted to further evaluate their effectiveness and feasibility for the FS. These cost evaluations should include an economic analysis of the marketability for beneficial uses of these end products so that accurate remedial unit costs can be estimated.

Once final contaminants of concern, remedial cleanup goals, and potential volumes of sediment are identified for the Portland Harbor project, the case studies for the selected candidate technologies should be reviewed to ensure the treatment efficiencies are achievable given Site conditions. Discussions with the technology vendors will then be required to refine remedial unit costs for each process option.

With the completion of the Round 2 Report, it was possible to preliminarily determine the percentage of sediment that may require pre-treatment prior to disposal if a removal GRA is selected. As discussed in Section 7, iAOPCs can be grouped into six groups based on the presence and concentration of various iCOCs. Approximately 69 percent of the total estimated project volume is driven by the potential need to address elevated concentrations of PCBs. Based on an initial evaluation, approximately 31 percent of the sediment contained within the Site limits may benefit from treatment. The viability of the treatment options will be evaluated in detailed in the FS report.

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Tables

Table 1. Summary and Evaluation of Ex Situ Treatment Technologies.

	Effectiveness			**Implementability**			**Cost[2]**		
Treatment Technology	**Addresses Site iCOCs**	**Level of Demonstration[1]**	**Demonstrated Effectiveness**	**Resources Required**	**Required Treatability Testing**	**Primary GRA Compatibility**	**Unit Cost Per Cubic Yard**	**Associated Pay Items**	**Probability of Further Evaluation and Considerations for Evaluation in FS**
Pre-treatment									
In-barge Dewatering	N/A	Full-scale	Moderate to High	Minimal staging areas; days to meet goals	None	Dredging – mechanical	Low	Dredging	Very Likely - Regularly implemented and low cost
Lagoon Dewatering	N/A	Full-scale	High	Large staging areas; months to meet goals	None	Dredging – mechanical or hydraulic	Low	Dredging	Unlikely - Large staging area is required to site facility
Geotextile Tube Dewatering	N/A	Limited Full-scale	Moderate to High	Moderate to large staging areas; weeks/months to meet goals	Bench-scale (possible pilot) during design	Dredging – hydraulic	Low to Moderate	Dredging	Likely - Implementation would depend on dredge methodology
Mechanical Dewatering	N/A	Full-scale	High	Minimal staging areas; days to meet goals; equipment maintenance	Bench-scale during design	Dredging – mechanical or hydraulic	Low	Dredging	Very Likely - Regularly implemented and low cost
Reagent Dewatering	See Cement S/S	Full-scale	Moderate to High	Minimal staging areas; days to meet goals; equipment maintenance	Bench-scale during design	Dredging – mechanical	Low to Moderate	Dredging	Very Likely - Regularly implemented and low cost
Biological Methods									
Land Treatment	TPH and PAHs	Full-scale	Low to High	Large staging areas; months/years to meet goals	Bench- and pilot-scale during design	Dredging – dewatered	Low to Moderate	Dredging and Dewatering; potential pre-FS testing	Unlikely - Large staging area is required to site facility
Composting	PAHs	Full-scale	Low to High	Large staging areas; months/years to meet goals	Bench- and pilot-scale during design	Dredging – dewatered	Low to Moderate	Dredging and Dewatering; potential pre-FS testing	Unlikely - Large staging area is required to site facility
Biopiles	VOCs, SVOCs, TPH, and Pesticides	Full-scale	Low to High	Large staging areas; months/years to meet goals	Bench- and pilot-scale during design	Dredging – dewatered	Low to Moderate	Dredging and Dewatering; potential pre-FS testing	Unlikely - Large staging area is required to site facility
Slurry-phase Treatment	VOCs and SVOCs	Full-scale	Low to High	Minimal staging areas; months to meet goals; equipment maintenance	Bench- and pilot-scale during design	Dredging – hydraulic or slurried	Moderate	Dredging; potential pre-FS testing	Unlikely - Implementation may be dependent on dredge methodology
Physical/Chemical Methods									
Particle Separation	Metals and Organics	Full-scale	Moderate to High	Minimal staging areas; days to meet goals; equipment maintenance; compatible end-use	Bench-scale during design	Dredging – mechanical	Moderate	Dredging	Likely - Viable implementation would depend on high sand concentrations
Blending	Low level metals and organics	Full-scale	High	Minimal staging areas; days to meet goals; equipment maintenance	Bench-scale during design	Dredging – dewatered	Moderate to High	Dredging and Dewatering	Unlikely - Can be costly depending upon prevailing aggregate prices
Cement S/S	Metals and select organics	Full-scale	Moderate to High	Minimal staging areas; days to meet goals; equipment maintenance; compatible end-use	Bench-scale during design	Dredging – mechanical	Low to Moderate[3]	Dredging	Very Likely - Regularly implemented and low cost
Sorbent Clay S/S	Select organics	Bench-scale	Moderate to High	Minimal staging areas; days to meet goals; equipment maintenance; compatible end-use	Bench-scale during design	Dredging – mechanical	Moderate	Dredging	Unlikely - Can be costly and not effective for all iCOCs. May be better implemented as an in situ technology.

Table 1. Summary and Evaluation of Ex Situ Treatment Technologies.

	Effectiveness			Implementability			Cost[2]		
Treatment Technology	**Addresses Site iCOCs**	**Level of Demonstration[1]**	**Demonstrated Effectiveness**	**Resources Required**	**Required Treatability Testing**	**Primary GRA Compatibility**	**Unit Cost Per Cubic Yard**	**Associated Pay Items**	**Probability of Further Evaluation and Considerations for Evaluation in FS**
Asphalt Emulsion	Metals and Organics	Bench-scale	Moderate to High	Minimal staging areas; days to meet goals; equipment maintenance; compatible end-use	Bench-scale during design	Dredging – mechanical	Low to Moderate[3]	Dredging	Very Likely - Regularly implemented and low cost
Sediment Washing	Metals and Organics	Limited Full-scale	Moderate to High	Minimal staging areas; days to meet goals; equipment maintenance; compatible end-use	Bench-scale during design (potentially during FS)	Dredging – mechanical or hydraulic	Moderate to High[3]	Dredging	Unlikely - Additional permitting may be required; additional treatment of by-products may be required
Chemical Extraction	Organics	Pilot-scale	Moderate to High	Minimal staging areas; weeks/months to meet goals; equipment maintenance	Bench-scale during design (potentially during FS)	Dredging – mechanical or hydraulic	High to Very High	Dredging	Unlikely - Additional permitting may be required; additional treatment of by-products may be required
Chemical Oxidation	Organics	Pilot-scale	Moderate	Minimal staging areas; weeks to meet goals; equipment maintenance	Bench-scale during design (potentially during FS)	Dredging – mechanical or hydraulic	High to Very High	Dredging	Unlikely - Additional permitting may be required; additional treatment of by-products may be required
Dehalogenation	PCBs, Dioxins/Furans, Pesticides, and SVOCs	Pilot-scale	Moderate to High	Minimal staging areas; months to meet goals; equipment maintenance; moderate energy draw	Bench-scale during design (potentially during FS)	Dredging – dewatered	High to Very High	Dredging and Dewatering	Unlikely - Additional permitting may be required; additional treatment of by-products may be required
Thermal Methods									
Incineration	Volatile metals and Organics	Full-scale	High	Minimal staging areas; days to meet goals; equipment maintenance; significant energy draw	Possible bench-scale during design	Dredging – mechanical or hydraulic	High to Very High	Dredging	Unlikely - Additional permitting may be required
Pyrolisis	Organics	Pilot-scale	High	Minimal staging areas; days to meet goals; equipment maintenance; significant energy draw	Possible bench-scale during design	Dredging – dewatered	High	Dredging and Dewatering	Unlikely - Additional permitting may be required
Thermal Desorption	PCBs, PAHs, VOCs, SVOCs, and Pesticides	Pilot-scale	Moderate to High	Minimal staging areas; days to meet goals; equipment maintenance; significant energy draw; compatible end-use	Bench-scale during design	Dredging – dewatered	Moderate to High[3]	Dredging and Dewatering	Unlikely - Additional permitting may be required
Vitrification	Metals and Organics	Pilot-scale	High	Minimal staging areas; days to meet goals; equipment maintenance; significant energy draw; compatible end-use	Possible bench-scale during design	Dredging – dewatered	Moderate to High[3]	Dredging and Dewatering	Unlikely - Additional permitting may be required

Notes:

1-Includes demonstrations performed on sediment; not inclusive of upland soil or sludge.

2-Low: <$40 per cubic yard; Moderate: $40 to $80 per cubic yard; High: $80 to $160 per cubic yard; Very High: >$160 per cubic yard

3-Lower end of cost scale is achievable if marketable uses are identified to support end-use products. Economic analysis would be required.

● This table supports Section 7.1 of the main document, which provides additional detail regarding the general evaluation criteria. Listed cost ranges were selected, in part, for initial comparison to the cost of transport and disposal of material from the Site to a nearby subtitle D landfill (approximately $50 per cy to $65 per cy). However it should be noted that while these implementation costs include a general mobilization fee, they do not consider costs associated with other necessary supporting tasks noted in the table.

Table 2. Summary and Evaluation of In Situ Treatment Technologies.

	Effectiveness			Implementability			Cost[2]		
Treatment Technology	**Addresses Site iCOCs**	**Level of Demonstration[1]**	**Demonstrated Effectiveness**	**Resources Required**	**Required Treatability Testing**	**Primary GRA Compatibility**	**Unit Cost Per Cubic Yard**	**Associated Pay Items**	**Probability of Further Evaluation and Considerations for Evaluation in FS**
Biological/Chemical									
Enhanced Bioremediation	PAHs and SVOCs	Pilot-scale	Moderate to High	Treatment area is extensive; years to meet goals; regular monitoring; success is difficult to assess	Bench- and pilot-scale during FS	Enhanced Natural Recovery	Low to Moderate	Long-term monitoring; potential pre-FS testing	Unlikely - High concentrations of chlorinated organics toxic to beneficial microorganisms; technology not well demonstrated
Phytoremediation	Metals, Pesticides, PAHs, and TPH	Pilot-scale	Moderate to High	Treatment area is extensive; years to meet goals; regular monitoring; success is difficult to assess	Bench- and pilot-scale during FS	Enhanced Natural Recovery	Low to Moderate	Disposal of harvested plants; long-term monitoring; potential pre-FS testing	Unlikely - Not effective with PCBs; high concentrations of chemical toxic to plants; limited to shallow sediments; technology not well demonstrated[3]
Chemical Oxidation	Metals and Organics	Pilot-scale	Moderate to High	Treatment area is extensive; months to meet goals; regular long-term maintenance; success is difficult to assess	Bench- and pilot-scale during FS	Enhanced Natural Recovery	High	Long-term monitoring	Unlikely - Costly; technology not well demonstrated
Contaminant Sequestration									
In Situ S/S	Metals and Select Organics	Pilot-scale	Low to High	Minimal staging areas; months to meet goals; periodic monitoring; success is difficult to assess	Bench- and pilot-scale during design	Capping	High	May reduce value of property due to berth restrictions; long-term monitoring	Unlikely - Costly; technology not well demonstrated in water
In Situ Vitrification	Metals and Organics	Pilot-scale	Moderate to High	Treatment area is extensive; year to meet goals; equipment maintenance; moderate energy draw; success is difficult to assess	Pilot-scale during design	Capping	High to Very High	May reduce value of property due to berth restrictions	Very Unlikely - Costly; technology not well demonstrated
Electrochemical Remediation	Metals and Select Organics	Pilot-scale	Low to Moderate	Treatment area is extensive; months to meet goals; equipment maintenance; moderate energy draw; success is difficult to assess	Pilot-scale during FS	Enhanced Natural Recovery	Moderate	Long-term monitoring	Unlikely - Costly; technology not well demonstrated
Enhanced Cap Materials	Metals and Select Organics	Pilot-scale	Moderate	Minimal staging areas; months to meet goals; maintenance of cap materials; periodic monitoring; success is difficult to assess	Bench- and pilot-scale during design	Capping	Low	May reduce value of property due to berth restrictions; long-term monitoring	Very Likely - Low cost; capping technology enhancement[4]

Notes:

1-Includes demonstrations performed on sediment; not inclusive of upland soil or sludge.

2-Low: <\$40 per cubic yard; Moderate: \$40 to \$80 per cubic yard; High: \$80 to \$160 per cubic yard; Very High: >\$160 per cubic yard

3-Technology may be retained if it is determined to be compatible with any potentially identified habitat enhancement areas.

4-Technology would only be retained in the event traditional capping is not effective in protecting the environment.

● This table supports Section 7.1 of the main document, which provides additional detail regarding the general evaluation criteria. Listed cost ranges were selected, in part, for initial comparison to the cost of transport and disposal of material from the Site to a nearby subtitle D landfill (approximately \$50 per cy to \$65 per cy). However it should be noted that while these implementation costs include a general mobilization fee, they do not consider costs associated with other necessary supporting tasks noted in the table.

Table 3. Preliminary Screening Criteria.

Contaminant	Oregon DEQ	USEPA Region 6	
	Soil RBC Residential (mg/kg)	**Soil Screening Level Residential (mg/kg)**	**Soil Screening Level Industrial* (mg/kg)**
Aldrin	2.9E-02	2.9E-02	1.1E-01
Arsenic (non-cancer endpoint)	--	2.2E+01	2.8E+02
Arsenic (cancer endpoint)	3.9E-01	3.9E-01	1.8E+00
Cadmium and compounds	1.5E+03	3.9E+01	5.6E+02
Dieldrin	3.0E-02	3.0E-02	1.2E-01
DDD	2.4E+00	2.4E+00	1.1E+01
DDE	1.7E+00	1.7E+00	7.8E+00
DDT	1.7E+00	1.7E+00	7.8E+00
Dibutyl phthalate	--	6.1E+03	6.8E+04
Endrin	1.8E+01	1.8E+01	2.1E+02
Mercury and compounds	2.3E+01	2.3E+01	3.4E+02
Total Petroleum Hydrocarbons (TPHs)			
Generic Gasoline	7.2E+02	--	--
Generic Diesel / Heating Oil	3.9E+03	--	--
Generic Mineral Insulating Oil	9.8E+03	--	--
Polychlorinated biphenyls (PCBs)	2.2E-01	2.2E-01	8E-01
Polynuclear Aromatic Hydrocarbons (PAHs)			
Acenaphthene	2.9E+03	3.7E+03	3.3E+04
Anthracene	2.1E+04	2.2E+04	1.0E+05
Benz[a]anthracene	1.5E-01	1.5E-01	2.3E+00
Benzo[b]fluoranthene	1.5E-01	1.5E-01	2.3E+00
Benzo[k]fluoranthene	1.5E+00	1.5E+00	2.3E+01
Benzo[a]pyrene	1.5E-02	1.5E-02	2.3E-01
Chrysene	1.5E+01	1.5E+01	2.1E+02
Dibenz[ah]anthracene	1.5E-02	1.5E-02	2.1E-01
Fluoranthene	2.3E+03	2.3E+03	2.4E+04
Fluorene	2.6E+03	2.6E+03	2.6E+04
Indeno[1,2,3-cd]pyrene	1.5E-01	1.5E-01	2.3E+00
Naphthalene	3.4E+01	1.2E+01	2.1E+02
Pyrene	1.7E+03	2.3E+03	3.2E+04
Silver and compounds	3.9E+02	3.9E+02	5.7E+03
2,3,7,8-TCDD (dioxin)	3.9E-06	3.9E-06	1.8E-05
Zinc	--	2.3E+04	1.0E+05

Notes:

*Based on outdoor industrial worker exposure including dermal contact.

Table 4. Summary of iAOPC Group Categories and Volumes.

iAOPC Group	iAOPCs in Group	Area of iAOPC Group (acre)	Estimated depth of contamination (ft)	Estimated Volume (cy)	Percent of Total Project Volume	iCOC Driver	In Situ iCOC Concentration Ranges[4]	Comments
A	2, 6, 8, 9, 16, 20, 25, 27	24.81	10	400,270	6	PCBs	All samples < 0.22 mg/kg	Treatment likely not required prior to disposal. Screening concentration of 0.22 mg/kg is based on the ODEQ upland soil RBCs.
B	4, 5, 7, 12, 13[1], 17, 18, 23, 24, 26	155.16	10	2,503,258	38	PCBs	All samples < 1 mg/kg	Treatment likely not required prior to disposal. Screening concentration of 1 mg/kg is based on the ODEQ generic remedy soil cleanup level for PCBs and USEPA soil cleanup level under 40CFR761 for unrestricted residential land use.
C	1, 3, 19, 22	103.56	10	1,670,000	25	PCBs	Average ~ 1 mg/kg; Average Max ~ 16 mg/kg	Treatment likely not required prior to disposal; viability will depend on final remedial goals and refined costs.
D	10, 15, 21	43.09	10	695,000	10	Arsenic	Average ~ 11 mg/kg; Average Max ~ 35 mg/kg	Treatment is potentially viable, but will depend on final remedial goals and refined costs. The average PCB concentration of sediment in iAOPC Group D is less than 1 mg/kg.
E	14	40.78	15	990,000	15	Pesticides	Average ~ 31 mg/kg; Average Max ~ 1,790 mg/kg[2]	Treatment is potentially viable, but will depend on final remedial goals and refined costs. Pre-treatment may also be required prior to disposal. The maximum PCB concentration of sediment in iAOPC Group D is less than 1 mg/kg.
F	11	17.56	15	425,000	6	TPH PAHs	Average ~ 6,710 mg/kg; Average Max ~ 89,250 mg/kg Average ~ 63 mg/kg; Average Max ~ 780 mg/kg[3]	Treatment is potentially viable, but will depend on final remedial goals and refined costs. Pre-treatment may also be required prior to disposal. The maximum PCB concentration of sediment in iAOPC Group D is less than 1 mg/kg.

Notes:

[1] Estimated elevated concentrations of PCBs in iAOPC 13 were identified in surface samples only. The average PCB surface concentration in the iAOPC is less than 1 mg/kg and the maximum concentration measured is 3.1 mg/kg; therefore, it is not likely that treatment would be considered as a viable alternative in the Feasibility Study. The total volume of sediment associated with this iAOPC is approximately 40,000 cy.

[2] Concentrations of total 2,4' and 4,4'-DDT are noted in the table. Other pesticides are present at elevated levels in the surface and subsurface sediment. See Section 7 for a discussion of dioxin concentrations.

[3] Concentrations of benzo(a)pyrene are noted in the table. Other PAHs are present at elevated levels in the surface and subsurface sediment.

[4] Concentration range data was summarized from Tables 11.3.1 through 11.3.20 of the Round 2 Report. Averages include detected and non-detected concentrations in surface and subsurface samples.

- This table supports Section 7.2 of the main document, which analyzes the various iAOPCs with respect to potential upland disposal and cleanup levels to determine which sediments would require landfill disposal (or treatment) under a removal GRA scenario. Note that comparison of in situ sediment concentrations to upland disposal and soil cleanup screening levels was performed solely to preliminarily estimate the volume of sediments that could potentially benefit from ex situ treatment in lieu of direct landfill disposal, or may requirement pre-treatment prior to disposal. These screening levels are not an indicator of any in situ toxicity and should not be confused with in-river sediment cleanup goals, which have not yet been determined for the Site.

Figures

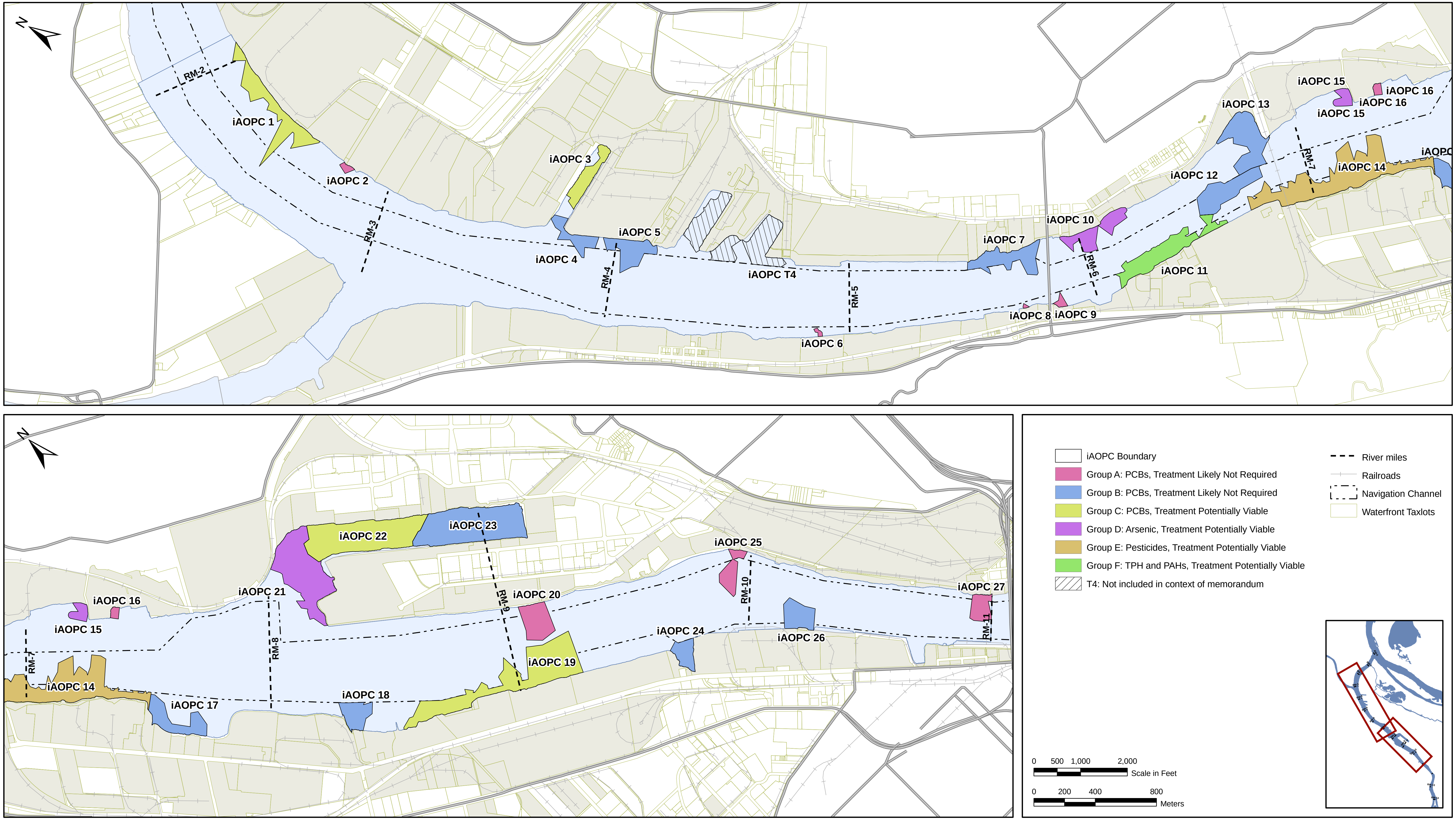

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Figure 1
Portland Harbor RI/FS
Treatability Study Literature Survey Technical Memorandum
Initial Areas of Potential Concern Grouped By Driver iCOCs
River Mile 02 to 11