United States
Environmental Protection
Agency

Office of
Research and Development
Washington DC 20460

EPA/625/6-91/028
April 1991

Handbook

Remediation of Contaminated Sediments

EPA/625/6-91/028
April 1991

Handbook

Remediation of Contaminated Sediments

Center for Environmental Research Information
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

AET	Apparent Effects Threshold
ANSI	American National Standards Institute
ARAR	Applicable or Relevant and Appropriate Regulation
ARCS	Assessment and Remediation of Contaminated Sediments
BEST	Basic Extraction Sludge Treatment
CAA	Clean Air Act
CAD	Contained Aquatic Disposal
CDF	Confined Disposal Facility
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSD	Criteria and Standards Division
CWA	Clean Water Act
DOD	Department of Defense
EIS	Environmental Impact Statement
EP	Extraction Process
EPA	Environmental Protection Agency
EqP	Equilibrium Partitioning
ERL	Environmental Research Laboratory
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GLNPO	Great Lakes National Program Office
GLWQA	Great Lakes Water Quality Agreement
ISV	In Situ Vitrification
LEEP	Low Energy Extraction Process
LTTS	Low Temperature Thermal Stripping
MPRSA	Marine Protection, Research, and Sanctuaries Act
NEP	National Estuary Program
NEPA	National Environmental Policy Act
NETAC	National Effluent Toxicity Assessment Center
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
OERR	Office of Emergency and Remedial Response (Superfund)
OMEP	Office of Marine and Estuarine Protection
QAPP	Quality Assurance Program Plan
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
RCRA	Resource Conservation and Recovery Act
RHA	Rivers and Harbors Act
ROV	Remote Operated Vehicle
SAB	Science Advisory Board
SARA	Superfund Amendments and Reauthorization Act
SBLT	Standard Batch Leachate Test
SITE	Superfund Innovative Technology Evaluation
SLT	Standard Leachate Test
SQC	Sediment Quality Criteria
TCLP	Toxicity Characteristic Leaching Procedure
TEA	Triethylamine
TIE	Toxicity Identification Evaluation
TSCA	Toxic Substances Control Act
UCS	Unconfined Compressive Strength
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
VOC	Volatile Organic Compound

ACKNOWLEDGEMENTS

This document is a compilation of material applicable to the remediation of sites that contain contaminated sediments. The information was compiled by Mr. Timothy Voskuil of EQUITY ASSOCIATES, Inc., Knoxville, Tennessee under the technical direction of Mr. Ed Barth of the Center for Environmental Research Information, Cincinnati, Ohio. Dr. Carol Bass of the Office of Emergency Response, Washington, D.C. provided program office input. Many individuals contributed to the preparation and review of this document; a partial listing appears below.

Development of Material

Physical and Chemical Characteristics of Sediments

Dr. Robert P. Gambrell, Louisiana State University, Baton Rouge, Louisiana.
Dr. William H. Patrick, Louisiana State University, Baton Rouge, Louisiana.

Sediment Toxicity Methods

Dr. Carol Bass, USEPA, Office of Emergency Response, Washington, D.C.
Mr. Chris Zarba, USEPA, Office of Water, Washington, D.C.

Procedures for Characterization of Contaminated Sediments

Dr. Steve McCutcheon, USEPA, Environmental Research Laboratory, Athens, Georgia
Mr. Jan Miller, USACE, Chicago, Illinois

Removal and Transport

Mr. Jan Miller, USACE, Chicago, Illinois

Pre-Treatment

Mr. Daniel Averett, USACE, Waterways Experimental Station, Vicksburg, Mississippi

Treatment Technologies

Mr. Daniel Averett, USACE, Waterways Experiment Station, Vicksburg, Mississippi
Mr. Ed Barth, USEPA, Center for Environmental Research Information, Cincinnati, Ohio
Mr. Rich Griffiths, Risk Reduction Emergency Laboratory, Edison, New Jersey
Dr. George Hyfantis, International Waste Management Systems, Knoxville, Tennessee
Mr. Tommy Meyers, USACE, Waterways Experiment Station, Vicksburg, Mississippi
Dr. Gary Sayler, Center for Environmental Biotechnology, University of Tennessee, Knoxville, Tennessee
Mr. Dennis Timberlake, USEPA, Risk Reduction Laboratory, Cincinnati, Ohio

Disposal

Mr. Jan Miller, USACE, Chicago, Illinois

Technical Reviewers

Mr. Joe Corrado, Malcolm Pirnie, Inc., White Plains, NY

Mr. Merten Hinsenveld, Fellow-North Atlantic Treaty Organization/Committee for Challenges of Modern Society (for the Netherlands)

Mr. Mike Kravitz, USEPA, Office of Water Regulations and Standards, Washington, D.C.

PREFACE

Contaminated sediments may pose risks to both human and environmental health. Such sediments may be found in large sites, such as the harbors of industrialized ports. However, they are also frequently found in smaller sites, such as streams, lakes, bayous, and rivers. In response to the risk that contaminated sediments pose, new methods for the remediation of contaminated sediment problems have developed rapidly during the last few years. Remediation options include no action (monitored natural attenuation), removal, treatment, and containment. All areas of contaminated sediment remediation have seen considerable development, especially technologies for the treatment of contaminated sediments.

This handbook focuses on small site contaminated sediments remediation with particular emphasis on treatment technologies. It is designed to provide a succinct resource booklet for government regulatory personnel, permit writers, remedial project managers, environmental scientists and engineers, plant owner/operators, environmental consultants, and other individuals with responsibilities for the management of contaminated sediments.

The handbook is organized to address the major concerns facing contaminated sediment remediation. Chapter I describes the physical and chemical characteristics of sediment, with special emphasis on ways in which sediment property changes affect contaminant mobility. Chapter II addresses sediment toxicity assessment and describes the current status of the EPA effort to address this important topic. Chapter III discusses sampling techniques and analytical and modeling methods used to characterize contaminated sediments. Chapter IV describes removal and transport options. Chapter V presents pre-treatment technologies. Chapter VI, the primary focus of this handbook, describes four major classes of treatment technologies. This chapter offers a comprehensive overview of specific treatment technologies and addresses applicability, limitations, and demonstrated results; it also presents references for further information. Finally, Chapter VII reviews disposal alternatives for contaminated sediments that are not treated.

CHAPTER 1

PHYSICAL AND CHEMICAL CHARACTERISTICS OF SEDIMENTS

1.1 Introduction

Sediment is the material that settles to the bottom of any body of water. Its primary components are interstitial water and soil particles. Interstitial water can comprise up to 90 percent of the total volume of unconsolidated, top sediment horizons and close to 50 percent of deeper, more compacted sediments. Soil particles found in sediments are derived from surface erosion of soils in the watershed, bank erosion, and redistribution of the bed load in waterways. Sediments vary widely in particle size distribution and are generally finer in texture than their source soils. Segregation of particle size occurs within the water body as a result of currents such that the smaller particles accumulate in quiescent zones and coarser particles are found where the current is greater. Organic matter, another important component of sediment, may range from near zero to greater than 10 percent of the sediment solid phase. Minor (but not necessarily unimportant) components of sediments include shells and other animal parts, plant detritus, sewage, and industrial wastes such as metals, other inorganic chemicals, synthetic organic compounds, and oil and grease.

Sediments are a very important part of aquatic ecosystems and in and of themselves should not be considered a problem. They can become problematic in at least three ways: excessive sedimentation due to human activity (erosion from agriculture or construction, etc.) can blanket the bottom of aquatic ecosystems and cause environmental damage in a number of ways; excessive sedimentation in areas of human commerce can disrupt shipping and require maintenance dredging; and contaminants can accumulate in sediments to the point where they endanger human and/or ecosystem health. This third type of problem is the focus of this document.

Sediments are considered contaminated when anthropogenic sources of pollution exist in high enough concentrations and are sufficiently available to affect human and/or ecosystem health. Contaminated sediments threaten human health when humans drink water contaminated by contact with sediments, eat organisms (such as fish and shellfish) contaminated through bioaccumulation in the food chain, or come in direct dermal contact with contaminated sediments. Contaminants impact ecosystems by increasing the mortality rates and/or by decreasing the growth or reproductive rates of susceptible populations. These impacts can be transferred throughout the ecosystem via food chain links and other ecological mechanisms.

Contaminants enter the water body from point sources (such as municipal and industrial effluents), non-point sources (such as agricultural and urban runoff), and other sources (such as spills, leaks, and dumping of wastes). A portion of the contaminants may then settle in the sediments. Common contaminants of concern include halogenated hydrocarbons (PCBs, dioxins, many pesticides, etc.), polycyclic aromatic hydrocarbons (PAHs such as naphthalene, pyrenes, etc.), and other organics (such as benzene), as well as metals (including iron, manganese, lead, cadmium, and mercury). Although many of the organic contaminants do degrade with time, the rates of degradation are generally slow and these chemicals tend to remain in the sediments for long periods of time, thus increasing their impact on the environment. Metals, as elements, do not degrade.

The physical and chemical characteristics of sediments exert a great deal of influence upon the bioavailability of sediment contaminants. These characteristics vary greatly from site to site. As a result, site characteristics should impact remediation decisions. This chapter reviews sediment characteristics to evaluate when selecting from among remediation alternatives. These alternatives include no action, treatment, containment, and disposal. Important physical and chemical changes may occur in contaminated sediments during their removal, handling, transport, treatment, and disposal. Important factors to consider during this selection process include the following:[1]

1. Nature and magnitude of the contamination.
2. Chemical and physical properties of the sediment.
3. Remediation alternatives potentially available.
4. Behavior of the contaminant(s) under different remediation alternatives.

5. Potential changes in the physical and/or chemical properties of sediments under different remediation alternatives.
6. Supplemental management practices that may be applied at a disposal site to further enhance contaminant immobilization.

These factors must be considered because the physical and chemical properties of a dredged material, and a change in those properties, can have a substantial effect on release of contaminants. Understanding these changes and the interaction between sediments and contaminants enables selection and management of remediation alternatives to minimize contaminant release.[2]

1.2 Properties of Sediments Affecting Contaminants

Sediments requiring remediation can vary widely in terms of physical and chemical properties.[3,4] The primary physical characteristic is texture, or the distribution of sand, silt, and clay sized particles. Generally, sandy sediments have little attraction for either toxic metals or synthetic organics (pesticides and industrial organics). Fine textured sediments such as silt and clay have a much greater affinity for all classes of contaminants. Fine-textured material at the sediment-water interface and suspended silt and clay particles effectively scavenge contaminants from the water column. These particles tend to accumulate in more quiescent reaches of waterways. Separation of the less contaminated sandy fraction from contaminated sediments can often yield a material clean enough for disposal without restriction while also reducing the volume of the contaminated sediment requiring treatment.

Another very important physical property is the organic matter content. Fine textured sediments, more so than sandy sediments, generally contain from one to several percent naturally occurring humic material derived from the microbial transformation of plant and animal detritus. Humic material may be present as discrete particulates or as coatings on clay particles and is important in two respects: the humic material greatly increases the affinity of sediments for metals and nonpolar organic contaminants and it serves as an energy source for sediment microbial populations.

Measurement of in situ water content is a third physical property of sediments usually important to remediation decisions.

The chemical properties of sediments also greatly affect the mobility and biological availability of contaminants. Sediment acidity and oxidation/reduction status are two very important chemical parameters.[5,6] Strongly acidic (low pH) conditions can slow microbial activity and increase the soluble levels of toxic metals. Weakly acidic, neutral, and slightly alkaline conditions (higher pH) favor metal immobilization processes. The oxidation-reduction status of a sediment, measured as redox potential, has a major effect on the retention or release of a number of metals, either directly or as a result of the difference in reactions of metals with oxidized and reduced sediment constituents. Changes in pH and redox potential of contaminated sediments from their initial condition at a dredging site to different conditions at a remediation site can substantially affect contaminant immobilization processes. Other important chemical properties of sediments include salinity conditions, sulfide content, the amount and type of cations and anions, and the amount of potentially reactive iron and manganese.

1.3 Forms and Reactions of Contaminants

Typical trace and toxic metal contaminants include copper, zinc, cadmium, lead, chromium, nickel, arsenic, mercury, selenium, and sometimes others. These elements are usually present in soils and sediments at low concentrations from natural sources. It is when one or more of these contaminants is present in elevated concentrations that they pose a potential problem. Real problems exist if these excess metals are released to the water column or are present in forms readily available to plants and animals that come in contact with the sediment material.

Metals dissolved in the water column or pore water are considered most available to organisms. Metals bound to clay minerals and humic material by cation exchange processes are also considered relatively available due to some equilibrium between these bound metals and dissolved metals. On the opposite extreme are metals bound within the crystal lattice structure of clay minerals. Metals in this form are essentially permanently immobilized and unavailable. Between these extremes are potentially available metals. The bulk of metals in contaminated sediments are in these potentially available forms. A listing of some of the common chemical forms of metals ranging from most available to least available is presented in Table 1-1.

Table 1-1. Availability of Metals in Common Chemical Forms

A. Readily available:
- dissolved
- exchangeable

B. Potentially available:
- metal carbonates
- metal oxides and hydroxides
- metals adsorbed on, or occluded with, iron oxides
- metals strongly adsorbed, or chelated, with humic materials
- metals precipitated as sulfides

C. Unavailable:
- metals within the crystalline lattice structure of clay minerals

Metals may be mobilized or immobilized if the chemical environment of the sediment or dredged material changes. Therefore, understanding the influence of the sediment chemical environment, and controlling changes in this environment, are important to the selection of disposal alternatives for contaminated sediments. Table 1-2 shows the fate of the potentially available metals as sediment conditions change.

It should be mentioned that there may be a complementary interaction between some of these processes as the pH or oxidation status of a sediment is altered. As metals are released from one form, they may be immobilized again by another process. However, the potential efficiency of this complementary interaction of processes depends on the particular properties of the sediment material.

Organic contaminants can vary widely in water solubility depending on their molecular composition and functional groups. Like metals in a sediment-water system, most organic contaminants tend to become strongly associated with the sediment solid phase, particularly the humic fraction. Thus, at most sites, the distribution of organic contaminants between dissolved and solid phases is a function of their water solubility and the percent of naturally occurring humic materials in the sediment. However, at heavily contaminated sites, organic contaminants also associate with petroleum-based or sewage-based organics.

Unlike metals, however, organic contaminants do degrade. Though all organic contaminants degrade at some rate, some have half-lives on the order of several decades. Some organics are subject to enhanced degradation rates under certain sediment chemical conditions.

Table 1-2. Typical Fate of Potentially Available Metals in a Changing Chemical Environment

Metal Type	Initial Condition	Environmental Change	Result
carbonates, oxides, and hydroxides	salts in the sediment	reductions of pH	release of the metals as the salts dissolve
adsorbed on iron oxides	adsorbed in sediment	sediment becomes reducing or acidic	iron oxides become unstable and release metals
chelated to humic	chelated in sediment	strongly immobilizes metal in both reducing and oxidizing sediments (However, there is some indication that the process is less effective if a reduced sediment becomes oxidized)	
sulfides	very insoluble precipitate	sediment becomes oxidized	sulfides become unstable, oxidize to sulfates, and release the metals

1.4 References

1. Gambrell, R.P., W.H. Patrick, Jr., and R.M. Engler. A Biogeochemical Evaluation of Disposal Options. In: Dredging and Dredged Material Disposal, Volume 1, R.L. Montgomery and J.W. Leach, eds. American Society of Civil Engineers, 1984. pp. 467-477.

2. Gambrell, R.P., R.A. Khalid, and W.H. Patrick, Jr. Disposal Alternatives for Contaminated Dredged Material as a Management Tool to Minimize Adverse Environmental Effects. DS-78-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, December, 1978.

3. Moore, T.K. and B.W. Newbry. Treatability of Dredged Material (Laboratory Study). Technical Report D-76-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1976. 102 pp.

4. Khalid, R.A., R.P. Gambrell, M.G. Verloo, and W.H. Patrick, Jr. Transformations of Heavy Metals and Plant Nutrients in Dredged Sediments as Affected by Oxidation-Reduction Potential and pH. Volume 1: Literature Review. Contract Report D-77-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1977. 221 pp.

5. Gambrell, R.P., R.A. Khalid, and W.H. Patrick, Jr. Chemical Availability of Mercury, Lead, and Zinc in Mobile Bay Sediment Suspension as Affected by pH and Oxidation-Reduction Conditions. Environmental Science and Technology, 14:431-436, 1980.

6. Khalid, R.A., R.P. Gambrell, and W.H Patrick, Jr. Chemical Availability of Cadmium in Mississippi River Sediment. Journal of Environmental Quality, 10:523-529, 1981.

CHAPTER 2

SEDIMENT TOXICITY ASSESSMENT

2.1 Introduction

Assessing the toxicity of sediments and any potential threat they pose to human health and the environment is an important step in the remediation process. Presently, several different kinds of tools are available to use in making decisions concerning sediment assessment and desired levels of remediation. Primary tools include environmental regulations and sediment assessment methods; descriptions of their current status form the major sections of this chapter.

2.2 Environmental Regulations that Relate to Contaminated Sediments

Section 121(d) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), provides that a cleanup must meet the most stringent standard of all the applicable or relevant and appropriate regulations (ARARs), whether that standard originates from another federal environmental law or from a state law. Types of ARARs include:

1. Chemical-specific ARARs - Health or risk-based concentration limits or ranges in various environmental media for specific hazardous substances, pollutants, or contaminants. Chemical-specific ARARs may define protective cleanup levels.
2. Action-specific ARARs - Controls or restrictions on particular kinds of activities related to management of hazardous substances, pollutants, or contaminants. Action-specific ARARs may set controls or restrictions for particular treatment and disposal activities.
3. Location-specific ARARs - Restrictions on activities within specific locations such as flood plains or wetlands.

Sources of ARARs for the remediation of contaminated sediments include international agreements and federal and state statutes and regulations. Major environmental regulations that may apply to sites with contaminated sediments are summarized below. EPA has also published descriptions of these regulations.[1]

2.2.1 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

In addition to the provisions for meeting ARARs mentioned above, the broader objectives of CERCLA are to protect human health and the environment by responding to potential or existing hazardous substance releases, remediating or cleaning up contaminated areas, and assessing liability for remediation actions and resource damages. In general, CERCLA provisions relate either to contamination at abandoned sites where there is a continuing threat of more widespread contamination or to emergency spills. Currently used hazardous sites are generally covered by the Resource Conservation and Recovery Act (RCRA).

CERCLA provides broad authority to locate areas with contaminated sediments. EPA can undertake studies or investigations if it believes a hazardous substance release has occurred or may occur. Studies on the degree and extent of contamination and potential routes of human exposure to a hazardous substance are generally determined through preliminary assessments and may include sampling and testing sediments during site investigations.

2.2.2 Clean Water Act (CWA)

The CWA was designed to restore the physical, chemical, and biological integrity of the nation's navigable waters. There are broad, general requirements under the CWA to locate waters that are not meeting water quality standards and, by extension, waters that have contaminated sediments. The CWA also has specific provisions relating to contaminated sediments: it authorizes the EPA to identify and remove contaminated sediments in harbors and navigable waterways; to identify contaminated sediments in the Chesapeake Bay; to identify contaminated estuaries in the National Estuary Program (NEP); and to identify and demonstrate remedial options in the Great Lakes. This last provision is being fulfilled under the directions of the Great Lakes National Program Office (GLNPO) as part of the Assessment and Remediation of Contaminated Sediments (ARCS) program. Finally, the CWA authorizes the development of criteria which may apply to dredging and dredged material disposal, assessment, source control, and remediation.

2.2.3 Resource Conservation and Recovery Act (RCRA)

RCRA's overall objectives are to minimize the generation of hazardous waste and to treat, store, and dispose of hazardous wastes so as to minimize present and future threats to human health and the environment. Since one of RCRA's main goals is to prevent the initial release of hazardous wastes into the environment, all treatment, storage, or disposal facilities must meet detailed design, operation, maintenance, and monitoring requirements before receiving an EPA operating or closure permit. RCRA permittees, or applicants for RCRA permits,might have to locate contaminated sediments and RCRA provisions could require a permittee to remediate the sediments in many circumstances.

2.2.4 Marine Protection, Research, and Sanctuaries Act (MPRSA)

The major purpose of MPRSA is to regulate the dumping of all sewage sludge, industrial waste, and dredged material into the ocean in order to prevent or strictly limit the dumping into ocean waters of any material that would adversely affect human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities. The U.S. Army Corps of Engineers (USACE) and EPA have jointly developed protocols to determine if dredged materials can be disposed of in the ocean. These protocols consist of a tiered testing scheme which initially relies on existing information to make a decision on potential contamination. This may be followed by an evaluation of the chemical and physical characteristics of the dredged material and overall environmental conditions at the site. This in turn may be followed by bioassays and bioaccumulation studies to determine whether disposal of the material would result in unacceptable adverse impacts.

2.2.5 Toxic Substances Control Act (TSCA)

TSCA's objective is to ensure that the manufacturing, processing, distribution, use, and disposal of chemical substances and mixtures do not present an unreasonable risk of injury to human health or the environment. TSCA applies to the procedure for dealing with contaminated sediments in two ways: first, a contaminant that is commonly found in sediments in excess of sediment criteria may be subject to manufacturing bans, and second, sediments contaminated with greater than 50 ppm PCBs may have to be disposed of by TSCA-approved methods.

2.2.6 Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)

FIFRA provisions are similar to TSCA provisions in that the use of a biocide could be restricted nationwide or in certain regions of the country if it commonly exceeded sediment quality criteria. Many of the persistent pesticides have use restrictions under FIFRA and more pesticides may be added to the restricted list.

2.2.7 Clean Air Act (CAA)

The CAA is similar to both FIFRA and RCRA in that emission control provisions would only become important if it could be demonstrated that air emissions were responsible for sediment contamination over wide-spread areas. Alternatively, air emissions from the treatment and disposal of contaminated sediments may have to meet CAA standards.

2.2.8 National Environmental Policy Act (NEPA)

NEPA requires the preparation of an Environmental Impact Statement (EIS) for many federally-funded projects. EIS preparation provides an opportunity to explore the options available for dredging and disposal of contaminated dredged material. NEPA's intent is to incorporate environmental considerations into decision-making at the federal level. National dredging projects are typical of the types of projects that require EISs. NEPA does not provide the legal authority for making decisions, however, and all aspects of control of dredging and dredged material disposal are covered by other environmental statutes.

2.2.9 Rivers and Harbors Act (RHA)

The RHA provides authority for the USACE to carry out projects for the improvement of navigation. It does not authorize dredging for environmental improvement (such as the removal of contaminated sediments). The Water Resources Development Act of 1990 does provide the USACE with some authority to remove contaminated sediments.

2.2.10 Endangered Species Act of 1973

Dredge and fill projects, as well as other activities regarding contaminated sediments, can potentially adversely impact threatened and endangered wildlife species due to habitat degradation or destruction. Thus, such projects fall under the jurisdiction of the Endangered Species Act of 1973.

2.2.11 Great Lakes Water Quality Agreement (GLWQA)

The GLWQA between Canada and the United States is an agreement to restore and enhance water quality in the Great Lakes System. Under the GLWQA, the International Joint Commission Dredging Subcommittee has developed specific sediment classification protocols to assist in determining appropriate disposal options for navigational dredging projects.

2.2.12 State Environmental Statutes that Relate to Contaminated Sediments

Finally, state laws may also apply to contaminated sediments. Examples include state requirements for disposal and transport of radioactive wastes, state approval of water supply system additions or developments, state ground-water withdrawal approvals, state water quality standards, and state air toxics regulations.[2]

2.3 Current Development of Sediment Assessment Tools

Although sediments are an extension of the water column, assessment of sediment toxicity is much more complex than assessment of water quality. Due to the nature of sediment chemistry, presence of contaminants does not necessarily mean that the sediment is toxic. For example, contaminants may be present but chelated with humic material in the sediment and thus unavailable.

This problem has become increasingly apparent in recent years and the EPA is developing a national strategy to address this issue. Under the lead of the Office of Water, the following steps are being taken: (1) review of sediment assessment methods, (2) development of sediment quality criteria, (3) development of the Toxicity Identification Evaluation, and (4) discussion of the need for a consistent, tiered testing approach to sediment quality assessment.

2.3.1 Sediment Methods Classification Compendium

In order to meet a growing concern for establishing a regulatory tool that can be used in the assessment of sites with suspected sediment contamination, a national sediment criteria development effort was undertaken by EPA's Criteria and Standards Division.[3] A Sediment Classification Methods Compendium was developed to serve as a reference for methods that could be used to assess the quality of chemically contaminated sediments.[4] This compendium describes the various methods, as well as their advantages, limitations, and existing applications. These methods are listed and described in Table 2-1.

Each method either directly or indirectly attempts to delimit levels of contamination within sediments such that above those levels either (1) acute and/or chronic toxicological effects become manifest or (2) some amount of bioaccumulation occurs. The sediment quality assessment methods described can be classified into two basic types: numeric or descriptive (see Table 2-1). Numeric methods are chemical-specific and can be used to generate numerical sediment quality values. Descriptive methods are qualitative and cannot be used alone to generate numerical sediment quality values for particular chemicals.

It should be pointed out that the assessment methods in the compendium are not at equal stages of development, and that certain methods (or combinations of methods) are more appropriate for specific management actions than are others. The compendium does not provide guidance on which methods to apply for specific situations or on how different methods can be used as part of a decision-making framework.[4,5]

2.3.2 Sediment Quality Criteria (SQC)

Currently, the EPA is working toward the development of nationally applicable sediment quality criteria. SQC will represent the EPA's best recommendation of sediment contaminant concentrations that will not unacceptably affect benthic organisms or their uses. SQC will be developed separately for each contaminant. At current funding levels, SQC for six non-ionic organic contaminants are scheduled to be developed in FY91, with an additional six to eight criteria documents appearing each year thereafter.

The equilibrium partitioning (EqP) method is the EPA's selected method to establish national SQC. The EqP approach relies on established water quality criteria to assess sediment toxicity. The first basic assumption of the EqP approach is that sediment toxicity is correlated to

Table 2-1. Sediment Quality Assessment Methods[4]

Method	Type Numeric	 Descriptive	 Combination	Concept
Bulk Sediment Toxicity	x			Test organisms are exposed to sediments that contain unknown quantities of potentially toxic chemicals. At the end of a specific time period, the response of the test organisms is examined in relation to a specified biological endpoint.
Spiked-Sediment Toxicity	x			Dose-response relationships are established by exposing test organisms to sediments that have been spiked with known amounts of chemicals or mixtures of chemicals.
Interstitial Water Toxicity	x			Toxicity of interstitial water is quantified and identification evaluation procedures are applied to identify and quantify chemical components responsible for sediment toxicity. The procedures are implemented in three phases: 1) characterization of interstitial water toxicity, 2) identification of the suspected toxicants, and 3) confirmation of toxicant identification.
Equilibrium Partitioning	x			A sediment quality value for a given contaminant is determined by calculating the sediment concentration of the contaminant that would correspond to an interstitial water concentration equivalent to the EPA water quality criterion for the contaminant.
Tissue Residue	x			Safe sediment concentrations of specific chemicals are established by determining the sediment chemical concentration that will result in acceptable tissue residues. Methods to derive unacceptable tissue residues are based on chronic water quality criteria and bioconcentration factors, chronic dose response experiments or field correlations, and human health risk levels from the consumption of freshwater fish or seafood.
Freshwater Benthic Community Structure		x		Environmental degradation is measured by evaluating alterations in freshwater benthic community structure.
Marine Benthic Community Structure		x		Environmental degradation is measured by evaluating alterations in marine benthic community structure.
Sediment Quality Triad	x	x	x	Sediment chemical contamination, sediment toxicity, and benthic infauna community structure are measured on the same sediment. Correspondence between sediment chemistry, toxicity, and biological effects is used to determine sediment concentrations that discriminate conditions of minimal, uncertain, and major biological effects.
Apparent Effects Threshold	x		x	An AET is the sediment concentration of a contaminant above which statistically significant biological effects (e.g., amphipod mortality in bioassays, depressions in the abundance of benthic infauna) would always be expected. AET values are empirically derived from paired field data for sediment chemistry and a range of biological effects indicators.

the concentration of the contaminants in the interstitial water and not to the total sediment concentration. The second basic assumption is that contaminants partitioned between the interstitial water and the sediment sorbents (such as organic carbon) are in equilibrium. Therefore, for a given contaminant, if the total sediment concentration, the concentration of sorbent(s), and the partitioning coefficient are known, then the interstitial contaminant concentration can be calculated. The interstitial contaminant concentration can then be compared to established water quality criteria to assess sediment toxicity.[6,7,8]

Due to variation in the specific sediment sorbent(s) that different classes of contaminants sorb to, methodologies for deriving SQC vary with different classes of compounds. For non-ionic organic chemicals the methodology requires normalization to organic carbon. For metal contaminants a methodology is under development and is expected to require normalization to acid volatile sulfide.

2.3.3 Toxicity Identification Evaluation (TIE)

Over the past two years, the National Effluent Toxicity Assessment Center (NETAC) at the Environmental Research Laboratory in Duluth, Minnesota has been developing and publishing guidance concerning methods to identify specific causes of acute toxicity in aqueous samples. These TIE methods, although originally developed for effluents, have been applied successfully to toxic aqueous sediment fractions (pore water, elutriates). The ability to identify compounds responsible for sediment toxicity could prove to be critical to initiating control of their release by point source dischargers and also could be helpful for attributing contamination to specific historical discharges for the purpose of remedial activities.

NETAC's assistance in this project will target high priority sediment toxicity problems, preferably in systems with a limited number of dischargers. In addition to identifying the source of toxicity problems, NETAC's analysis may include recommendations on the methods for solving these problems. These initial cases will also serve as models for conducting sediment TIEs.

2.3.4 Tiered Testing

The development of a consistent tiered testing methodology may provide a uniform basis for EPA decisions regarding the regulation and remediation of contaminated sediments. The need for such a methodology is currently under discussion at EPA. One possible model is the tiered testing scheme used to evaluate the suitability of dredged materials for ocean dumping. This scheme is described in the "Green Book," currently being updated by the EPA's Office of Marine and Estuarine Protection (OMEP) and the USACE.[9] The testing scheme consists of four tiers:

1. Analysis of existing information and identification of contaminants of concern.
2. Evaluation of sediment and site conditions.
3. Evaluation of acute bioassays and short-term bioaccumulation studies.
4. Evaluation of chronic bioassays and long-term bioaccumulation studies.

Evaluation at successive tiers is based on increasingly extensive and specific information that may be more time-consuming and expensive to generate, but that provides increasingly comprehensive evaluations for environmental effects.

2.4 References

1. USEPA. Contaminated Sediments: Relevant Statutes and EPA Program Activities. EPA 506/6-90/003, U.S. Environmental Protection Agency, Washington, D.C., 1990.

2. USEPA. National Oil and Hazardous Substance Pollution Contingency Plan. Final Rule, U.S. Environmental Protection Agency, February, 1990.

3. Zarba, C. National Perspective on Sediment Quality. In: Contaminated Marine Sediments - Assessment and Remediation. National Academy Press, Washington, D.C., 1989.

4. USEPA. Sediment Classification Methods Compendium. Final Draft Report, U.S. Environmental Protection Agency, June, 1989.

5. USEPA. Report of the Sediment Criteria Subcommittee of the Ecological Processes and Effects Committee: Evaluation of the Sediment Classification Methods Compendium. EPA-SAB-EPEC-90-018, U.S. Environmental Protection Agency, Washington, D.C., 1990.

6. Di Toro, D.M. A Review of the Data Supporting the Equilibrium Partitioning Approach to Establishing Sediment Quality Criteria. In: Contaminated Marine Sediments - Assessment and Remediation. National Academy Press, Washington, D.C., 1989.

7. USEPA. Briefing Report to the EPA Science Advisory Board on the Equilibrium Partitioning Approach to Generating Sediment Quality Criteria. EPA 440/5-89-002, U.S. Environmental Protection Agency, Washington, D.C., April, 1989.

8. USEPA. Report of the Sediment Criteria Subcommittee of The Ecological Processes and Effects Committee - Evaluation of The Equilibrium Partitioning (EqP) Approach for Assessing Sediment Quality. EPA-SAB-EPEC-90-006, U.S. Environmental Protection Agency, Washington, D.C., February, 1990.

9. USEPA and USACE. Draft Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters. EPA-503-8-90/002, U.S. Environmental Protection Agency, Washington, D.C., January, 1990.

CHAPTER 3

PROCEDURES FOR CHARACTERIZATION OF CONTAMINATED SEDIMENTS

3.1 Introduction

Characterization of contaminated sediments begins with the identification of contaminants present. While a list of contaminants is important, a description of the vertical and horizontal distributions of the contaminants within the sediments is also necessary due to the heterogeneity of most sediments. Characterization of the sediments is also important, as sediment characteristics will have profound effects on contaminant availability (see Chapter One) and should impact remediation decisions. Sediment characterization should include physical and chemical characteristics but also distributions of these within the site of concern. Modeling sediment transport and contaminant fate and transport will give additional insight into sediment characteristics. Key to efficient and economical characterization is the development of a sampling plan and the selection of the proper sampling method.

3.2 Sampling Plan

In order to properly sample and characterize contaminated sediments, extensive planning must first be done. The sequence in the planning stage should include:

1. Identification of sampling purposes and objectives.
2. Compilation of available data on the site of concern.
3. Collection of preliminary field data.
4. Development of a detailed sampling plan.

Developing a sampling plan appropriate for the site and sampling objectives increases the quality of the site characterization and minimizes characterization costs. Unfortunately, due to site variability, a systemized sampling plan applicable to all sites is not feasible.

3.2.1 Identification of Sampling Purposes and Objectives

The scope of effort is dependent on this decision. Purposes for sediment sampling and testing might include:

1. Determine distribution of specific contaminants.
2. Determine sediment contaminant mobility.
3. Determine existing impacts on aquatic/benthic fauna.
4. Determine disposal alternatives (regulatory).
5. Determine disposal alternatives (treatability).

No single sampling/analysis plan will serve all these purposes equally well.

3.2.2 Compilation of Available Data

This data should include the following:

1. Water depths/tidal fluctuations.
2. Obstructions (bridges, pipelines, etc.).
3. Access sites for mobilizing equipment.
4. Sediment depths (dredging or construction history).
5. Sources of contaminants (point and non-point) and other factors affecting contaminant distributions.
6. Hydraulic/other factors affecting sediment distribution.
7. Historic sediment quality data.
8. Survey benchmarks (for referencing sediment and water elevations).

3.2.3 Collection of Preliminary Field Data

Given the costs of sampling and of laboratory analyses, it is prudent to conduct some cursory field studies before developing the sampling and analysis plan. Such studies should be mandatory where any existing physical information is lacking. The amount of time and money that can be saved by simply visiting the site in a small boat and poking a long stick in the mud cannot be overestimated.

3.2.4 Development of a Detailed Sampling Plan

Once the first three steps have been completed, the specifics of the sampling and analysis plan can be developed. These include contractual, logistical, and statistical considerations. The plan developed as a part of step four should include details on:

1. Locations of samples (lateral and vertical).
2. Types of samples (grab or core).
3. Number and volumes of samples required.
4. Sampling procedures and equipment.
5. Supporting vessels/equipment.
6. Types of analytical tests required.
7. Quality Assurance Program Plan (QAPP) for sampling and analysis.
8. Cost estimate.

3.3 Sampling Methods

There are a number of sampling devices that are presently being used to collect samples. Choosing the most appropriate sediment sampler for the study will depend on the requirements of the sampling plan. Attention should be paid to sample linings: metal linings may introduce metal contaminants into the sediment samples; plastic linings may introduce organic contaminants into the sediment samples.

Biological collections are generally accomplished by trawling or dredging. Sediment collections have been made with spoons, scoops, trowels, core samplers, and grab samplers.

3.3.1 Spoons, Scoops, and Trowels

Spoons, scoops, and trowels are only useful in shallow water. They are less costly than other samplers, easy to use, and may be useful if numerous samples are intended; their low cost allows disposal between sample sites. In general, however, these devices are somewhat undesirable because the reproducibility of sampling area, depth, and volume from one sampling site to another is poor. They also tend to disrupt the sediment during sampling.[1]

3.3.2 Core Samplers

These may be used in both shallow and deep aquatic systems on a variety of substrate conditions. Core samplers are generally preferred over other samplers because (1) core samplers can sample to greater depth, (2) core samplers maintain the complex integrity of the sediment, and (3) core samplers do not disturb the substrate as much as other sampling procedures.[2]

Core samplers have several limitations: (1) core samplers do not work well in sandy or rocky substrates, (2) core samplers collect smaller amounts of sediment and therefore may require additional sampling, and (3) most coring devices are expensive, difficult to handle, and, consequently, have limited use under moderate wave conditions.

There are many different types of core sampling equipment that may be used for sediments. Some require the use of a tripod or truck mounted drill rig operated on a floating plant (barge). Some hand held units can be operated from smaller vessels. Core sampling devices include the split-spoon, the piston-tube or Chicago tube, the vibracore, and hand augers.

The split-spoon sampler is driven by a hammer or weight into the sediment. This method is especially suited for compacted sediments. Good recovery of samples in loose sediments is less dependable. The spoon is typically 2-3 inches in diameter and 2-5 feet long. Successive vertical samples can be taken by driving casing (5 inch pipe) and cleaning out the drill hole between samples.

The piston-tube or Chicago tube sampler is well suited for soft, fine-grained sediments. The sampler is advanced to the starting depth and a tube (typically 3-4 inch diameter) extended hydraulically. Recovery is usually very good since the sample is held in the tube by a partial vacuum. Discrete vertical samples can be obtained without casing.

The vibracore is a long continuous tube that is driven into the sediment using a vibrating action. This method is suited to soft, noncompacted sediments. The entire core is withdrawn and the tube cut into segments for sample extraction. Good recovery with this method requires that the tube penetrate a layer of compacted material, which forms a "cap" at the bottom. The vibration of the tube has been known to consolidate the sample and lose some vertical integrity (a 5-foot drive might produce a 4-foot sample).

Hand augers can be used for sampling very shallow areas or on river banks. Hand operated corers, deployed by a cable from a boat, have been used to collect shallow cores.

3.3.3 Grab Samplers

Grab samplers are less expensive, easier to handle, and often require less manpower than core samplers. Unfortunately, grab samplers cause considerable disruption of the sediment. Dredge samplers promote loss of the fine-grained fraction of the sediment as well as water soluble compounds and volatile organic compounds (VOCs) which may be present in the sediment. One important criterion for selection of the proper grab sampler is that it consistently collect samples to the required depth below the sediment.

Grab samplers, such as the Ponar and Eckman dredge samplers, are small, lightweight, and can be operated by hand from a small boat. They only collect surface sediments (top 3-6 inches). They have problems with any consolidated (hard packed) deposits. For larger volumes of sample, sometimes needed for treatability tests, a small, commercial clamshell dredge (1-3 cubic yard bucket) can be used.

3.3.4 Other Sampling Considerations

In conjunction with sediment toxicologic assessments, the type and degree of contamination in the interstitial water should be determined. Immediate collection of the interstitial water is recommended since chemical changes may occur even when sediments are stored for a short period of time. Collection of the sediment interstitial water can be accomplished by several methods: centrifugation with filtration, squeezing, suction, and equilibrium dialysis. Each method may alter the original water chemistry. Therefore, decisions about methods for collecting interstitial water should be based on expected contaminants.

Sediment samples should be separated from the collection devices and transported in plastic, polyethylene, or glass containers. Samples that contain volatile compounds should be refrigerated (4° C) or kept on ice to prevent further volatilization. Sediments that are suspected of organic contamination should be transported in brown, borosilicate glass containers with teflon lid liners. Plastic or polycarbonate containers are recommended for metal-bearing sediments. Additional information on sample containers, preservation, storage times, and volume requirements are available in other guidance documents.[3]

3.4 Physical and Chemical Analyses

The type of analysis performed on sediment collected is specific to the purpose and objectives of the plan. There is no "standard" laundry list of analyses which is appropriate to all cases. Some important analyses for consideration are identified in the following paragraphs. Francingues et al[4] provide guidance on testing sediment characteristics.

Physical characteristics often measured are particle size and distribution, organic carbon or volatile matter content, and total solids/specific gravity. Particle size is usefully described by the general size classes of gravel, sand, silt, and clay. Organic carbon should be measured by high temperature combustion rather than chemical oxidation. The latter method does not necessarily fully degrade all carbon classes. Total solids/specific gravity analyses both require a dry sample and are performed in conjunction with each other.[3]

Important chemical analyses include those for pH, oxidation-reduction, salinity conditions, and sulfide content as well as the amount and type of cations and anions, and the amount of potentially reactive iron and manganese. Much can be inferred from the pH and oxidation-reduction conditions when they are analyzed in conjunction with the physical properties.[5] The pH becomes a problem when the dredged material has a pH below 5 or above 8.5 or when it changes during handling and disposal. Whether the sediments are oxidizing or reducing will affect the availability of various contaminants during handling and disposal of the sediments.[6]

3.5 Modeling Sediment Transport and Contaminant Fate and Transport

Sediment transport and contaminant transport and fate models have two applications: (1) they can be used as a screening tool in predicting the environmental and health impacts from contaminant exposure during various remediation actions and (2) they can be used diagnostically to investigate sources of contamination. Current models are limited in their predictive ability to function as a screening tool or crude design model, but are developed to such a degree that they are being applied in this respect for the Buffalo River, New York. Diagnostic modeling is being done for the Sheboygan River, Wisconsin.

Sediment transport models are linked to hydrodynamic models and predict sediment movement due to circulation. Different models have been developed for a variety of sediment environments including lakes, harbors, estuaries, coastal areas, and rivers. The models may be one-, two-, or three-dimensional, depending on the nature of the water body. The one-dimensional models, HYDRO1D-DYNHYD, HYDRO1D-RIVMOD, and HSPF, are used for rivers, streams, and watersheds. The two-dimensional model, HYDRO2D-V, is generally the first choice of the Environmental Research Laboratory (ERL) and has application for estuaries, shallow lakes and bays, and streams. The HYDRO2D-V is being used to model arsenic contamination in New Jersey and is planned for use in Montana mining district streams and in modeling the south bay in San Francisco Bay. The three-dimensional model, HYDRO3D-V, has application for stratified bodies of water, such as lakes, and has been tested in PCB studies for Green Bay, Wisconsin. Correct data is important to proper functioning of these models. These models are in different stages of refinement, but all are available from the ERL in Athens, Georgia.[7,8,9]

Fate and transport models mimic the physical and chemical environment of sediments and predict how contaminants and sediments interact, particularly as conditions change. The HYDRO2D-V, also used as a sediment transport model, has been used to model adsorbed contaminants, but does not incorporate other contaminant processes. The WASP4 model is a general purpose, mass balance model incorporating a number of parameters and is considered the state-of-the-art fate and transport model by ERL and a number of EPA offices. The WASP4 has been adopted for toxics management by the Great Lakes National Program Office. Studies using WASP4 focus on Green Bay, Lake Ontario, and Saginaw Bay. The WASP4 also simulates fish and food chain bioaccumulation and is being used to model these in the Buffalo River, New York; the Sheboygan River, Wisconsin; and Saginaw Bay, Michigan.

3.6 References

1. USFWS. U.S. Fish and Wildlife Service Lands Contaminant Monitoring Operations Manual: Sediment Sampling Reference Field Methods, Appendix I. Final Report, U.S. Fish and Wildlife Service, 1989.

2. USEPA. Report of the Sediment Criteria Subcommittee of the Ecological Processes and Effects Committee: Evaluation of the Sediment Classification Methods Compendium. EPA-SAB-EPEC-90-018, U.S. Environmental Protection Agency, Washington, D.C., 1990. 25 pp.

3. USEPA and USACE. Draft Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters. EPA-503/8-90-002, U.S. Environmental Protection Agency, Washington, D.C., 1990.

4. Francingues, N.R., M.R. Palermo, C.R. Lee, and R.K. Peddicord. Management Strategy for Disposal of Dredged Material: Contaminant Testing and Controls. Miscellaneous Paper D-85-1, USACE Waterways Experiment Station, Vicksburg, Mississippi, 1985.

5. USACE. Dredging and Dredged Material Disposal. EM 1110-2-5025, U.S. Army Corps of Engineers, Washington, D.C., 1983.

6. Gambrell, R.P., R.A. Khalid, and W.H. Patrick, Jr. Disposal Alternatives for Contaminated Dredged Materials as a Management Tool to Minimize Adverse Environmental Effects. DS-78-8, U. S. Army Corps of Engineers, Washington, D.C., 1978.

7. Hayter, E.J. and S.C. McCutcheon. Finite Element Hydrodynamic and Cohesive Sediment Transport Modeling System FCSTM-H. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia, 1988.

8. Sheng, Y.P., M. Zakikhani, and S.C. McCutcheon. Three Dimensional Hydrodynamic Model for Stratified Flows in Lakes and Estuaries (HYDRO3D): Theory, User Guidance, and Applications for Superfund and Ecological Risk Assessments. EPA/600/***/***, U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia, 1991.

9. Sheng, Y.P., P.E. Eliason, X. J. Chen, and J.K. Choi. A Three-Dimensional Numerical Model of Hydrodynamics and Sediment Transport in Lakes and Estuaries: Theory, Model Development, and

CHAPTER 4

REMOVAL AND TRANSPORT

4.1 Introduction

The process of selecting removal and transport technologies should be driven by treatment and/or disposal decisions. This is because treatment/disposal options typically have the higher costs and are more controversial from a social, political, or regulatory perspective. For example, incineration would require less energy if the waste to be incinerated had a higher solid content. If it is the treatment of choice for a particular site, then dredges which produce a low solid content slurry (high water content slurry) may not be a feasible alternative. Other criteria are also important and will be identified in this chapter.

Another concern during the removal and transport of contaminated sediments is the danger of introducing contaminants into previously uncontaminated areas. Contamination during these steps occurs primarily from the resuspension of sediments during removal and from spills and leaks during transport. Accordingly, the decision to remove must be made only after careful consideration of all non-dredging remedial options, including no action and in situ containment or remediation. Of course, the nature of the contamination, or site considerations, may make removal and transport necessary.

4.2 Removal

To increase efficiency and reduce sediment resuspension, dredges, operational controls, and barriers should be used together. Of these, dredges actually remove the sediments; operational controls and barriers minimize the resuspension and spread of contaminated sediments during removal.[1] These three removal components are described below; following are descriptions of possible small site solutions.

4.2.1 Dredges

In the selection of a dredge type for the removal of contaminated sediments, four factors should be considered:[2]

1. Volume - the volume of material to be removed will determine the scale of operations and the time frame available for removal.
2. Location - obstacles (bridges, shallow water, etc.), distance to the disposal area, and human use patterns at and near the site are examples of location concerns.
3. Material - consolidated sediments, large amounts of debris, and the contaminants of concern impact dredge selection.
4. Pre-treatment - requirements of the sediment treatment technology (dewatering, etc.) must also be considered.

There are three types of dredges available for the removal of contaminated sediments: mechanical, hydraulic, and pneumatic. Historically, mechanical and hydraulic dredges have been the most commonly used in the United States (they are compared in Table 4-1). Pneumatic dredges are relative newcomers and are generally foreign made; they have been developed specifically for contaminated sediments. All three dredge types are described in more detail below. In addition to the references cited in this chapter, the following documents will also assist in the selection of the proper dredge for the site: USACE,[3] Hayes,[4,5] and McClellan et al.[6]

Mechanical dredges remove sediments by the direct application of mechanical force to dislodge sediment material. The force is commonly applied, and the material scooped away, with a bucket. The most commonly used mechanical dredge is the clamshell dredge. The clamshell dredge has widespread application for the removal of contaminated sediments, although the use of a modified, watertight bucket may be required. Conventional earth-moving equipment (backhoes, etc.) may also be considered for sediment removal in certain scenarios. Dipper dredges, bucket ladder dredges, and dragline dredges should not be used in the removal of contaminated sediments due to excessive sediment resuspension.[2] Clamshell dredges and earth-moving equipment are summarized in Table 4-2. Relative cost is applicable across Tables 4-2, 4-3, and 4-4.

Table 4-1. Comparison of Hydraulic and Mechanical Dredges[2]

Dredge Type	Advantages	Disadvantages
Mechanical:	excavation can proceed at the sediment's in situ water content dredges are highly maneuverable no depth limitations for clamshell dredges all types of debris can be removed good dredging accuracy	potential for large amounts of sediment resuspension dredged material must be rehandled production capacity is generally lower than Hydraulic unit costs are typically higher than Hydraulic
Hydraulic:	resuspension of sediment is limited dredged material can be piped directly to the disposal area, eliminating the need for rehandling production capacity is generally higher than Mechanical unit costs are typically lower than Mechanical	large volume of water removed with the sediment must be treated prior to disposal or release slurry pipelines can obstruct navigational traffic most debris cannot be removed hydraulically nonhopper dredges cannot be operated in rough water

Table 4-2. Comparison of Selected Mechanical Dredges[7]

Technique	Applications	Limitations	Secondary Impacts	Availability/ Transportability	Production (yd^3/hr)	Maximum Depth of Use (feet)	Relative Cost
Clamshell	Small volumes of sediments; confined areas and near structures; removal of bottom debris; nonconsolidated sediments; interior waterways, harbors	Low production rates; cannot excavate highly consolidated sediments or solid rock	Considerable resuspension of sediments	Dredge head can be moved over existing roads as-is and mounted on conventional crane; widely available	30-600	100	Low
Conventional Excavation Equipment	Small volumes of sediments in shallow or dewatered areas	Restricted capacities and reach; limited to very shallow water depths	Considerable resuspension of sediments	Can be moved over existing roads; widely available	60-700	N/A	Low

Hydraulic dredges use centrifugal pumps to remove sediments in a liquid slurry form. They are widely available in the U.S. Often a cutterhead, or similar device, is fitted to the suction end of the dredge to assist in dislodging bottom materials. New dredge designs attempt to reduce the amount of resuspension caused by dredging and to decrease the water content of the pumped slurry. Common hydraulic dredges are compared in Table 4-3.

Pneumatic dredges are a subcategory of hydraulic dredges that use compressed air and/or hydrostatic pressure instead of centrifugal force to remove sediments. Thus, they produce slurries of higher solid concentrations than hydraulic dredges. They also cause less resuspension of bottom materials. Common pneumatic dredges include Airlift dredges, the "Pneuma," and the "Oozer" (both of Japanese design). Although pneumatic dredges have been used extensively in Europe and Japan, they have only limited availability in the United States.[7,8] Pneumatic dredges also require a minimum of 7 1/2 feet of water—deeper than for mechanical or hydraulic dredges—to function properly. Table 4-4 compares common pneumatic dredges.

4.2.2 Operational Controls

Operational controls, like proper dredge selection, assist in reducing resuspension of sediments. These controls include the cutter speed, the depth of cut, the swing speed and/or speed of advance, and the positioning of equipment. Operator experience is of primary importance in implementing operational controls.

One example of operational control is cut technique. Because sediments are often unstable, disruption of a side slope may cause significant resuspension of contaminated sediments. One solution to the problem of resuspension is dredging technique. Typically, when dredging a side slope, a box cut is made and the upper half of the cut sloughs to the specified slope. To minimize resuspension, the specified slope should be cut by making a series of smaller boxes. This method, called "stepping the slope," will reduce but not eliminate sloughing.[9] If stepping the slope causes unacceptable resuspension, it may be best to avoid dredging completely (if risk assessment shows this to be a viable alternative). Capping sediments in situ may successfully reduce contaminant mobility.

4.2.3 Barriers

Barriers help reduce the environmental impact of sediment removal. Structural barriers include dikes, sheet pilings, caissons, and other weir enclosures. Non-structural barriers include oil booms, pneumatic barriers, sediment traps, silt curtains, and silt screens. Application of barrier options is site specific and functions to control contaminants only during removal.

4.2.4 Small Site Solutions

Several different solutions may be viable for removing contaminated sediments from a small site. For example, many small sites may be found in shallow lagoons, marshes, or streams, which do not permit the operation of deep-draft, barge-mounted dredges. Horizontal auger-cutter dredges have a draft of less than two feet and may be able to operate under such conditions. They are also typified by low resuspension of sediment, making them viable alternatives for the removal of contaminated sediments. The Mud Cat is a common type of horizontal auger-cutter dredge.[10]

It also may be possible to use divers with hand-held dredges to clean up particular types of contaminated sites.[7] For example, Environment Canada oversaw the clean-up of a perchloroethylene and carbon tetrachloride spill in the St. Clair River. These chemicals formed visible bubbles on the sediment that divers could identify and remove with specially designed hand-held dredges. By doing this, the contaminants were collected in a relatively

Table 4-3. Comparison of Selected Hydraulic Dredges[7]

Technique	Applications	Limitations	Secondary Impacts	Availability/ Transportability	Vessel Length/ Draft (feet)	Production (yd^3/hr)	Maximum Depth of Use (feet)	Relative Cost+
Portable Hydraulic (including small cutterhead)	Moderate volumes of sediments; lakes and inland rivers; very shallow depths (to 18 inches)	Limited to waves of less than one foot; depending on model, has low production rates and limited depth	Moderate resuspension of sediments	Readily moved over existing roads, may require some disassembling; widely available	25-50/ 2-5	50-1850	50	Low
Hand-held Hydraulic	Small volumes of solids or liquids in calm waters; for precision dragging	Operated from above-water units only in shallow waters	Moderate resuspension of sediments	Easily moved over existing roads; can be assembled using commonly available equipment	N/A	10-250	1000	Low
Plain Suction	Large volumes of free-flowing sediments and liquids; shallow waters and interior waterways	Dredged material 80-90% water; cannot operate in rough, open waters; susceptible to debris damage; can cause water traffic disruption	Moderate resuspension of sediments	Transport in navigable waters only	100/5-6	25-10,000	60	Med.
Cutterhead	Large volumes of solids and liquids; up to very hard and cohesive sediments; calm waters	Dredged material is 80-90% water; cannot operate in rough, open waters; susceptible to damage and weed clogging	Moderate resuspension of sediments	Transport in navigable waters only; wide availability	50-250/ 3-14	25-10,000	50	Med.

+Costs vary with site characteristics; cutterhead dredges may be the cheapest hydraulic dredge for a project involving more than a few thousand cubic yards.

Table 4-4. Comparison of Selected Pneumatic Dredges[7]

Technique	Applications	Limitations	Secondary Impacts	Availability/ Transportability	Vessel Length/ Draft (feet)	Production (yd³/hr)	Maximum Depth of Use (feet)	Relative Cost
Airlift	Deep dredging of loose sediment and liquids; for use in interior waters	Not for consolidated sediments; dredged material is 75% water	Resuspension of sediment is low	Dredge head can be moved over existing roads; not widely available in the United States	100/3-6	60-390	N/A	Med.
Pneuma	Nonconsolidated solids and liquids in interior waterways	Not for consolidated sediments; not for shallow waters; may cause obstruction to water traffic	Resuspension of sediment is low	Dredge head can be moved over existing roads; not widely available in the United States	100/5-6	60-390	150	High
Oozer	Soft sediments and liquids from river beds or harbor bottoms; relatively shallow depths	Modest production rates; may cause obstruction to water traffic	Resuspension of sediment is low	Dredge head can be moved over existing roads; not widely available in the United States	120/7	500-800	N/A	High

concentrated form, thereby avoiding the need to remove and treat large amounts of sediments. This technique was particularly appropriate since dredges available at the time of the spill (1985) would have caused considerable resuspension of the contaminants.[11] If divers are used in removing contaminated sediments, suits that prevent skin contact with the water and that are impervious to contaminant penetration may be required. Emergency medical back-up units may also be important. Risk to humans may be avoided by using Remote Operated Vehicles (ROVs) in place of divers. ROVs may be as effective as divers in many situations where divers might be considered.

Small sites may also be accessible to isolation and subsequent excavation. For example, if the contaminated sediments are found in a small stream, the flow could be blocked and diverted with cofferdams and the sediments subsequently removed with a backhoe.[7]

4.3 Transport

The primary emphasis during transport is towards spill and leak prevention. Transport options include pipelines, barges or scows, railroads, trucks, or hopper dredges. Selection of transport options will be affected by both dredge selection and pre-treatment and treatment decisions.

During transport, spills occur primarily during the loading and unloading of sediments and special care should be taken during these operations. The impact of spills during transport may further be minimized by careful equipment and route selection. Finally, all options used in the transportation of contaminated wastes should be decontaminated after use. Operational controls for transport options are listed in Table 4-5.

4.4 Compatibility With Downstream Processing

Two additional factors to consider when making dredging removal and transport decisions are distance to the disposal site and compatibility with disposal processes. Mechanically dredged sediments are usually transported by barge and/or truck; hydraulically dredged sediments are usually piped directly to the processing site. Because of the mass and volume of water in the slurry, transporting dredged material by tank truck or rail is prohibitively expensive. Therefore, hydraulic dredging may not be feasible if the processing site is not nearby. Furthermore, depending on the processing technology, slurried sediments may have to be dewatered prior to treatment, thus adding to cost.

4.5 References

1. Averett, D.E., B.D. Perry, and E.J. Torrey. Review of Removal, Containment, and Treatment Technologies for Remediation of Contaminated Sediments in the Great Lakes. Miscellaneous Paper EL90-25, U.S. Army Corps of Engineers, Vicksburg, Mississippi, 1990.

Table 4-5. Controls for Transport Options[1]

Pipeline Controls	Barge/Scow Controls	Rail Controls	Truck Controls	Hopper Dredge Controls
Pipeline Routing	Loading/ Unloading	Route Selection	Route Selection	Loading/ Unloading
Pipeline Selection	Pump Controls	Car Selection	Truck Selection	Pump Controls
Leak Detection	Route/ Navigation	Loading/ Unloading	Loading/ Unloading	Route/ Navigation
Redundancy of Safety Devices	Decontamination	Decontamination	Decontamination	Decontamination

2. Sukol, R.B. and G.D. McNelly. Workshop on Innovative Technologies for the Treatment of Contaminated Sediments, June 13-14, 1990. EPA/600/2-90/054, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1990.

3. USACE. Dredging and Dredged Materials Disposal. EM 1110-2-5025, U.S. Army Corps of Engineers, Washington, D.C., 1983.

4. Hayes, D.F. Guide to Selecting a Dredge for Minimizing Resuspension of Sediments. Environmental Effects of Dredging, Technical Notes. No. EEDP-09-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1986.

5. Hayes, D.F. Sediment Resuspension by Selected Dredges. Environmental Effects of Dredging, Technical Notes. No. EEDP-09-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1988.

6. McLellan, T.N., R.N. Havis, D.F. Hayes, and G.L. Raymond. Field Studies of Sediment Resuspension Characteristics of Selected Dredges. Technical Report No. HL-89-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1989.

7. USEPA. Responding to Discharges of Sinking Hazardous Substances. EPA 540/2-87-001, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1987.

8. Herbich, J.B. Developments in Equipment Designed for Handling Contaminated Sediments. In: Contaminated Marine Sediments - Assessment and Remediation. National Academy Press, Washington, D.C., 1989.

9. USACE. Disposal Alternatives for PCB-Contaminated Sediments from Indiana Harbor, Indiana, 2 Vols. Final Draft, U.S. Army Corps of Engineers, Vicksburg, Mississippi, 1987.

10. Ebasco Services Incorporated. Final Supplemental Feasibility Study Report: Marathon Battery Company Site (Constitution Marsh and East Foundry Cove) Village of Cold Springs, Putnam County, NY, Ebasco Services Incorporated, 1986.

11. Rogers, G.K. The St. Clair Pollution Issue. Water Research Journal of Canada, 21(3): 283-294, 1986.

CHAPTER 5

PRE-TREATMENT

5.1 Introduction

Pre-treatment technologies are defined as those methods that prepare dredged materials for additional treatment and/or disposal activities.[1] They are not effective in the removal or treatment of toxic materials in sediments. Pre-treatment decisions are greatly influenced by dredging, treatment, and disposal decisions. Pre-treatment objectives include:

1. To enhance or accelerate settling of the dredged material solids.
2. To reduce the water content of the dredged material solids.
3. To separate coarser, potentially cleaner solids from the fine-grained, more contaminated solids (particle classification).
4. To reduce the overall cost of the remedial action.

Pre-treatment technology types include slurry injection, dewatering, and particle classification. They are primarily applicable to hydraulically dredged sediment.[1] Handling and rehandling concerns should also be addressed in pre-treatment decisions concerning contaminated sediments.

Pre-treatment literature uses a number of definitions in referring to the solid/water ratio in sediments and slurries. *Percent solid* (or solid content) is defined as the ratio of solid mass to total sediment mass. In this document, *percent water* (or water content) and *percent moisture* (or moisture content) are equivalent; both are defined as the ratio of water mass to total sediment mass. (Water content also has a geotechnical engineering definition in which water content is defined as the ratio of water mass to solid mass.[2]) As long as water is the only liquid in the sediment percent solid and percent water (or percent moisture) are equivalent to each other. For example, 30 percent solid is equivalent to 70 percent water. Obviously, contaminants may be found in both the solid and water fractions and add weight to both fractions, but this added weight will not be addressed in this document. Finally, the literature generally (although not always) speaks of percent water when discussing the slurries generated by dredging and when discussing disposal options. On the other hand, the literature speaks of percent solid when discussing pre-treatment products and treatment requirements. This protocol will be followed in this handbook.

5.2 Slurry Injection

Slurry injection is the injection of chemicals, nutrients, or microorganisms into the dredged slurry. Slurry injection is described first in order to emphasize the mixing advantage that accrues if the injection occurs as the sediment is dredged, prior to passage through the transport pipeline. As mechanically dredged sediments are not piped, this mixing advantage applies only to hydraulically dredged sediments.

Chemical injections condition the sediment for further treatment and/or accelerate the settling of suspended solids. Promotion of settling may be important because the small colloidal-sized particles that settle very slowly are often more highly contaminated than the bulkier sediments. Chemical clarification is a type of chemical injection process that increases the settling rate by the addition of chemical coagulants which promote coagulation or flocculation and hence settling. Coagulants include inorganic chemicals, such as the salts of iron and aluminum, and organic polymers. When using chemical clarification, a settling period must follow the mixing of coagulant and sediment in order to complete the process.

Nutrient and/or microbe injections may enhance biodegradation of organics, either by providing a suitable environment for microbe growth or by supplying the microbes themselves. Possible nutrient additions include nitrogen, phosphorus, organic carbon sources, oxygen, and micronutrients, depending on the deficiencies of the sediment. Microorganisms, cultured to degrade a toxic material, can be injected into slurries containing that toxin. At present, microbe injections have not been demonstrated for large quantities of dredged material.[1]

microbe injections have not been demonstrated for large quantities of dredged material.[1]

5.3 Dewatering

The objective of dewatering is to increase the solid content (decrease the water content) of sediments for one or more of the following reasons:

1. Dewatered sediments are more easily handled.
2. Dewatering is normally required prior to incineration to reduce fuel requirements.
3. Dewatering reduces the costs of many treatment processes, particularly thermal processes.
4. Dewatering is required prior to land disposal.
5. Dewatering reduces the costs of transporting sediments to their ultimate disposal by reducing their volume and weight.

In most cases, the percent solids content of a dewatered sediment is set by the requirements for subsequent treatment and disposal. Each treatment technology has an optimum range of percent solid, above or below which the technology will not operate efficiently and economically, if at all. For example, combustion requires that the solid content be greater than 24 percent, preferably in the 28-30 percent range for more economical operation.[3] Sediments will vary in percent solid depending on location and dredging technology. Mechanical and pneumatic dredges remove sediment at or near in situ solid concentrations, while hydraulic dredges remove sediments in a liquid slurry (usually 5-15 percent solid) and are more likely to require dewatering. Variations in clay and organic matter content can influence the percent solid achieved by the various dewatering technologies.

Dewatering technologies can be subdivided into two general processes: air drying processes and mechanical processes.

5.3.1 Air Drying Process

"Air drying" refers to those dewatering techniques by which the moisture is removed by natural evaporation and gravity or by induced drainage. Air drying is less complex, easier to operate, and requires less operational energy than mechanical dewatering. Air drying also can produce a dryer sediment than mechanical dewatering, up to 40 percent solids under normal operation and over 60 percent solids with additional drying time or with the use of underdrainage systems. Air drying processes do, however, require a larger land area and are more labor intensive than mechanical processes. Contaminant releases via seepage, drainage, and volatilization during the dewatering process must also be considered.[3]

The most widely applicable and economical air drying process available for sediments is an appropriately managed confined disposal facility (CDF). CDFs are engineered structures designed to retain solids during dredging and provide storage time for gravity drainage, consolidation, and evaporation. The rate of dewatering may be accelerated by using underdrains, pumps, or wick drains. The use of CDFs for dredged material disposal is discussed in Chapter Seven.

5.3.2 Mechanical Processes

Mechanical dewatering involves processes in which water is forced out of the sediment through mechanically induced pressures. Mechanical dewatering processes include the following: filtration, including belt filter presses, chamber filtration, and vacuum rotary filtration; centrifuges, including solid bowl and basket; and gravity thickening. Following is a description of these technologies. Applications, limitations, and relative costs of selected dewatering technologies, including CDFs, are identified in Table 5-1.

<u>Belt filter presses</u> dewater by carrying the sediment between two tensioned porous belts and squeezing out the water as the sediment/belt "sandwich" passes over and under various size rollers. All belt filter presses incorporate the following features: a polymer conditioning zone, a gravity zone, a low pressure zone, and a high pressure zone. Polymer conditioning produces a superflocculation phenomenon that allows water to drain more efficiently. The gravity drainage zone and the low pressure zone prepare the sediment for the high pressure zone, where most of the water removal actually takes place.

Belt filter presses are common dewatering choices in Europe and the United States. They can dewater sediment rapidly and do not take as large an area as the air drying processes. Belt filter presses are thus often used in confined locations (such as cities) and where large volumes of sediment must be dewatered. They do not dewater as completely as air drying processes, however, and may be limited by the percent solid demands of the treatment to be used. Furthermore, if the sediment is very gritty, the belts may wear out rapidly.[3]

<u>Chamber filter presses</u> also use positive pressures, but apply the pressure to the sediments inside rigid, individual filtration chambers operated in parallel.

Table 5-1. Summary of Dewatering Techniques[7]

Technique	Applications	Limitations	Secondary Impacts	Relative Cost
Confined Disposal Facility	Dewatering sediment of any grain size to a solids content of up to 60 percent and up to 99 percent solids removal. Generally used for large scale dredging operations where land space is available.	Requires large land areas. Requires long set-up time. Labor costs associated with removal or dewatering sediments are high. Systems using gravity drainage are prone to clogging. Systems using vacuums require considerable maintenance and supervision. Systems based on electro-osmosis are costly.	Potential for groundwater contamination. Potential for localized odor and air pollution problems.	Low to High
Belt Filter Press	Used to dewater fine grained sediments. Capable of obtaining relatively dry filter cake containing up to 45 to 70* percent solids; able to achieve solids capture of 85 to 95%. Generally best suited of filtration methods for mobile treatment systems.	Performance is very sensitive to incoming feed characteristics and chemical conditions. Belts can deteriorate quickly in presence of abrasive material.	Generates a substantial amount of waste water that must be treated.	Medium
Chamber Filtration	Used to dewater fine grained sediments. Capable of obtaining a relatively dry filter cake with a solids content up to 50 to 80* percent; able to achieve a high solids capture rate of up to 98%.	Costly and energy intensive. Replacement of filter media is time consuming.	Generates a wash water that must subsequently be treated.	High
Vacuum Rotary Filtration	Used to dewater fine grained sediments capable of obtaining a filter cake of up to 35 to 40% solids and a solids capture rate of 88 to 95%.	Least effective of the filtration methods for dewatering. Energy intensive.	Generates a wash water that must be treated.	High
Solid Bowl Centrifuge	Thickening or dewatering sediments; able to obtain a dewatered sludge with 15 to 35% solid; solids capture typically ranges from 90 to 98%. Suitable for areas with space limitations.	Not as effective in dewatering as filtration or lagoons. Process may result in a build-up of fines in effluent from centrifuge. Scroll is subject to abrasion.	No significant secondary impacts.	Med. to High
Basket Centrifuge	Thickening or dewatering sediments; able to obtain a dewatered sludge with 10 to 25% solids. Solids capture ranges from 80 to 98%. Suitable for areas with space limitations. Good for hard-to-dewater sludges.	Not as effective in dewatering as solid bowl centrifuge, filtration, or dewatering lagoons. Process may result in a build-up of fines in effluent from centrifuge. Units cannot be operated continuously without complex controls.	No significant secondary impacts.	Med. to High
Gravity Thickening	Thickening of sediment slurries to produce a concentrate that can then be dewatered using filtration or dewatering lagoons. Able to produce a thickened product with a solids concentration of 15 to 20%.	Least effective method for dewatering sediment slurries. Requires use of a substantial amount of land.	Potential for localized odor and air pollution problems.	Low to Med.

*Percent solids achievable may represent values for optimal conditions and do not necessarily represent normally expected values. Dredged sediments are often fine-grained and difficult to dewater to the maximum indicated values.

Vacuum rotary filtration uses negative pressure to pull the water to the interior of a drum while the sediments adhere to the exterior.

Centrifuges use the centrifugal forces created by a rapidly rotating cylindrical drum or bowl to separate solids and liquids based on variations in density. There are two types of dewatering centrifuges: the solid bowl centrifuge and the basket centrifuge.

Gravity thickening is accomplished in a continuous flow tank. Sediments settle to the bottom and are removed by gravity or pumping. Water overflows the tank and leaves through an effluent pump. Gravity thickeners are used primarily in tandem with other pre-treatment technologies; they reduce the hydraulic load to subsequent pre-treatment options.

5.4 Particle Classification

Particle classification separates the slurry according to grain size or removes oversize material that is incompatible with subsequent processes. Classification by grain size is important in the management of sediments contaminated with toxic materials since the contaminants tend to adsorb primarily onto fine grain clay and organic matter. The small grain solids of a specific size or less can be treated while the relatively non-contaminated, coarser soils and sediments can be disposed of with minimal or no additional treatment. Separation technology for a given site depends on the following: volume of contaminated sediments; composition of the sediments, such as gradation, percent clays, and percent total solids; characterization of the contaminants; types of dredging or excavation equipment used; and site location and surroundings, including available land area. Particle classification options include screening processes that depend on size alone, processes that depend on particle size and density or density alone, and processes that depend on conductive or magnetic properties of the particles.[1]

Particle classification technologies include: impoundment basins, hydraulic classifiers, hydrocyclones, grizzlies, and screens. Following is a description of these technologies. Applications, limitations, and relative costs for the first three listed particle classification technologies are identified in Table 5-2.

Impoundment basins allow suspended particles to settle by gravity or sedimentation. A slurry of dredged material is introduced at one end of the basin; settling of solids — depending on the particles' diameters and specific gravities — occurs as the slurry flows slowly across the basin. The flow resulting at the opposite end has a greatly reduced solids content. Multiple impoundment basins in a series can separate sediments across a range of sizes.

Hydraulic classifiers are rectangular tanks that function similarly to impoundment basins. They have a series of hoppers along the length of a tank which collects sediments of various sizes. Motor-driven vanes sense the level of solids and activate discharge valves as the solids accumulate in each hopper. Hydraulic classifiers may be used in tandem with spiral classifiers to separate fine grained materials such as clay and silt. Portable systems that incorporate hydraulic and spiral classifiers are available.

Hydrocyclones use centrifugal force to separate sediments. A hydrocyclone consists of a cone-shaped vessel into which a slurry is fed tangentially, thereby creating a vortex. Heavier particles settle and exit at the bottom while water and sediments exit through an overflow pipe. Hydrocyclones may be useful where a sharp separation by particle size is needed.

Grizzlies are vibrating units reliable in the removal of oversized material, such as bricks and rocks. Grizzlies are very rugged and are useful in reducing the amount of abrasive material in order to minimize wear on subsequent, more delicate, technologies.

Screens may be vibrating or stationary and operate by selectively allowing particles to pass through them. As the slurry passes over the screen, fine-grained particles and water sift through the screen and larger particles slide over the screen. Screens come in a variety of types with a variety of applications to contaminated sediments.

5.5 Handling/Rehandling

The amount of handling and rehandling required by various pre-treatment options will also influence pre-treatment decisions. Especially with severely contaminated sediments, all equipment that comes in contact with the sediments will require subsequent decontamination. For example, air drying heavily contaminated sediments requires that the sediments be put in the drying structure and later rehandled when the dewatered sediments are removed in a more highly concentrated form. Rehandling also mechanically disrupts the sediments and increases the probability of introducing contaminants into the environment. Conversely, a series of pre-treatment steps requiring rehandling may be the most efficient way of separating the contaminated sediments and preparing them for treatment. For example, the Dutch are using particle classification (hydrocyclones) and dewatering (belts, filter presses, chamber filter presses, and others)

Table 5-2. Summary of Sediment/Water Separation Techniques[7]

Technique	Applications	Limitations	Secondary Impacts	Relative Cost
Impoundment Basin	Used to remove particles down to a grain size of 20 to 30 microns without flocculants, and down to 10 microns with flocculants. Provide temporary storage of dredged material. Allow classification of sediments by grain size.	Requires large land areas. Requires long set-up time.	Potential for groundwater contamination.	High
Hydraulic Classifier	Used to remove particles from slurries in size range of 74 to 149 microns (fine sand to coarse sand).	Hydraulic throughput is limited to about 250 to 300 tph regardless of size. Not capable of producing a sharp size distinction. Requires use of large land area for large scale dredging or where solids concentrations are high.	No significant impacts.	Med.
Hydrocyclones	Used to separate and classify solids in size range of 2,000 microns or more down to 10 microns or less.	Not suitable for dredged slurries with solids concentrations greater than 10 to 20 percent.	No significant impacts.	Med.

to improve the quality of dredged material prior to treatment or disposal. Such a series is similar to the "treatment train" described in Chapter Six.

Although methods of treatment are not addressed in this document, the water generated during dewatering generally contains contaminants and suspended solids and may require further treatment.

5.6 References

1. Averett, D.E., B.D. Perry, and E.J. Torrey. Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes. Miscellaneous Paper EL90-25, U.S. Army Corps of Engineers, Vicksburg, Mississippi, 1990.

2. USACE. Confined Disposal of Dredged Material. EM 1110-2-5027, U.S. Army Corps of Engineers, September, 1987.

3. USEPA. Dewatering Municipal Wastewater Sludges. EPA-625/1-87-014, U.S. Environmental Protection Agency, Cincinnati, Ohio, September, 1987.

4. USEPA. Responding to Discharges of Sinking Hazardous Substance. EPA-540/2-87-001, U.S. Environmental Protection Agency, Cincinnati, Ohio, September, 1987.

CHAPTER 6

TREATMENT TECHNOLOGIES

6.1 Introduction

Treatment technologies, for the purpose of this chapter, are defined as those technologies that destroy, remove, immobilize, isolate, or otherwise detoxify the contaminants in the sediments. The selection of a treatment technology (or a train of technologies) is based on sediment characteristics, contaminant types, location, cost, and prior and subsequent decisions in the remediation sequence.

This chapter presents a logic for screening technologies followed by a description of technologies by type. Technologies included in this chapter have all been at least bench-scale tested on contaminated sediments. Technologies which potentially apply to sediments, but which have not yet been tested, or which have been tested only on soils, have not been included. Due to the rapid advance of contaminated sediment remediation science, the catalog of technologies included in this document should not be viewed as exhaustive. Finally, primarily because of the site-specific influence that sediments and contaminants have on them, costs are not discussed in this chapter.

6.2 Technology Screening Logic

The first step in selecting an appropriate remedial alternative is to determine treatment goals. In determining treatment goals, questions of whether to remediate a site and what degree of cleanup is necessary should be addressed. Once these questions are answered, methods to be used in achieving the desired remediation can be determined.

6.2.1 Screening for Feasible Technologies

Contaminants and contaminant concentrations vary widely between sites and within sites. Furthermore, there is usually a high degree of variability among site characteristics. Because of these sources of variability, selection of appropriate and feasible remediation techniques for contaminated sediments is a complex task. No simple management plan or screening procedure exists for selecting among available options. A screening logic is needed that can take into account specific site factors, the degree of protection required, costs, and availability and reliability of cleanup alternatives. The Environmental Protection Agency provides guidance on technology screening in *The Feasibility Study Development and Screening of Remedial Action Alternatives.*[1] The following section is a description of a technology screening logic based on the process used for contaminated sediments at the New Bedford Harbor site, Massachusetts.

The fundamental steps in searching for a feasible technology to remediate a contaminated sediment are to: (1) identify site and contaminant characteristics, (2) develop a list of treatment options, and (3) conduct a detailed evaluation of the possible treatments. <u>Step one</u> has been discussed in Chapters One, Two, and Three and will not be addressed here.

<u>Step 2</u>. The initial list of treatment options should be fairly complete. Although this list may be somewhat cumbersome, technologies will be developing so rapidly over the next few years that a technology option should not be dismissed unless it has received fair consideration. For example, Allen and Ikalainen presented a list of 56 potential treatment technologies that were grouped into four general treatment classes (Table 6-1). This list was developed to screen treatments for the New Bedford Harbor site, parts of which are highly contaminated with both PCBs and metals. In the initial screening, more than half the treatments were eliminated because they would not work with metals or organics in either a sediment or water matrix.[2]

<u>Step 3</u>. The detailed evaluation of the initial list should be based on selected, appropriate criteria. For example, Allen and Ikalainen's criteria were based on effectiveness, implementation (engineering and control considerations), and costs.[2] This detailed evaluation will produce a short list of feasible and effective technologies.

Table 6-1. Identification of Hazardous Waste Treatment Technologies Considered for the Treatment of New Bedford Harbor Sediments[2]

TECHNOLOGY	Sediment Matrix	Water Matrix	For PCB Treatment	For Metal Removal
Biological				
Advanced Biological Methods	Yes	No	Yes	No
Aerobic Biological Methods	No	Yes	No	No
Anaerobic Biological Methods	Yes	No	No	No
Composting	Yes	No	No	No
Land Spreading	Yes	No	No	No
Physical				
Air Stripping	No	Yes	No	No
Soil Aeration	Yes	No	No	No
Carbon Adsorption	No	Yes	Yes	No
Flocculation/Precipitation	No	Yes	Yes	Yes
Evaporation	Yes	Yes	No	No
Centrifugation	Yes	No	No	No
Extraction	Yes	No	Yes	No
Filtration	Yes	No	No	No
Solidification	Yes	No	Yes	Yes
Granular Media Filtration	No	Yes	No	Yes
In Situ Adsorption	Yes	No	Yes	No
Ion Exchange	No	Yes	No	Yes
Molten Glass	No	No	Yes	No
Steam Stripping	No	Yes	No	No
Supercritical Extraction	Yes	No	Yes	No
Vitrification	Yes	No	Yes	Yes
Particle Radiation	No	No	Yes	No
Microwave Plasma	No	No	Yes	No
Crystallization	No	Yes	No	No
Dialysis/Electrodialysis	No	Yes	No	No
Distillation	No	Yes	No	No
Resin Adsorption	No	Yes	No	Yes
Reverse Osmosis	No	Yes	No	Yes
Ultrafiltration	No	No	No	No
Acid Leaching	Yes	No	No	Yes
Catalysis	No	No	No	No
Chemical				
Alkali Metal Dechlorination	Yes	No	Yes	No
Alkaline Chlorination	No	No	No	No
Catalytic Dehydrochlorination	No	No	Yes	No
Electrolytic Oxidation	No	No	No	No
Hydrolysis	No	Yes	No	No
Chemical Immobilization	Yes	No	No	Yes
Neutralization	Yes	No	No	No
Oxidation/Hydrogen Peroxide	Yes	Yes	No	No
Ozonation	No	No	No	No
Polymerization	Yes	No	No	No
Ultraviolet Photolysis	No	No	Yes	No
Thermal				
Electric Reactors	Yes	No	Yes	No
Fluidized Bed Reactors	Yes	No	Yes	No
Fuel Blending	No	No	Yes	No
Industrial Boilers	No	No	Yes	No
Infrared Incineration	Yes	No	Yes	No
In Situ Thermal Destruction	No	No	Yes	No
Liquid Injection Incineration	No	No	Yes	No
Molten Salt	No	No	Yes	No
Multiple Hearth Incineration	Yes	No	Yes	No
Plasma Arc Incineration	No	Yes	Yes	No
Pyrolysis Processes	Yes	No	Yes	No
Rotary Kiln Incineration	Yes	No	Yes	No
Wet Air Oxidation	No	Yes	No	No
Supercritical Water Oxidation	Yes	Yes	Yes	No

The detailed evaluation of technology options also requires a system for ranking the options within the identified criteria. Unfortunately, a universal quantitative ranking system is not possible. The reasons for this include: necessary assumptions made regarding the applicability of most alternatives, widely varying knowledge about the performance of some alternatives in terms of the specified criteria, how to consider tradeoffs between different alternatives, and the fact that different individuals or committees will rank the criteria for a given alternative differently.[3]

Carpenter reported a comprehensive technology screening and ranking procedure for PCB contaminated sediments. Approximately 20 technologies were evaluated that fitted into six general classifications (low-temperature oxidation, chlorine removal, pyrolysis, removal and concentration, vitrification, and microbial degradation). Keeping in mind the rapid development of treatment technologies, it is still appropriate to note that at that time, the only proven technology available was believed to be dredging and incineration.[4]

6.2.2 Treatment Train Approach

The "treatment train approach" is a valuable concept for remediating contaminated sediments. Taking such an approach acknowledges the complexity of dealing with contaminated sediments and the fact that a multifaceted approach, combining several technologies into a sequence of steps, may permit more flexibility in addressing problems. In many cases, a treatment train may be essential to clean up sediments containing different types of contaminants. For example, in their work on screening technologies suitable for New Bedford Harbor, Allen and Ikalainen reported eliminating a number of methods because these specific technologies could not deal with both organics and metals.[2] With a treatment train approach, it may be possible to effectively couple two or more technologies to successfully address a contamination problem where no single technology would perform satisfactorily.

Technologies coupled in a treatment train should be evaluated for more than just their ability to address specific contamination problems. The complementary nature of technologies should be considered. For example, in a hypothetical sediment contaminated with metals and PCBs, dewatering might be done to prepare the sediment for a metal extraction process. While the dewatering and metals extraction process may do little to remove PCBs, they may make the sediment a suitable candidate for destruction of the PCBs through incineration. In this train, the lowered water content of the sediment reduces incineration costs, while the reduction of metals in the sediment simplifies treatment of incineration off-gases.

Currently, most technologies for the remediation of contaminated sediments are going to require dredging. Thus, the key sequence of events in a treatment train approach will very likely include the following: dredging, transport, possible pre-treatment, treatment, post-treatment (including possible treatment of off-gases or waste-water), and placement of the cleaned material.

A treatment train approach was tested at the bench-scale level on sediments contaminated with both metals and organics from the Halby Chemical site in Wilmington, Delaware. Low temperature thermal desorption was evaluated as a pre-treatment step to remove compounds that may impede the solidification/stabilization process. While it did successfully remove most volatile and semi-volatile compounds, results indicated that low temperature thermal desorption may not be needed as a pre-treatment step prior to solidification/stabilization for these sediments.[5]

The Dutch bench-tested a treatment train approach involving solvent extraction and biodegradation of sediments contaminated with PAHs. Results indicated that when preceded by hydrocyclone separation, the overflow could be treated by basin aeration (a biodegradation method) and the underflow could be treated in one of three ways: by solvent extraction with triethylamine (TEA) if heavily contaminated; by biodegradation if the contaminants are not too strongly sorbed to sediment particles; and by reuse without further treatment if not polluted.[6]

In summary, because of the inability of most technologies to treat more than one type of contaminant, the concept of a treatment train approach utilizing several technologies in sequence may add the flexibility needed to make many projects feasible and more cost effective.

6.2.3 Side Stream

The term "side stream" refers primarily to the need to address contaminants generated by primary technologies. Whereas incineration may effectively destroy the organic contaminants in dredged material, the off-gases and/or ash may contain other types of contaminants. Thus, side stream treatment may be required to further treat contaminants collected. Presumably, these side stream products would be more easily treated by methods which are more conventional and less costly than the technology required to clean the sediments initially. Necessary side stream technologies would be part of the overall evaluation for a remediation approach.

6.3 Extraction Technologies

Extractive treatment technologies remove organic or metallic contaminants from sediments but do not destroy or chemically alter the contaminant. Effluent streams will be much more concentrated with the contaminant than was the original sediment. Extractive treatment technologies should be viewed as one part of a treatment train since organic contaminants still need to be destroyed after extraction. The contaminant-rich effluent from extraction technologies can be treated by any of a number of thermal, physical/chemical, and/or biological treatment technologies. By concentrating the contaminants in a smaller volume of sediment or residual, a significant cost savings may be realized.

Traditionally, the term "extraction" has referred to chemical extraction, but as used here it refers to a larger group of technologies that essentially achieve volume reduction by removing a contaminant from a waste stream and then concentrating it. For example, soil washing is usually thought of as being separate from chemical extraction, but using the present definition, soil washing is considered an extraction technology.

Extraction technologies may have application for the treatment of contaminated sediments. The large volume of material to be treated coupled with the relatively low concentration of contaminants make technologies capable of volume reduction and the concentration of contaminants attractive.

6.3.1 Chemical Extraction

Chemical extraction involves removing contaminants from sediment by dissolution in a solvent that is later recovered and treated. A variety of chemical extraction processes exist and they employ a number of solvents. Solvents are chosen based on contaminant solubility and on whether the contaminant is organic or inorganic.

CF Systems Organic Extraction Process. CF Systems Corporation has developed a critical fluid solvent extraction with liquified gas technology that has been applied in pilot scale studies to contaminated sediments (Figure 6-1). Liquified gases (propane and/or butane) at high pressure are used to extract oils and organic solvents from sediments in a continuous process. After contact with the sediment, the contaminated solvent enters a separator where the pressure is reduced and the solvent is decanted from the oil phase. The solvent is then compressed and recycled. Materials that are primarily contaminated with heavy metals or inorganic compounds are not appropriate for this technology.

CF Systems Organic Extraction Process was demonstrated under EPA's Superfund Innovative Technology Evaluation (SITE) program at the New Bedford Harbor site, Massachusetts. The site was listed on the National Priority List (NPL) because PCB concentrations in the sediment ranged from 50 ppm to 30,000 ppm. The sediment treated in the extraction process was 30-40 percent solids, of which 37 percent was sand, 41 percent was silt, and 22 percent was clay. Table 6-2 shows the percent reduction in PCB feed concentration from each of the demonstration tests.

Basic Extraction Sludge Treatment (BEST). The BEST process, developed by Resources Conservation Company, is an extraction process capable of treating sediment contaminated with PCBs, hydrocarbons, and other high molecular weight organics. The process contacts one part sediment with one to seven parts of a secondary or tertiary amine, usually triethylamine (TEA). The extraction step takes place at near ambient temperatures and pressures and at a pH of 10. Under these conditions TEA is simultaneously miscible with oil and water. The extracted solids are removed by centrifugation and then dried to remove residual TEA. The contaminant rich liquid phase is heated, reducing the TEA solubility in water. The resulting TEA/oil phase is decanted from the water phase. The TEA/oil phase is sent to a stripping column where the TEA is recovered and the oil is discharged. The water phase is also sent to a stripping column to remove residual TEA (Figure 6-2).

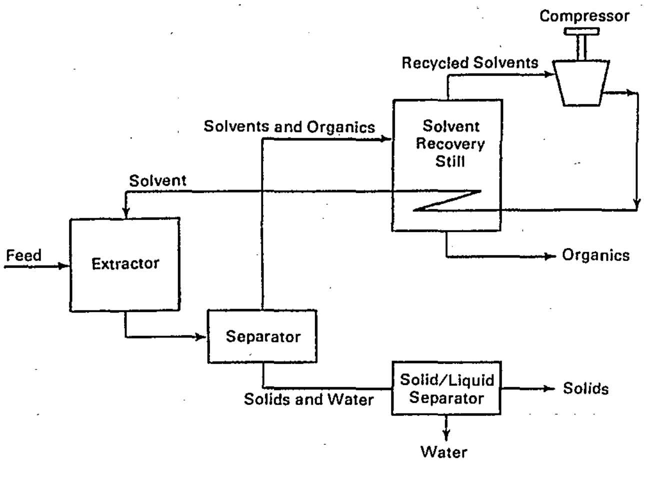


Figure 6-1. CF Systems Organic Extraction Process Source: CF Systems Corporation

Table 6-2. Demonstration Test Results of CF Systems Organic Extraction Process[8]

Test Number	Number of Passes	PCB Feed Conc.	Percent Reduction
2*	10	350	89 percent
3	3	288	72 percent
4	6	2575	92 percent
5	3	--	Decontamination

*Test #1 was the shakedown test.

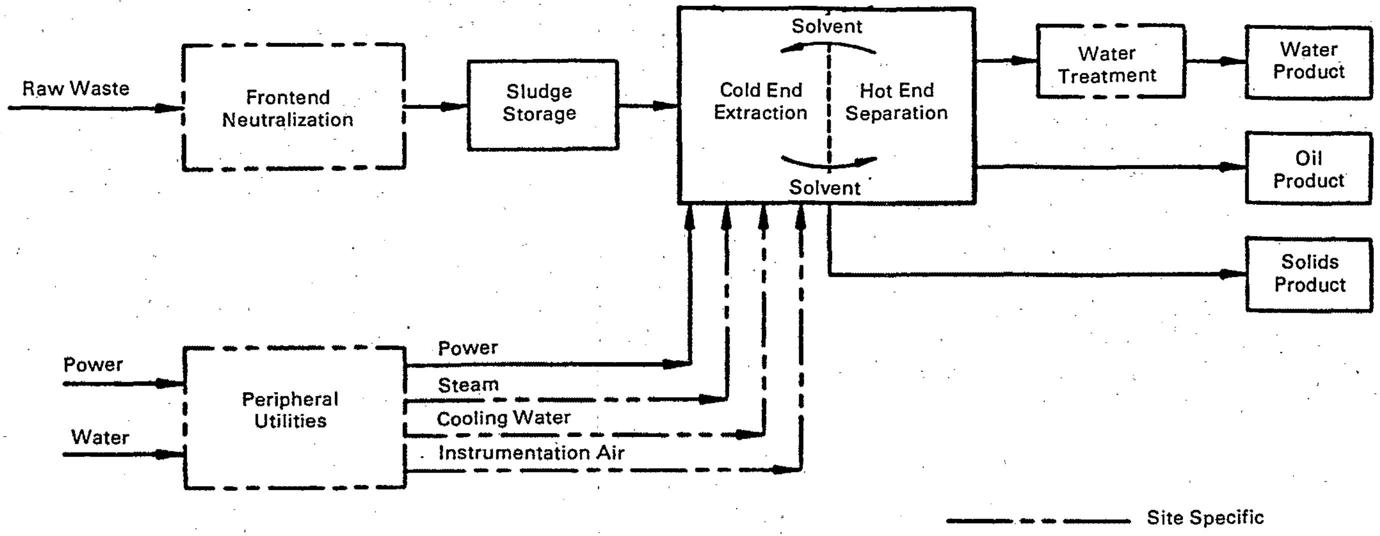


Figure 6-2. BEST Chemical Extraction Process
Source: Resources Conservation Company

Bench-scale treatability studies of the BEST process were conducted on lagoon sediments from the Arrowhead Refinery Superfund site in Hermantown, Minnesota. The sediments were contaminated with both metals and organics. Results showed that the BEST process successfully separated the contaminated wastes into three fractions: aqueous, oil-containing organics, and solids. Due to process difficulties in handling metals, lead was found in both the oil and solid fractions. Other bench-scale tests conducted on a variety of sediments indicated PCB removals of 96 percent in all cases and better than 99 percent in most cases.[7]

In a process similar to the BEST process, TEA was bench-tested in the Netherlands as an extraction solvent for the removal of PAHs from sediments. Results indicated removal efficiencies of 90-99 percent and that several extraction steps may be necessary to increase efficiency. Toluene was also tested as an extraction solvent, but was not as efficient as TEA.[6]

Low Energy Extraction Process (LEEP). The LEEP is being developed in conjunction with Enviro-Sciences, Inc., by Applied Remediation Technology. It uses a hydrophilic leaching solvent to extract organic contaminants from sediments and then concentrates the contaminants in a hydrophobic stripping solvent. Advantages include conversion of a high-volume, solid waste stream to a low-volume, liquid waste stream, operation at ambient conditions with low energy requirements, and use of simple processes and equipment. Disadvantages include necessary further treatment of the solvent stream and the contaminant specific nature of the selected leaching solvent. Bench-scale tests conducted on sediments from Waukegan Harbor, Illinois reduced PCB concentrations from 3200 ppm to 1 ppm. Plans exist to test a pilot-scale unit capable of treating 30 to 50 tons/hour.[9]

Acetone Extraction. Acetone has been successfully used by the Department of Defense (DOD) to remove explosives (TNT, DNT, etc.) from sediments. Unfortunately, this process concentrates the acetone-dissolved explosives in an enclosed container and may be very dangerous.[10] For this reason, acetone extraction was abandoned in favor of rotary kiln incineration (see Rotary Kiln Incineration below).

Low Temperature Thermal Stripping (LTTS). LTTS consists of indirectly heating the contaminated sediment to 250-800°F in an effort to volatilize contaminants and thereby remove them from the solid matrix. Volatilized organic contaminants subsequently pass through a carbon adsorption unit or combustion afterburner for destruction. LTTS systems generally may be used to remove volatile organic compounds from sediments. The system will be ineffective in removing metals and high boiling point organics. Feeds with a high moisture content (>60 percent) may require dewatering prior to treatment in order to make LTTS economically feasible. The high moisture content increases energy requirements and reduces the process throughput rate (see Figure 6-3). Bench-scale tests of contaminated sediments from the Halby Chemical site in Wilmington, Delaware indicated that LTTS successfully removed most volatile and semivolatile compounds at temperatures between 300° and 500°F with between 15 and 30 minutes residence time.[5]

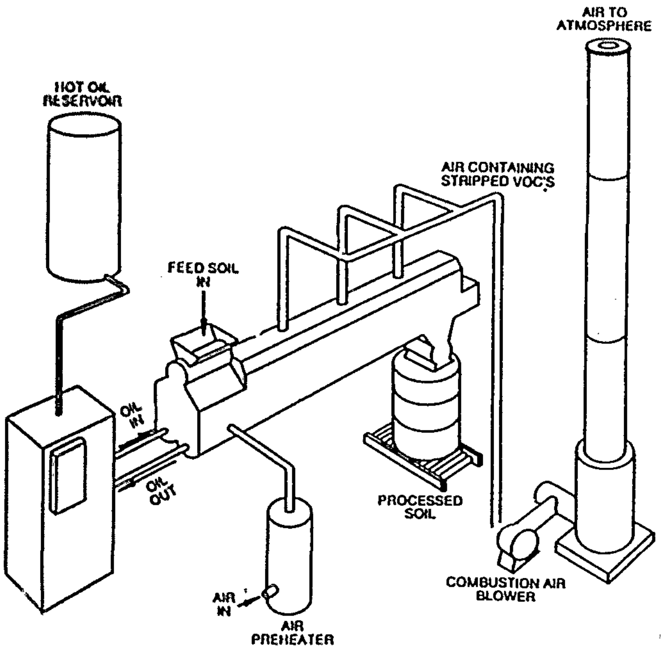


Figure 6-3. Low Temperature Thermal Stripping Source: U.S. Army Toxic and Hazardous Materials Agency. Aberdeen Proving Ground.

6.3.2 Soilwashing

Soil washing is a water-based, volume reduction process in which contaminants are extracted and concentrated into a small residual portion of the original volume using physical and chemical means. The principal process involves transfer of the contaminants from the sediment to the wash water and their subsequent removal from the water. The small volume of contaminated residual concentrate is then treated by destructive or immobilizing processes. By changing steps in the process, soil washing may be made amenable to a variety of site characteristics.

Full-scale commercial soil washing plants have been operating in Europe since 1982. Seventeen plants are currently in operation, nine devoted solely to contaminated sediment remediation. Depending on the size of the facility, these plants are capable of handling from 10-130 tons of soil or sediment/hour. Contaminants treated by these plants include metals and a variety of organics, but individual plants are limited in their ability to handle certain contaminants. EPA also found that the effectiveness of the European soil washing plants may be limited at certain sites by the size of particles they rejected (particle classification is an early step in the European soil washing process).[11]

6.4 Destruction/Conversion

Destruction and conversion technologies attempt to transform organic contaminants into the relatively benign end products resulting from thermal or chemical destruction or bacterial metabolism. While metals are difficult for these technologies to handle, some options do concentrate metals into a waste product (e.g., slag or plant biomass) that makes subsequent disposal simpler. However, sediments that are contaminated with both organics and metals may require pre-treatment or careful disposal of wastes.

6.4.1 Thermal Destruction

The applicability of a number of thermal processing methods on sediments has already been demonstrated in private and government sponsored cleanups. Although incineration and other thermal technologies have been shown to be among the most effective treatment technologies for hazardous and toxic waste destruction, costs may be high for sediments due to the intensive energy requirements for burning materials with high water contents and due to regulatory requirements for the subsequent disposal of ash and slag.

Ideally, the ultimate goal of thermal destruction is to convert waste materials into benign end-products (CO_2, H_2O vapor, SO_2, NO_x, HCl, and ash). Temperatures may range from 300°F to over 1650°F. In high temperature applications where strong oxidation is involved, the use of 50-150 percent excess air is not uncommon.

The suitability of contaminated sediments for the application of thermal treatment processes is determined by the physical and chemical makeup of the material and the volume to be treated. These characteristics impact:

1. The extent of particle classification required.
2. The amount of dewatering required and the selection of a dewatering method.
3. The type of thermal treatment utilized.
4. Air pollution control system design.
5. Treatment of residual ash prior to final disposal.

Pre-treatment options (#1 and #2 above) were discussed in Chapter Five. Thermal treatment side streams (#4 and #5) and thermal treatment options (#3) are described below.

Thermal treatment side streams may require additional treatment. The bottom and fly ash produced from incineration is likely to contain some residual heavy metals and may require further management. This may substantially increase the cost of the soil/sediment treatment process; however, recent tests conducted on slags obtained from a rotary kiln (which handled all types of hazardous wastes from around the Netherlands) indicated that up to 80 percent of the slags tested did not require further management.[12] The off-gases from sediments incineration generally require venturi- or injector-type scrubbers, ionizing wet scrubbers, fabric filters or baghouses, or electrostatic precipitators.[13,14]

Types of processes used to thermally remediate sediments include rotary kiln incineration, infrared incineration, circulating bed combustion, and vitrification. Generally, treatment methods with higher temperatures are required for contamination consisting of high concentrations of recalcitrant organics, such as PCBs. Due to varying site characteristics and regulatory requirements, selection of the best thermal treatment system should be based on projected technical performance as assessed from field pilot tests.

Rotary Kiln Incineration. A rotary kiln incinerator is a cylindrical, refractory-lined shell that is fueled by natural gas, oil, or pulverized coal. The kiln rotates to create turbulence and, thus, improve combustion. This thermal process is capable of handling a wide variety of solid wastes, with residence times ranging from a few seconds to hours for bulk solids. Combustion temperatures range from 1200 - 3000°F.[15]

Rotary kiln combustion is amenable to sediments contaminated with organics. Prior to being fed into the kiln, oversized debris and drums must be crushed or shredded. Waste characteristics that are not suited for rotary kiln systems include high inorganic salt content which causes degradation of the refractory and slagging of the ash, and high heavy metal content which can result in elevated emissions of heavy metals which are difficult to collect with air pollution control equipment.

Rotary kiln incineration has been used at two sites by the Department of Defense (DOD) to decontaminate sediments contaminated with explosives (TNT, DNT, etc.). These sites were at ammunition plants near Grand Island, Nebraska and Shreveport, Louisiana.[16] Two additional ammunition plants, near Savannah, Illinois and Childersburg, Alabama are presently under contract to be cleaned-up via rotary kiln incineration. Pilot studies have already been conducted at the Savannah, Illinois site.

In the Netherlands, several companies have been operating commercial soil and sediment cleaning plants. For example, NBM Bodemsanering BV has been operating a plant since 1986. At this plant, contaminated soils and sediments are incinerated in a rotary tube furnace. Dewatering and particle screening precede incineration; treatment of off-gases and waste-water follows incineration. The plant cleans soils and sediments to the satisfaction of Dutch regulations. The plant has a maximum capacity of 15 tons/hour under optimal conditions, and an annual capacity of 85,000 tons.

Over the next ten years, this thermal process is to be implemented on a full scale to remediate approximately 500,000 cubic meters (653,970 CY) of dredged sediments from the Neckar River in Germany. Conditions at the Neckar River site demand that sediments be removed on a regular basis. Additionally, a method for recycling these cadmium contaminated sediments was devised. The overall process involves the conversion of the material into spherical aggregate for the production of masonry blocks and lightweight concrete. The steps in the process involve dewatering via a screen belt press, mixing of the sediments with clay and additives, pelletizing the mixture, and then thermally processing in a rotary kiln at temperatures of 2100°F. The end product is an expanded clay of various sizes (0-16 mm) with a high compressive strength and excellent insulation properties. The cadmium boils off during incineration and is captured in the off-gas treatment process.[17]

Infrared Incineration. Infrared incineration systems are designed to destroy solid hazardous wastes through tightly controlled process parameters using infrared energy as the auxiliary heat source. This system consists of a rectangular carbon steel box lined with layers of a lightweight, ceramic fiber blanket. Infrared energy, provided by silicon carbide resistance heating elements, is used to bring the organic wastes to combustion temperature (500 - 1850°F) for residence times of 10 - 180 minutes. The remaining organics are destroyed in a gas-fired chamber, using temperatures of 1000 - 2300°F at residence times of approximately 2 seconds.[18,19]

Full-scale tests of the Shirco Infrared System have been conducted on lagoon sediments from the Peak Oil Superfund site in Brandon, Florida. The sediments were contaminated with metals, PCBs, and other organics. Lead in the ash failed to pass the EP Toxicity Test, but it did pass the TCLP. All organic compounds in the ash were below regulatory limits.[20] Available data suggest that this process is suitable for solid wastes containing particles from 5 microns to 2 inches in diameter and having up to a 50 percent moisture content, which would suggest that this process is conducive to the handling of sediments.

Circulating Bed Combustion (CBC). The CBC is an outgrowth of conventional fluidized bed incineration, which is primarily applicable to homogeneous sludges and slurries. This treatment process is capable of treating solids, sludges, slurries, and liquids; the high degree of turbulence and mixing caused by air velocities of up to 20 feet/second ensures treatment of a wide variety of wastes at temperatures below 1560°F. Retention times range from 2 seconds for gases to approximately 30 minutes for larger feed materials (less than one inch). A CBC developed by Ogden Environmental Services, Inc. has treated PCB contaminated sediments from the Swanson River Oil Field, Alaska in field demonstrations. This technology is well-suited for materials with relatively low heating values.[21,22,23]

Vitrification. Vitrification is a process in which hazardous wastes are subjected to very high temperatures and converted into a glassy substance. Organic contaminants are destroyed by the heat and inorganic contaminants are immobilized in the glass. Vitrification is potentially applicable for a wide range of organic and inorganic contaminants.

In situ vitrification (ISV) is a vitrification process in which joule heating occurs when a high current of electricity is passed through graphite electrodes inserted in the soil. The resulting heat melts the soil, destroying organic contaminants and incorporating inorganic contaminants in the melt. As the melt cools, it forms an obsidian-like, leach-resistant glass. Engineering scale tests have been performed on PCB contaminated sediments from New Bedford Harbor which indicate destruction and removal efficiencies of greater than 99.99999 percent for organics following off-gas treatment. TCLP testing resulted in leach extract that contained metal concentrations below the regulatory limits.[24,25] One disadvantage of ISV is that the process is not efficient for sediments with a high water content and, thus, contaminated sediments may have to be dredged and dewatered. Alternatively, dikes may isolate the contaminated sediments from the aquatic environment and thus enable the subsequent implementation of ISV. The process may also be limited by site characteristics. For example, large volumes of barrels tend to cause short circuits.

6.4.2 Chemical Conversion

Chemical destruction technologies chemically transform a toxic chemical into a relatively benign product. Few of these technologies have been applied to the remediation of contaminated sediments. Nucleophilic substitution will be the only technology described here.

Nucleophilic Substitution. Nucleophilic substitution uses a nucleophilic reagent to dechlorinate aromatic, organic compounds, such as PCBs and dioxins, in a substitution reaction. Common reagents include alkali metals in polyethylene glycol (APEG) or in polyethylene glycol methyl (APEGM). Proper control of temperature and reaction time maximizes process efficiency. Temperature and reaction time are site-specific characteristics and should be determined by prior testing. Nucleophilic substitution requires dewatering of sediments.[26]

The Galson Research Corporation tested a nucleophilic substitution process on PCB contaminated sediments from New Bedford Harbor. The process they tested used potassium hydroxide and polyethylene glycol (KPEG). Dimethyl sulfoxide (DMSO) served as a phase-transfer catalyst to promote PCB extraction. Bench-scale studies of the KPEG showed reduction of 6,000 to 7,500 ppm PCBs to 4 ppm in 12 hours at 165°C and residual recovery of 98 percent.[27]

6.4.3 Biodegradation

Biological degradation is the conversion of organic wastes into biomass and harmless metabolic byproducts, such as CO_2, CH_4, and inorganic salts. Microorganisms (principally bacteria and fungi) make up the most significant group of organisms involved in biodegradation. The rate of contaminant biodegradation is determined by the following:

1. The presence of appropriate microorganisms.
2. Adequate concentrations of essential nutrients.
3. The availability and concentration patterns of the compound to be degraded.
4. Contaminant effects on microbial population activity.

Heavy metals in the slurry can inhibit biodegradation. For that reason, a pre-treatment step to remove or decrease the concentration of such inhibitors may be needed. Methods for pre-treatment may consist of soil washing, metal extraction, and biological treatment utilizing algal cells in silica gel medium to remove heavy metals.

There are many bench-scale studies of biodegradation, but few field applications to contaminated sediments. The transition from the laboratory to the field is very difficult because acclimation of microorganisms is much easier in the laboratory.

The biodegradation of contaminated sediments can be done by removing the contaminated sediments and then treating or by leaving the sediments in place and treating in situ.

Removal and Treatment. Removal allows three types of biodegradation treatment processes: composting, bioslurries, and solid phase treatment. A near-site biodegradation process that treats the contaminated sediments on barges near the removal site will be described separately.

Composting involves the storage of highly biodegradable and structurally firm materials such as chopped hay or wood chips mixed with a 10 percent or less concentration of biodegradable waste. There are three designs for aerobic compost piles: the open windrow system, the static windrow system, and in-vessel composting. In-vessel composting may also be anaerobic; anaerobic conditions are maintained by flushing the vessel with nitrogen. Anaerobic efficiency appears to be less than that obtained using aerobic vessels. Laboratory tests conducted by Dutch researchers of an aerobic system indicated that the total quantity of oxygen supplied may be more important than frequency of aeration.[6]

Composting is relatively insensitive to toxic impacts on microbes. Field demonstrations of composting for the remediation of lagoon sediments contaminated with TNT have been conducted at the Louisiana Army Ammunitions Plant. Results indicated that contaminant concentrations decreased from 12,000 ppm to 3 ppm.[28]

Bioslurries treat the contaminated sediment in a large bioreactor. The system is designed to maintain intimate mixing and contact of the microorganisms with the hazardous waste compounds. The slurry is mechanically agitated in a reactor vessel to keep the solids suspended and to maintain the appropriate reaction conditions. Additives such as inorganic and organic nutrients, oxygen, acid or alkali for pH control, or commercial preparations of microorganisms may be necessary. A typical soil slurry feedstock contains approximately 50 percent solids by weight. Dissolved oxygen levels must be maintained and temperatures should be stabilized to range between 60-160°F. Biodegradability of the pollutants, the sediment matrix, and the characteristics of the contaminant(s) dictate retention time.

Another bioslurry method for treating dredged sediments utilizes anaerobic digesters. These are air tight reactor vessels with provisions for venting or collecting methane and carbon dioxide. A methanogenic consortia (found in anaerobic digesters or sewer sludge digesters) does the work. The consortia consists of four different bacterial groups, each of which metabolizes a different class of compounds.

Bioreactors were studied at the bench-scale level in the Netherlands. Results from these fourteen day batch studies indicated removal efficiencies ranging from 82-95 percent for cutting oil and other organics in loam and loamy sand.[11] Other research by the Dutch indicated that bioreactors had higher degradation rates than either land farming or aerated basins.[6]

Solid phase treatment, or land farming, has now been limited under the recently promulgated RCRA land disposal restrictions to the handling of RCRA wastes in lined land treatment units with leachate collection systems or in RCRA permitted tanks. The dredged materials are lifted into this prepared treatment unit. Land treatment is accomplished by adding nutrients (nitrogen and phosphorus) and exogenous microbial additives and by tilling the sediments to facilitate the transport of oxygen through the migration system.

Wastes are typically mixed to a depth of 6 to 12 inches, where the biochemical reactions take place. Tillage methods are more useful for materials containing higher concentrations of soils but will take more time to obtain target concentrations levels of pollutants than a bioslurry process. Treated soils must be delisted, if RCRA wastes were remediated.[9]

A near-site process developed by Bio-Clean requires dredging and subsequent treatment of the sediment in a series of nine processing units on barges, thus eliminating the need for transportation of contaminated sediments to a distant treatment site. The process uses naturally-occurring bacteria to aerobically degrade organic contaminants. The batch process involves the extraction, sterilization, and solubilization of the contaminants utilizing high temperature, high pH, and biodegradation.[26]

In Situ Biodegradation. In situ biodegradation has captured regulators' attention because leaving the sediments in place can limit the negative environmental impacts caused by dredging. In situ biodegradation relies on indigenous or introduced aerobic or anaerobic bacteria to degrade organic compounds in soils. Bioavailability is the key to successful in situ biodegradation. Sediment properties which impact bioavailability influence the interaction between sediment and contaminants. Such properties include type and amount of clay, cation exchange capacity, organic matter content, pH, the amount of active iron and manganese, oxidation-reduction conditions, and salinity.[26] The important site characteristics to be identified for in situ biodegradation are listed below:[29]

1. Characterization and concentration of wastes, particularly organics in the contaminated sediments.
2. Microorganisms present in the sediment and their capability to degrade, co-metabolize, or absorb the contaminants.
3. Biodegradability of waste constituents (half-life, rate constant).
4. Biodegradation products.
5. Depth, profile, and areal distribution of constituents in the sediments.
6. Sediment properties for biological activity (such as pH, oxygen content, moisture and nutrient contents, organic matter, temperature, etc).
7. Sediment texture, water-holding capacity, degree of structure, erosion potential of the soil.
8. Hydrodynamics of the site.

This form of treatment impacts both the sediments and surface water. Examples of disadvantages of in situ biodegradation include: (1) the technique is not suitable for soil contaminated with metals present in inhibitory concentrations; and (2) iron fouling can inhibit oxygen availability.

Research over the last decade suggests that naturally occurring bacteria may be able to biodegrade PCBs. Two separate and complementary degradation pathways are involved in the natural destruction of PCBs. In one pathway, anaerobic bacteria remove chlorine atoms from PCBs by reductive dechlorination. In the other pathway, aerobic bacteria destroy lightly chlorinated PCBs.[30,31] Both pathways have been documented in sediments and in laboratory studies, but they have not been shown to occur in sequence within the same natural system.[32] Current research focuses on linking these pathways in the laboratory, increasing the rate of degradation in each pathway, and in moving from bench-scale to field-scale demonstrations.

The most common in situ biodegradation process is enhancement of natural biochemical mechanisms for detoxifying or decomposing the soil contaminants. Examples of enhancement include increasing the sediment's dissolved oxygen levels (for aerobic degradation), providing alternative electron acceptors, enriching sediments with auxiliary carbon sources, and mixing the sediments to improve bacterial access to contaminants.

6.5 Containment

Containment is the immobilization and/or isolation of contaminated sediments. Solidification/stabilization is one type of containment option based on immobilization. Chapter VII describes disposal alternatives that provide containment by isolation.

6.5.1 Solidification/Stabilization

Solidification/stabilization refers to the use of additives or processes to transform hazardous waste into a more manageable or less toxic form by immobilizing the waste constituents. By producing a solid from a liquid or slurry, solidification/stabilization technologies improve the handling characteristics of the material, decrease the surface area from which contaminant transport may occur, and limit the mobility of a contaminant exposed to leaching fluids. Types of solidification/stabilization technologies include:[33]

1. Cement-based solidification/stabilization.
2. Pozzolonic solidification/stabilization.
3. Thermoplastic solidification/stabilization.
4. Organic polymerization solidification/stabilization.
5. Organophilic clay-based solidification/stabilization processes.

Solidification/stabilization functions both physically and chemically. Solidification is a physical process which refers to the conversion of a liquid or semi-solid to a solid. Solidification is considered an effective process in the immobilization of both metals and inorganics. Stabilization is a chemical process which refers to the alteration of the chemical form of contaminants. Generally, stabilization is considered an effective process in the immobilization of metals, but not organics. In fact, organics may actually interfere with solidification/stabilization setting reactions.[34]

The applicability of solidification/stabilization processes to the sediments of concern is determined by chemical and physical analysis. Several leach tests are available for this purpose. Listed wastes requires the Toxicity Characteristics Leaching Procedure (TCLP). Additional leaching tests may be chosen from American National Standards Institute (ANSI) procedures appropriate for the contaminant. Newer procedures, such as the Standard Batch Leachate Test (SBLT), are constantly being reviewed and accepted according to the need or circumstance.[33]

Physical testing, aimed at such product characteristics as bearing capacity, trafficability, and permeability, is accomplished through established engineering tests. For example, ratios of waste to binder in each system are evaluated using the Unconfined Compressive Strength (UCS) Test. Bulk density, permeability, and moisture content are also commonly tested to determine the degree of solidification/stabilization.

6.5.2 Sediment Applications of Solidification/ Stabilization

Following is a brief discussion of solidification/stabilization technology applications for contaminated sediments.

Marathon Battery. Bench-scale and pilot-scale tests were conducted to evaluate the application of solidification/ stabilization at the Marathon Battery Company site in the Village of Cold Spring, New York.[35] Between 1952 and 1979 hydroxides of cadmium, nickel, and cobalt were discharged into a marsh and a cove by the Marathon Battery Company. The feasibility study considered solidification/stabilization as an option.

Tests were conducted to confirm whether cadmium, cobalt, and nickel could be chemically stabilized or physically bound to the sediments to levels below the RCRA EP toxicity test limits. Three mixtures of waste and pozzolan and lime and three mixtures of waste and portland cement were tested. After 48 hours, two of the pozzolan and lime mixtures passed the RCRA EP toxicity test, but only one of the portland cement mixtures passed the RCRA EP toxicity test. Based on these limited laboratory results, sediment metals such as cadmium, cobalt, and nickel appeared to be immobilized.

New Bedford. The application of solidification/stabilization technology for the treatment and disposal of contaminated materials was tested at the bench-scale level at the New Bedford Harbor Superfund project.[36] The Upper Acushnet River Estuary in New Bedford, Massachusetts is contaminated by PCBs and heavy metals. Dredged samples were solidified and stabilized with Type I portland cement and a portland cement/proprietary reagent in three formulations.

Unconfined compressive strength was the key test for assessing physical solidification; batch leach tests using distilled-deionized water were the key tests for assessing chemical stabilization. Leachates, solidified and stabilized sediment, and untreated sediment samples were analyzed for concentrations of PCBs and metals, including cadmium and zinc. Unconfined compressive strength was 20 to 481 psi indicating a strong versatility for solidification. Batch leach tests showed that the chemical stabilization of the three formulations was similar. The leachability of cadmium and zinc was eliminated or substantially reduced. Leaching of PCBs was reduced by 10 to 100 times. However, copper and nickel were more readily mobilized after treatment.[36]

Indiana Harbor. The navigation channel at Indiana Harbor in northwestern Indiana is contaminated by metals, PCBs, and other organic contaminants. A study was conducted by the Environmental Laboratory, Department of the Army, Vicksburg, Mississippi to evaluate alternative methods for dredging and disposing of the contaminated sediments.[37]

Composite samples were tested and compared with Indiana water quality standards and EPA federal water quality criteria. The solidification/stabilization processes selected for this study were portland cement, portland cement with fly ash, portland cement with fly ash and/or sodium silicate, fly ash with lime, and various mixtures of proprietary polymers.

Unconfined compressive strength was used as a key indicator of physical solidification. The range in a 28-day unconfined compressive strength test was 48.5 psi to 682 psi for processes not involving sodium silicate. Higher strengths were obtained using portland cement with sodium silicate and portland cement with fly ash and sodium silicate. Trade-offs occurred between the costs of the setting agents and the quality of the product depending on the agents used for solidification and the dosage applied. Portland cement proved an excellent setting agent and yielded excellent physical stability.

Chemical leach tests were conducted to evaluate the chemical stability of solidified and stabilized samples. Serial, graded batch leach tests were used to develop desorption isotherms.[38] Coefficients for contaminant release were determined from desorption isotherms for comparison to those obtained from untreated sediments.

Cadmium and zinc were completely immobilized by some processes. Proprietary processes were among the best. Fly ash with lime in some cases increased concentrations of leachable contaminants. Solidification/stabilization did not significantly alter the sorption capacity of the sediment for organic carbon. Data were not available to evaluate the potential of solidification/stabilization technology to reduce the leachability of specific organic compounds.[37]

Buffalo River. A bench scale solidification/stabilization study was conducted to evaluate the effectiveness of solidification/stabilization technologies on the physical and chemical properties of Buffalo River sediment, New York. Binders selected for testing included portland cement, lime/fly ash, and kiln dust. The addition of activated carbon to the portland cement process was investigated to determine if it would absorb contaminants and improve the binding of organics. Physical tests conducted were the UCS wet/dry and freeze/thaw. Chemical tests conducted were the TCLP and Standard Leachate Test (SLT).

Halby Chemical Site. Bench-scale treatability studies were used to evaluate the effectiveness of solidification/stabilization for binding metals in sediments from Halby Chemical site in Wilmington, Delaware. Results indicated that the soils themselves do not leach appreciable amounts of metals under TCLP test conditions. Of the two binders studied (asphalt and cement), asphalt appeared to be the better binder for reducing leachate concentrations of arsenic and copper.[5]

6.6 References

1. USEPA. The Feasibility Study: Development and Screening of Remedial Action Alternatives. EPA 9355.3-01FS3, U.S. Environmental Protection Agency, 1989.
2. Allen, D.C. and A. J. Ikalainen. Selection and Evaluation of Treatment Technologies for the New Bedford Harbor (MA) Superfund Project. Superfund '88, Proceedings of the 9th National Conference, 1988. pp 329-334.
3. Male, J. W. and M. J. Cullinane, Jr. Procedure for Managing Contaminated Dredged Material. Journal of Waterway, Port, Coastal, and Ocean Engineering 114 (5): 545-564, 1988.
4. Carpenter, B. PCB Sediment Decontamination - Technical/Economic Assessment of Selected Alternative Treatments. EPA-600/S2-86-112, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1987.
5. Hokanson, S., R.B. Sukol, S. Giti-Pour, G. McNelly, and E. Barth. Treatability Studies on Soil Contaminated with Heavy Metals, Thiocyanates, Carbon Disulfate, Other Volatile and Semivolatile Organic Compounds. In: Proceedings of the 11th National Conference, November 26-28, 1990, Washington, D.C. Hazardous Materials Control Research Institute, 1990.
6. Dillen, M.R.B. van. Cleaning of Sediments Contaminated with Organic Micropollutants. Institute for Inland Water Management and Waste Water Treatment (RIZA), Ministry of Transport and Public Works, the Netherlands, undated.
7. USEPA. Engineering Bulletin: Solvent Extraction Treatment. EPA/540/2-90/013, U.S. Environmental Protection Agency, Washington, D.C., September, 1990.
8. USEPA. Technology Evaluation Report: CF Systems Organic Extraction System, New Bedford, Massachusetts. EPA/540/5-90/002, U.S. Environmental Protection Agency, January, 1990.
9. Sukol, R.B. and G.D. McNelly. Workshop on Innovative Technologies for Treatment of Contaminated Sediments, June 13-14, 1990. EPA/600-2-900/054, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1990.
10. Roy F. Weston, Inc. Pilot-Scale Development of Low Temperature Thermal Degradation and Solvent Extraction Treatment Technologies for Explosives Contaminated Waste Water Lagoons. U.S. Army Toxic and Hazardous Materials Agency, March, 1985.
11. USEPA. Assessment of International Technologies for Superfund Application. EPA/540/2-88/003, U.S. Environmental Protection Agency, September, 1988.
12. Schlegel, R. Residues from High Temperature Rotary Kilns and Their Leachability. In: Forum on Innovative Hazardous Waste Treatment Technologies: Domestic and International, Atlanta, Georgia, June 19-21, 1989. EPA/540/2-89/056, U. S. Environmental Protection Agency, Washington, D.C., 1989. pp. 195-230.
13. Brunner, C.R. Incineration: Today's Hot Option for Waste Disposal. Chemical Engineering, Vol. 94, No. 14, October 12, 1987.

14. Peacy, J. Special Roundup Feature Report on Incineration. Pollution Engineering, Vol. 16, No. 16, April, 1984.

15. USEPA. Mobile Treatment Technologies for Superfund Wastes. EPA 540/2-86/003(f), U.S. Environmental Protection Agency, September, 1986.

16. Roy F. Weston, Inc. Incineration Test on Explosives Contaminated Soils at Savannah Army Depot, Savannah, Illinois. DRXTH-TE-CR-84277, U.S. Army Toxic and Hazardous Materials Agency, April, 1984.

17. Nusbaumer, M. and E. Beitinger. Recycling of Contaminated River and Lake Sediments Demonstrated by the Example of Neckar Sludge. In: Forum on Innovative Hazardous Waste Treatment Technologies: Domestic and International, Atlanta, Georgia, June 19-21, 1989. EPA/540/2-89/056, U. S. Environmental Protection Agency, Washington, D.C., 1989. pp. 231-240.

18. USEPA. PCB Sediment Decontamination - Technical/Economic Assessment of Selected Alternative Treatments. EPA/600/2-86/112, U.S. Environmental Protection Agency, December, 1986.

19. USEPA. A Compendium of Technologies Used in the Treatment of Hazardous Wastes. EPA/625/8-87/014, U.S. Environmental Protection Agency, September, 1987.

20. USEPA. Shirco Infrared Incineration System. EPA/540/A5-89/010, U.S. Environmental Protection Agency, 1989.

21. USEPA. Superfund Innovative Technology Evaluation (SITE) Program. EPA/540/8-89/010, U.S. Environmental Protection Agency, 1989.

22. USEPA. The Superfund Innovative Technology Evaluation Program - Progress and Accomplishments Fiscal Year 1989. EPA/540/5-90/001, U.S. Environmental Protection Agency, March, 1990.

23. Wilbourn, R.G. and B.M. Anderson. Contaminated Soil Remediation by Circulating Bed Combustion. In: Forum on Innovative Hazardous Waste Treatment Technologies: Domestic and International, Atlanta, GA, June 19-21, 1989. EPA/540/2-89/056, U. S. Environmental Protection Agency, Washington, D.C., 1989. pp. 172-195.

24. Timmons, D.M., V. Fitzpatrick, and S. Liikala. Vitrification Tested on Hazardous Wastes. Pollution Engineering, June, 1990. pp. 76-81.

25. Reimus, M.A.H. Feasibility Testing of In Situ Vitrification of New Bedford Harbor Sediments. Battelle, Pacific Northwest Laboratories, Richland, Washington, 1988.

26. Averett, D.E., B.D. Perry, and E.J. Torrey. Review of Removal, Containment, and Treatment Technologies for Remediation of Contaminated Sediments in the Great Lakes. Miscellaneous Paper EL90-25, U.S. Army Corps of Engineers, Vicksburg, Mississippi, 1990.

27. Galson Research Corporation. Laboratory Treatment Results: KPEG Treatment of New Bedford Soils. East Syracuse, New York, 1988.

28. Williams, R.T. and C.A. Myler. Bioremediation Using Composting. Biocycle 31: 78-82, November, 1990.

29. USEPA. Handbook on In Situ Treatment of Hazardous Waste-Contaminated Soils. EPA/540/2-90/002, U.S. Environmental Protection Agency, January, 1990.

30. Bedard, D.L. Bacterial Transformation of Polychlorinated Biphenyls. In: Biotechnology and Biodegradation, D. Kamely, A. Chakrabarty, and G.S. Omenn, eds. Advances in Applied Biotechnology Series, Vol. 4, Portfolio Pub. Co., The Woodlands, Texas, 1990. pp. 369-388.

31. Abramowicz, D.A. Aerobic and Anaerobic Biodegradation of PCBs: A Review. Critical Reviews in Biotechnology, 10(3): 241-251, 1990.

32. Anid, P.J., L. Nies, J. Han, and T.M. Vogel. Hudson River Model. In: Research and Development Program for the Destruction of PCBs, Ninth Progress Report, June 1, 1989 - June 31, 1990. General Electric Company, Corporate Research and Development, Schenectady, New York, 1990.

33. USEPA. Stabilization/Solidification of CERCLA and RCRA Wastes: Physical Tests, Chemical Testing Procedures, Technology Screening, and Field Activities. EPA/625/6-89/022, U.S. Environmental Protection Agency, Risk Reduction Engineering Laboratory, Cincinnati, Ohio, 1989.

34. Jones, L. W. Interference Mechanisms in Waste Stabilization/Solidification. EPA 16001 S2-891067, U.S. Environmental Protection Agency, Risk Reduction Engineering Laboratory, Cincinnati, Ohio, 1990.

35. Ebasco Services Incorporated. Final Supplemental Remedial Investigation Report: Marathon Battery Company Site (Constitution Marsh and East Foundry Cove). Ebasco Services Incorporated, August, 1986.

36. Myers, T.E. and M. E. Zappi. New Bedford Harbor Superfund Project, Acushnet River Estuary Engineering Feasibility Study of Dredging and Dredged Material Disposal Alternatives, Laboratory-Scale Application of Solidification/ Stabilization Technology. EL-88-15, U.S. Army Corps of Engineers, Vicksburg, Mississippi, 1989.

37. USACE. Disposal Alternatives for PCB Contaminated Sediments from Indiana Harbor, Indiana, Vol. 1. Final Report, U. S. Army Corps of Engineers, 1987.

38. Houle, M. J. and D. E. Long. Interpreting Results from Serial Batch Extraction Tests of Wastes and Soils. In: Proceedings of the Sixth Annual Research Symposium on Hazardous Wastes. EPA-600/9-80-010, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980.

CHAPTER 7

DISPOSAL

7.1 Introduction

Disposal alternatives for dredged material consist of unrestricted and restricted options. Most dredged materials are the product of maintenance dredging; the majority of this material is not contaminated and is thus suitable for unrestricted disposal. Unrestricted alternatives include unrestricted open-water disposal ("dumping"), sanitary landfills, and beneficial uses. Since this document is concerned with the remediation of contaminated sediments, unrestricted options will not be discussed further. Restricted alternatives suitable for contaminated sediments include capping, confined disposal facilities, and hazardous landfills.

Pre-testing is essential in deciding on a particular restricted alternative and on the proper design of that alternative. Francingues et al[1] present tests that should be included as part of this decision making stage.

7.2 Capping

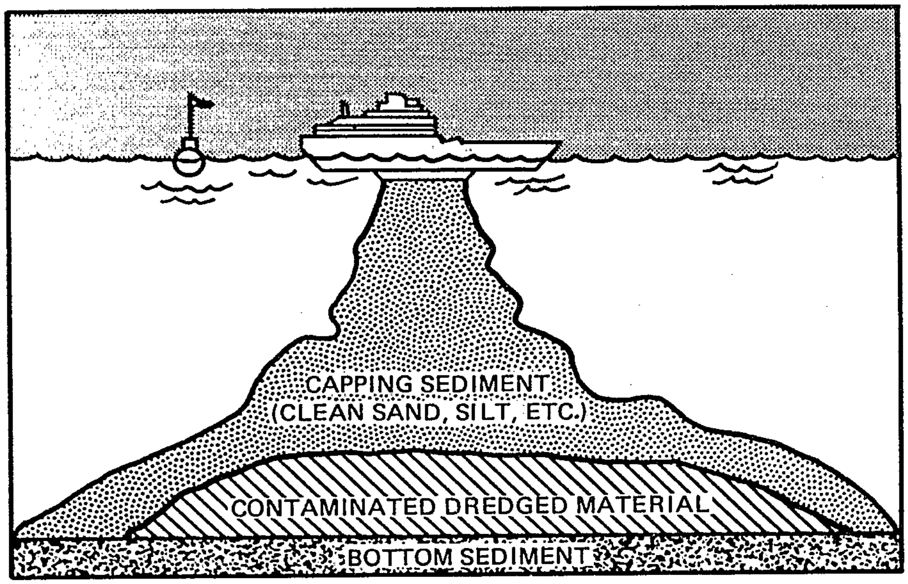
The principal concept for reducing long-term environmental effects associated with open water disposal is to "cap" (cover or encapsulate) the contaminated material with clean dredged material. Contaminated sediments can be capped with clean sediments in situ, or they can be dredged, moved, and then capped. By keeping contaminated sediment in the waterway, stable geochemical and geohydrologic conditions are maintained in the sediment, minimizing release of contaminants to surface water, ground water, and air. Placement of a clean cap or cover on top of the contaminated sediment sequesters diffusion and convection of contaminants into the water column and prevents bioturbation or uptake by aquatic organisms.[2] Capping could also be considered for disposal of residual solids from treatment or pre-treatment processes.[3]

Capping should not be considered a more elaborate version of conventional open-water dumping. Rather, capping is an engineering procedure and its successful performance depends on proper design and care during construction.[4] Six parameters have been identified as central to the design of an open-water disposal site: currents (velocity and structure), average water depths, salinity/temperature stratifications, bathymetry (bottom contours), dispersion and mixing, and navigation and positioning (location/distance, surface sea state, etc.).[5]

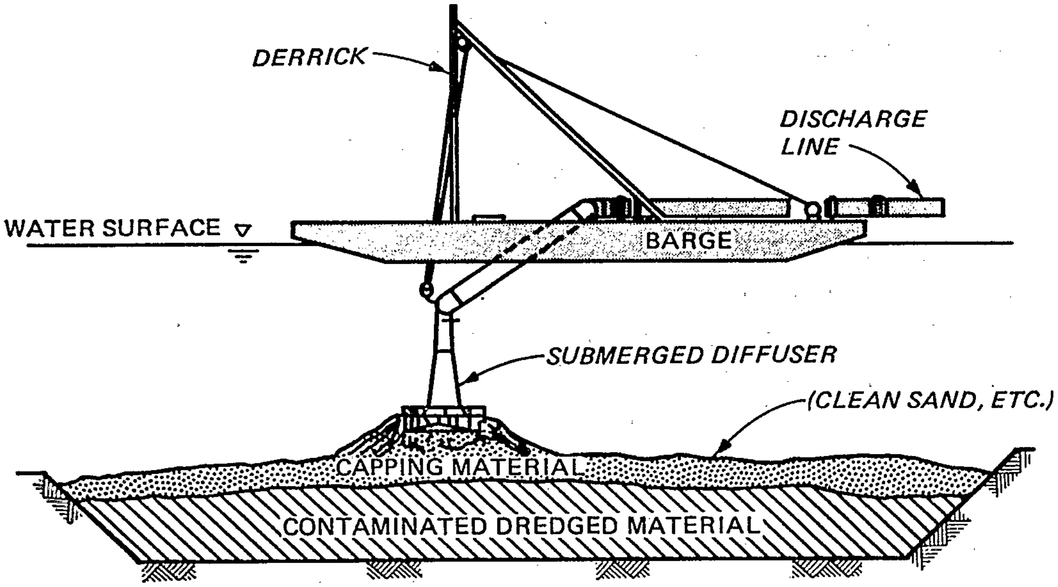
As shown in Figure 7-1, capping options include level bottom capping and contained aquatic disposal (CAD). Level bottom capping projects place the contaminated sediments on the existing bottom in a discrete mound. The mound is covered with a cap of clean sediment, usually in several disposal sequences to ensure adequate coverage. Where the mechanical conditions of the contaminated sediments and/or bottom conditions (slopes) require a more positive lateral control during placement, CAD options may be applied. These include the use of an existing depression, excavation of a disposal pit, or construction of one or more confining submerged dikes or berms.[4]

To reduce short term effects on the water column during placement, hydraulically dredged material may be discharged below the surface using a gravity downpipe or submerged diffuser. Such equipment not only reduces effects on the upper water column but also assists in accurate placement of the contaminated material and the clean capping material at the disposal site.[2]

Capping techniques may not be suitable for the most highly contaminated sediments. They may be favorable in some applications because of ease of implementation, lack of upland requirements, comparatively low cost, and highly effective contaminant containment efficiency. The principal disadvantages for open water disposal options are the concern for long term stability and effectiveness of the cap and the complications that may occur if remediation of the disposal site should be required in the future.[2] Capped sites will also require monitoring and maintenance to ensure site integrity.[4] Additional references for planning and designing capping operations include Truitt[6,7] and Palermo.[8]



a. Level bottom capping



b. Contained aquatic disposal

Figure 7-1. Schematic of Capping Options.[4]

Capping has been used as a disposal technology in Long Island Sound, the New York Bight, and Puget Sound, in the U.S.; in Rotterdam Harbor, in the Netherlands; and in Hiroshima Bay, in Japan. No problems have been reported at capped sites in Puget Sound, one of which is six years old. The Puget Sound capped sites include sediments capped in situ and sediments dredged and then capped.[3]

7.3 Confined Disposal Facility (CDF)

CDFs are engineered structures enclosed by dikes and designed to retain dredged material. They may be located upland (above the water table), partially in the water near shore, or completely surrounded by water. A CDF may have a large cell for material disposal, and adjoining cells for retention and decantation of turbid, supernatant water. A variety of linings have been used to prevent seepage through the dike walls. The most effective are clay or bentonik-cement slurries, but sand, soil, and sediment linings have also been used.

Location and design are two important CDF considerations. Terms to consider in the location of a CDF are the physical aspects (size, proximity to a navigable waterway), the design/construction (geology, hydrology), and the environment (current use of area, environmental value, environmental effects). The primary goal of CDF design is minimization of contaminant loss. Accordingly, potential contaminant pathways must be identified and controls and structures selected to limit leakage via these pathways. Contaminants are potentially lost via leachate through the bottom of the CDF, seepage through the CDF dikes, volatilization to the air, and uptake by plants and animals living or feeding in the CDF. Caps are the most effective way to minimize contaminant loss from CDFs, but selection of proper liner material is also an important control in CDFs. Finally, CDFs require continuous monitoring to ensure structural integrity.[9,10,11]

7.4 Landfills

Offsite landfills may be considered for highly contaminated material or for treated residuals. There are two types of landfills: sanitary and hazardous. Highly contaminated sediments or sediment wastes may be inappropriate for sanitary landfills and must be disposed of in hazardous landfills, which will add greatly to total treatment cost. Hazardous landfills must be designed to meet regulatory criteria and must have appropriate state and/or federal permits.

Because dredging often results in large quantities of dredged material with high water contents, dredging may not be compatible with landfill disposal. Large quantities of dredged material and high water content both increase the volume of material the landfill must accommodate and thus drive up costs. If use of a landfill is required, then specific pre-treatment options (such as dewatering) and/or treatment options may have to be considered.

7.5 References

1. Francingues, N.R., M.R. Palermo, C.R. Lee, and R.K. Peddicord. Management Strategy for Disposal of Dredged Material: Contaminant Testing and Controls. Miscellaneous Paper D-85-1, USACE Waterways Experiment Station, Vicksburg, Mississippi, 1985.

2. Averett, D.E., B.D. Perry, and E.J. Torrey. Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediments in the Great Lakes. Miscellaneous Paper EL90-25, U.S. Army Corps of Engineers, Vicksburg, Mississippi, 1990.

3. Fairweather, V. The Dredging Dilemma. Civil Engineering, August, 1990, pp. 40-43.

4. Palermo, M.R. et al. Evaluation of Dredged Material Disposal Alternatives for U.S. Navy Homeport at Everett, Washington. EL-89-1, U.S. Army Corps of Engineers, Vicksburg, Mississippi, January, 1989.

5. Cullinane, M.J., Jr., D.E. Averett, R.A. Shafer, J.W. Male, C.L. Truitt, and M.R. Bradbury. Alternatives for Control/Treatment of Contaminated Dredged Material. In: Contaminated Marine Sediments—Assessment and Remediation, National Academy Press, Washington, D.C., 1989. pp. 221-238.

6. Truitt, C.L. Engineering Considerations for Capping Subaqueous Dredged Material Deposits—Background and Preliminary Planning: Environmental Effects of Dredging, Technical Notes. EEDP-09-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1987.

7. Truitt, C.L. Engineering Considerations for Capping Subaqueous Dredged Material Deposits—Design Concepts and Placement Techniques: Environmental Effects of Dredging, Technical Notes. EEDP-09-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1987.

8. Palermo, M.R. Design Requirements for Capping, Environmental Effects of Dredging, Technical Notes. In preparation, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1991.

9. Cullinane, M.J., D.E. Averett, R.A. Schafer, J.W. Male, C.L. Truitt, M.R. Bradbury. Guidelines for Selecting Control and Treatment Options for Contaminated Dredged Material Requiring Restrictions. Final Report, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, September, 1986.

10. Sukol, R.B. and G.D. McNelly. Workshop on Innovative Technologies for Treatment of Contaminated Sediments, June 13-14, 1990. EPA/600/2-900/054. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1990.

11. Miller, J.A. Confined Disposal Facilities on the Great Lakes. U.S. Army Corps of Engineers, Chicago, Illinois, February, 1990.

☆U.S. GOVERNMENT PRINTING OFFICE: 1994 - 550-001/00212

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268-1072

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35

Official Business
Penalty for Private Use, $300

Please make all necessary changes on the above label, detach or copy, and return to the address in the upper left-hand corner.

If you do not wish to receive these reports CHECK HERE ☐; detach, or copy this cover, and return to the address in the upper left-hand corner.

EPA/625/6-91/028