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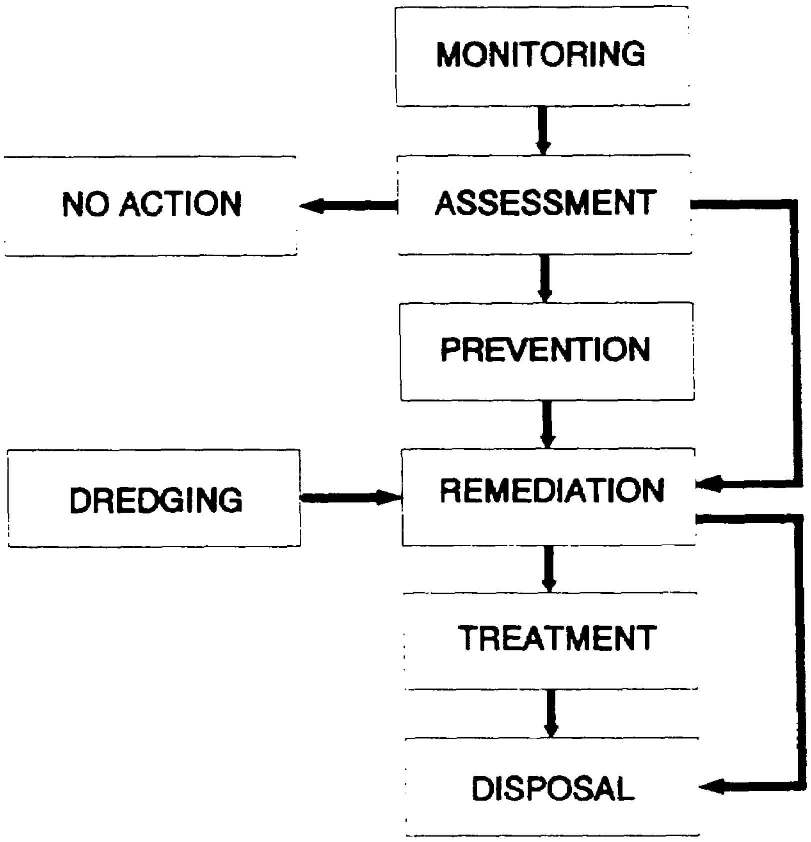
Selecting Remediation Techniques For Contaminated Sediment



SELECTING REMEDIATION TECHNIQUES FOR CONTAMINATED SEDIMENT

Office of Water
Office of Science and Technology
Standards and Applied Science Division
U.S. Environmental Protection agency
Washington, D.C. 20460

and

Office of Research and Development
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio 45219

ABSTRACT

The objective of this planning guide is to assist federal and state remedial managers, local agencies, private cleanup companies, and supporting contractors in the remedial decision-making process at contaminated sediment sites. It attempts to accomplish the following:

- Define the characteristics of contaminated sediments and of surrounding water bodies that affect remedy selection,
- Provide a streamlined process for selecting an appropriate remedy,
- Describe commonly-selected conventional remedies and potentially applicable innovative technologies.

Current literature on processing contaminated sediment has provided the generic content in this guide. This sediment-specific data has been consolidated for easy reference. It brings together conventional options and potential alternatives appropriate to these sites; it provides treatability study data and examples drawn from relevant case studies. An excellent companion document to this guide is *Remediation of Contaminated Sediments* (USEPA, 1991) which focuses on small site contaminated sediments remediation with particular emphasis on treatment technologies.

Innovative treatment of contaminated sediment is in the early stages of development. The remedial manager must be alert to the ongoing development of new remedies, new regulations, and new policy issues that may affect operations at contaminated sediment sites.

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

Appendices

FIGURES

TABLES

TABLES (continued)

ABBREVIATIONS AND SYMBOLS

AOC	area of contamination
ARARs	applicable or relevant and appropriate requirements
ARCS	alternative remedial contracts strategy
ARCS	assessment and remediation of contaminated sediments
ATSDR	Agency for Toxic Substances and Disease Registry
ATTIC	Alternative Treatment Technology Information Center
BCF	bioconcentration factor
BDAT	best demonstrated achievable technology
BOD	biochemical oxygen demand
BTX	benzene, toluene, xylene
CAA	Clean Air Act
CAD	contained aquatic disposal
CDF	confined disposal facility
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERI	Center for Environmental Research Information
CFR	Code of Federal Regulations
cm	centimeter
CO_2	carbon dioxide
COD	chemical oxygen demand
COLIS	Computer On-Line Information System
CRP	community relations plan
cu yd	cubic yard
CWA	Clean Water Act
dia	diameter

ABBREVIATIONS AND SYMBOLS (continued)

DMSO	dimethyl sulfoxide
DRE	destruction and removal efficiency
EIS	environmental impact statement
EP	extraction procedure
EP	equilibrium partitioning
EPA	United States Environmental Protection Agency
ERCS	emergency response cleanup services
FEMA	Federal Emergency Management Agency
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FPXRF	field-portable X-ray fluorescence
GLNPO	Great Lakes National Program Office
GLWQA	Great Lakes Water Quality Agreement
GPR	ground penetrating radar
H_2O	water
H_2O_2	hydrogen peroxide
HCl	hydrochloric acid
HNU	[manufacturer of] a device for measuring organic vapor concentrations
hr	hour
HRS	hazard ranking system
HSP	health and safety plan
HSWA	Hazardous and Solid Waste Amendments of 1984
IAG	interagency agreement
in	inch
kg	kilogram
KOH	potassium hydroxide

ABBREVIATIONS AND SYMBOLS (continued)

KPEG	a dehalogenation process
L	liter
lb	pound
LDRs	land disposal restrictions
m	meter
mg	milligram
mm	millimeter
MPRSA	Marine Protection Research and Sanctuaries Act
NAAQS	National Ambient Air Quality Standards
NaOH	sodium hydroxide
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NO_x	oxides of nitrogen
NPL	National Priorities List
O_3	ozone
OERR	Office of Emergency and Remedial Response
ORD	Office of Research and Development
OSWER	Office of Solid Waste and Emergency Response
OTTRS	Office of Technology Transfer and Regulatory Support
OVA	organic vapor analyzer
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzodioxin
PCDF	polychlorinated dibenzofuran
PCP	pentachlorophenol

ABBREVIATIONS AND SYMBOLS (continued)

PEG	polyethylene glycol
PNA	polynuclear aromatic hydrocarbon
POHC	principal organic hazardous constituent
POTW	publicly owned treatment works
ppb	parts per billion
ppm	parts per million
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
RAC	remedial action contractor
RCRA	Resource Conservation and Recovery Act
RI/FS	remedial investigation/feasibility study
ROD	record of decision
RM	remedial manager
RREL	Risk Reduction Engineering Laboratory
SAP	sampling and analysis plan
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
sec	second
SFLN	sulfolane
SO_2	sulfur dioxide
SVOC	semivolatile organic compound
SWDA	Solid Waste Disposal Act
SWMU	solid waste management unit
TCDD	tetrachlorodibenzo-p-dioxin
TCDF	tetrachlorodibenzofuran

ABBREVIATIONS AND SYMBOLS (continued)

TCL	target compound list
TCLP	Toxicity Characteristic Leaching Procedure
TDS	total dissolved solids
TOC	total organic carbon
TOX	total organic halogen
tpd	ton per day
TSCA	Toxic Substances Control Act
TSS	total suspended solids
μ	micron
UCS	unconfined compressive strength
μg	microgram
COE	United States Army Corps of Engineers
USCG	United States Coast Guard
USEPA	United States Environmental Protection Agency
VOC	volatile organic compound
WQC	water quality criteria
XRF	X-ray fluorescence

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Daniel Averett	- U.S. Army Corps of Engineers, Waterways Experiment Section
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Steve Garbaciak	- EPA, GLNPO, Remedial Programs
Donald Heller	- EPA, Region V, Office of RCRA Ohio Permitting Section
Jonathan G. Herrmann	- EPA, ORD/RREL, Physical/Chemical Systems Branch
Stephen Johnson	- EPA, Region V, PCB Control Section
Michael Kravitz	- EPA, OW/OST, Contaminated Sediment Section
Dave Petrovski	- EPA, Region V, Office of RCRA Michigan Permitting Section
Dennis Timberlake	- EPA, ORD/RREL, Physical/Chemical Systems Branch
Anne Weinert	- EPA, Region V
Howard Zar	- EPA, Region V, In Place Pollutant Task Force

EXECUTIVE SUMMARY

INTRODUCTION

This guide helps remedial managers select appropriate remedial techniques from conventional or innovative options, preferably already tested at bench, pilot, or field levels with contaminated sediments and/or soils.

Sediment is the mixture of assorted material that settles to the bottom of a waterbody. It includes the shells and coverings of molluscs and other animals, transported soil particles from surface erosion, organic matter from dead and rotting vegetation and animals, sewage, industrial wastes, other organic and inorganic materials, and chemicals.

Surface waters in the United States receive discharges of various liquid and solid wastes from three major sources:

- Point sources such as municipal and industrial effluents.
- Non-point sources such as agricultural runoff, soil entrainment, and airborne particles.
- Other sources such as spills, contaminated groundwater infiltration, and intentional aquatic dumping.

Many of these discharges contain toxic/hazardous materials that settle as sediment and persist in the environment because of their physicochemical properties. The contaminated sediment affects human health and the environment and causes losses of important resources such as drinking water.

Regulatory Issues

Under the Clean Water Act and Comprehensive Environmental Response, Compensation, and Liability Act, the U.S. Coast Guard and EPA are mandated to ensure safe cleanup of hazardous waste discharges and contaminated sediment. The potentially applicable regulations include:

- Clean Water Act (CWA)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

- Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
- Marine Protection, Research, and Sanctuaries Act (MPRSA)
- National Environmental Policy Act (NEPA)
- Resource Conservation and Recovery Act (RCRA)
- Rivers and Harbors Act
- Toxic Substances Control Act (TSCA)
- Water Resources Development Act
- International Law
- State Law

SITE CHARACTERIZATION

Site characterization and evaluation are necessary to select an appropriate remedy and identify the source and nature of the contaminants. Industrial plants and other potential point sources of contamination near the site should be identified to aid in identifying the type and level of contaminants.

The location of the site and its physical characteristics can affect sediment dredging activities. Access difficulties may prevent delivery of certain treatment equipment. Congested navigation channels can make dredging impractical. If the waterbody is a source of drinking water, dredging may require either extra precautions to prevent the spread of contaminant or provisions for an alternate water supply.

Waterbody information such as depth and width of waterbody, water current direction and velocity, wave height, suspended particulate concentration, sediment type and particle size, sediment organic carbon content, etc., are necessary to select an appropriate dredging method and a suitable remedy.

Sediment Characterization

Sediment particles vary in chemical composition and in physical properties. The constituents of sediment such as clay, organic matter, hydrated iron, manganese oxides, and associated characteristics, such as particle size, pH, oxidation-reduction conditions, and salinity of the waterbody affect the interaction between sediment particles and contaminants.

Sediment particle size influences the association of the contaminants with the sediment and the potential for contaminant migration. Smaller diameter particles often contain higher concentrations of contaminants. These small diameter particles remain suspended for longer periods of time, are easily resuspended in high tides, storms, and floods, and travel further from the contamination source. Organic carbon content of sediment influences the adsorption capacity of contaminants such as PCBs.

Particle size and organic content significantly affect the selection of a remedy. Many technologies cannot effectively remove contaminants that are strongly bound to small particles, while others have difficulty in processing fine particles. The mineralogy of the particle also affects the remedy selection.

Contaminant Characterization

Contaminants typically found in sediment can be classified as follows:

- Polynuclear aromatic hydrocarbons (PAHs)
- Pesticides
- Chlorinated hydrocarbons
- Mononuclear aromatic hydrocarbons (benzene and its derivatives)
- Phthalate esters
- Metals
- Nutrients
- Miscellaneous, such as cyanides and organo-metals.

These contaminants enter the waterbody from various sources and contact the sediment particles by direct sinking and subsequent adsorption on the sediment particles.

In most aquatic systems, the suspended sediment and the upper layer of the sediment bed contain higher contaminant concentrations than the overlying water column. Consequently, sediment becomes a reservoir of contaminants that can redissolve or migrate into the water column. The octanol/water partition coefficient, K_{ow}, has proved useful in predicting soil adsorption. Organic chemicals of environmental concern usually have very low solubilities in water. The lower the solubility, the greater the tendency of the organic compound to adsorb to the sediment particles.

SELECTION OF REMEDIAL OPTIONS

Table 1 displays conventional techniques and new treatments that, based on RODs dealing with contaminated sediment, may be potentially applicable. No remedial alternative can remove, contain, or treat contaminated sediment without some disturbance and consequent release of contaminants. Disturbance of bottom sediment can cause resuspension of contaminants into the water column. The selection of a remedial option must attempt to minimize such contaminant release.

Removal and Transport

The first step in the remedial selection process is to determine whether to treat the sediment *in situ*. Most often, sediment is dredged and either contained or treated *ex situ*. A primary concern during the removal and transport of contaminated sediments is the danger of introducing contaminants into previously uncontaminated areas. The choice of dredging depends on the nature of the sediment, the types of contaminants, the depth to bottom, the thickness and volume of sediment, the distance to next operation (e.g., disposal sites), and the available machinery. There are three major categories of dredging: mechanical, hydraulic, and pneumatic. The method of transportation for dredged material depends on the distance between the dredging and treatment sites. The principal transportation methods include: pipelines, barges, railroads, and trucks. Selection of transport options will be affected by both dredge selection and pretreatment and treatment decisions.

Pretreatment of the Sediment

Most sediment will require dewatering followed by particle classification to remove oversize material as pretreatment. Dewatering reduces the moisture content of sediment, allows handling and transport of the material as a solid, and prepares the sediment for a number of treatment and disposal technologies. Dredged material dewatering is traditionally accomplished in ponds or confined disposal facilities (CDFs), which rely on seepage, drainage, consolidation, and evaporation. These dewatering methods are generally effective, and low cost, but slow and require large areas. Common industrial methods include centrifugation, dewatering lagoons, filtration, and gravity thickening. Chemicals such as flocculating agents are added to accelerate the settling of suspended solids. Particle classification separates sediment particles based on one or more physical properties such as size, density, mass, magnetic characteristics, etc. Particle classification technologies include sieves and screens, hydraulic and spiral classifiers, cyclones, settling basins, and clarifiers.

Conventional Options

The conventional sediment handling methods are removal and disposal. This option is desirable when removal will not result in adverse environmental effects, conditions make in-place treatment ineffective, and when removal is necessary for other purposes. If the sediment presents environmental problems, it can be contained (e.g., capped in place), left in place (no action), treated *in situ*, dredged and treated or placed in a confined disposal facility (CDF), or combination of above techniques.

Confined disposal facilities (CDFs) are engineered structures designed to retain dredged material. They may be constructed either entirely away from the water, partially in water near the shore, or completely surrounded by water. They are used for disposal of about 30% of the dredged material produced by the Corps of Engineers Navigation Program. Costs for disposing dredged material in CDFs range from \$5 to \$20/cu yd. As with any other structure in water or near shore, CDFs are affected by wind and waves. Properly located and constructed CDFs can fairly well isolate contaminated sediment from the environment.

Subaqueous capping, also called **contained aquatic disposal (CAD)**, covers contaminated sediments with cleaner sediment with or without lateral walls. CADs are often deposits of sediments placed in a depression in the bottom of a water body, or in an excavated cavity which are then capped with cleaner deposits.[1]

The no-action option leaves the contaminated sediment in place so that natural sedimentation will bury and contain pollutants or natural biodegradation will take place. This option is appropriate when: the pollutant discharge source has been halted; the burial, dilution, or biodegradation process is rapid; sediment will not be remobilized by human or natural activities; or environmental effects of cleanup are more damaging than allowing the sediment to remain in place.

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[1] Capping is the controlled, accurate placement of contaminated dredged material at an open-water disposal site, followed by a covering or cap of clean isolating material. Level bottom capping is the placement of a contaminated material on the bottom in a mounded configuration and the subsequent covering of the mound with clean sediment. Contained aquatic disposal is similar to level bottom capping but with the additional provision of some form of lateral confinement (for example, placement in bottom depressions or behind subaqueous berms) to minimize spread of the materials on the bottom.

***In situ* treatments** involve in place addition and mixing of biological organisms or solidification/stabilization reagents with contaminated bottom sediment. Because of the difficulty in ensuring the thorough mixing required, *in situ* treatments have not been very popular.

Potentially Applicable Options

Several remedial options have the potential to treat contaminated sediments, but have limited supporting field data. The remedial options that can potentially treat contaminated sediments are as follows:

- Biological treatment
- Dechlorination
- Soil washing
- Solvent extraction
- Solidification/stabilization
- Incineration
- Thermal desorption

Many of these process options are not stand-alone processes, but may be components of a system that involves multiple treatment steps to address multiple contaminant problems. Waste preparation for these technologies include screening to remove oversize debris, particle size separation, dewatering, and pH adjustment. Table 1 presents application, feed stream characteristics, effectiveness, and cost of these remedial options. The three main waste streams generated in these treatment options are: air emissions that can be captured and treated; treated solids which if contaminated can either be treated by another technique or solidified and disposed in a landfill, or reused as a fill; water which can usually be treated in a conventional treatment system or discharged to a publicly owned treatment works (POTW).

CONCLUSIONS

Although treatment of contaminated sediments is in the early stages of application, EPA will use all its existing statutory authorities in a consistent, coordinated manner to pursue remediation of sediments that are causing ecological harm or posing unacceptable risks to human health. This document offers guidance on the selection of feasible remedial options for various situations.

TABLE 1. SUMMARY O REMEDIATION TECHNOLOGIES

Remediation technology	Application	eed stream characteristics	Effectiveness	Cost
Biological treatment	Pesticides, fuels, creosote, PCP, PCBs, some halogenated volatile organics, non-halogenated organics, aliphatics, aromatics, chlorinated aromatics	pH 4.5 to 8.5 Temperature 59 to 167 Moisture content 40 to 80% Nutrients C:N:P 100:10:1 to 100:1:0.5 Oxygen – 8 mg/L	Depends on the feed stream characteristics.	\$80 to \$150/cu yd (slurry phase) \$50 to \$80/cu yd (solid phase)
Physical/chemical treatment				
KPEG dechlorination	Dioxins, PCBs, chlorobenzenes	pH >2 Temperature 158 to 302 Water content <20% Chlorinated organics <5%	Efficiencies >98% have been reported for PCBs. PCB removal to less than 1 ppm is routinely achieved.	\$200 to \$500/cu yd
Solvent extraction	PCBs, volatile organics, halogenated solvents, petroleum waste, aromatics, metals	Oily organics <40% Solid content <20% Particle size <1/4 in	PCB reductions greater than 90% on harbor sediments.	\$200 to \$600/cu yd
Soil washing	Heavy metals, halogenated solvents, aromatics, PCBs, chlorinated phenols, pesticides, gasoline, and oils	Particle size 0.063-2 mm	90-99% for volatiles, 40-90% for semivolatiles	\$200 to \$400/cu yd
Solidification/stabilization	Inorganics; some success with oily sludges and solvents	Organics <20 - 45 wt% Semivolatiles <1% Solids >15% Oil and grease <10 wt% Phenols <5% PAHs <1% CN <0.3 wt%	Virtually total containment of insoluble metals; not effective on organics.	\$30 to \$165/cu yd
Thermal treatment				
Incineration	Volatiles, semivolatiles, PCBs, pesticides, dioxins/furans, organic cyanides	Moisture content <50% Particle size 1-2 mm Alkaline metals <5 wt% Halogens <8 wt%	Greater than 99% for organics.	\$475 to \$1,350/cu yd
Low temperature thermal desorption	Volatile and semivolatile organic compounds	Solids 1-1.5 in dia. Organics <10% Boiling points <800 Moisture content <60% pH 5-11 Solids content >20%	99% removal on VOCs and SVOCs.	\$110 to \$470/cu yd

SECTION 1

INTRODUCTION

PURPOSE AND SCOPE OF THIS DOCUMENT

This guide describes a selection process for remediation technologies that can be used at sites containing contaminated sediment. The selection process begins by identifying the following:

> **Site characteristics that may affect remedy selection:** physical/geological characteristics of the waterbody and use of the waterbody.
>
> **Sediment characteristics and behavior:** the sediment particle's tendency to deposit, resuspend, and adsorb/absorb contaminants, and other pertinent physical characteristics such as size. These characteristics determine the particle's behavior during dredging and treatment.
>
> **Contaminant characteristics and their behavior in sediment:** the physicochemical interaction of contaminants and sediments and how this affects remedy selection, and the role of physical and chemical characteristics in pre-treatment, treatment, and post-treatment.
>
> **Regulatory issues that affect selection of remedial options:** regulations dealing with contaminated sediment. The Clean Water Act, the Resource Conservation and Recovery Act, Comprehensive Environmental Response, Compensation, and Liabilitv Act, Toxic Substances Control Act, and interpretations of existing and emerging regulations.

The remedial option selection process continues with the investigation of appropriate sediment removal systems, any pretreatment necessary to process the sediment, the primary treatment options, and secondary treatment, if necessary, of residual streams. Using this information, the remedial manager can select the treatment alternative most likely to succeed in remediating a specific contaminated sediment site. This document gives the remedial manager guidance in selecting appropriate remedial techniques either from commonly selected conventional options, or from innovative options, preferably those already tested at bench, pilot, or field levels.

This guide covers the methods of selecting remedies for site-specific contaminated sediment in water bodies such as rivers, lakes, streams, ponds, and harbors. Since some water bodies exhibit ocean characteristics that could affect remedy selection, such as wave action, deep water, and tidal movement, this document discusses oceans as extensions of harbors or as disposal sites.

USE OF THIS DOCUMENT

This document is a technical resource for remedial managers providing a brief description of site, sediment, and contaminant characteristics as they might affect remedy selection, and compares the technologies that are most likely to be effective in remediating sites with the given characteristics. Sediment removal, transport, and pre- and post-treatment techniques are also included.

This guide helps a remedial manager select a treatment system based on the specific site characteristics, thereby streamlining the selection process, and focusing attention on those elements of a treatment system offering the greatest potential to be effective at the site. This is accomplished by providing decision trees and comparative tables that help eliminate marginal or inappropriate technologies and that emphasize potentially successful techniques.

ASSESSING CONTAMINATED SEDIMENTS

The remedial manager should become familiar with the extent of contaminated sediments and the environmental effects. A good introduction to the extent of sediment contamination is given in *An Overview of Sediment Quality in the United States* (USEPA, 1987c). To make a correct remedial decision, the remedial manager should know the state of the art in contaminated sediment treatments, and the regulatory issues that affect its treatment. Unfortunately, the contaminated sediment problem is not well defined. Investigations into its extent are only in the early stages and some regulations are still in their infancy. Some issues that will need to be addressed as the remedial process develops are the procedures for distinguishing between clean and contaminated sediment, the legal basis for regulating contaminated sediment, and techniques for defining, testing, and implementing remedies.

Since there are few widely tested and accepted sediment cleanup techniques, there are, in turn, no defined performance standards for remedy selection. Issues confronting those responsible for cleanups include: the damaging environmental side effects from sediment removal and treatment, cost, the absence of clear performance criteria, the lack of consensus regarding acceptable disposal of dredged sediment, little experimental data, and the difficulty of finding appropriate treatment methods for extremely large volumes of low-level contaminated sediment. Nevertheless, the remedial manager must define the extent of cleanup, the acceptable cleanup levels for the site, technical feasibility for each remedy, and the acceptable cost.

Description of Contaminated Sediment

The term "sediment", for the purposes of this document, encompasses the various materials that settle to the bottom of any water body. It includes the shells and coverings of molluscs and other water animals, transported soil particles from surface erosion, organic matter from dead and rotting vegetation and animals, sewage, industrial wastes, organic materials, inorganic materials, and chemicals. EPA defines sediment as soil, sand, and minerals washed from land into water usually after rain (USEPA, 1988c). Current regulatory trends tend to separate sediment/soil matrices from sludge.

Surface waters in the United States receive discharges of various liquid and solid wastes from industrial and municipal operations, agricultural and urban runoffs, accidental spills, leaks, dumping of waste, and precipitation carrying pollutants from the atmosphere. In general, there are three sources of sediment contamination:

- Point sources such as municipal and industrial effluents.
- Non-point sources such as agricultural runoff, soil entrainment, airborne particles.
- Other sources such as spills, contaminated groundwater infiltration, aquatic dumping.

Many of these discharges contain toxic/hazardous materials that settle in sediment and persist in the environment for long periods of time. This contaminated sediment may affect human health and the environment and cause losses of important resources such as drinking water. Humans can be exposed to the contaminants through such means as infiltration into drinking water, accumulation in the food chain, and direct dermal contact. Animals of the benthic community can absorb toxic substances from their surroundings. Contaminated sediment can be lethal to them and affect the food chains of larger animals, fish, birds, and mammals such as mink and man.

Determining Sediment Quality

The Federal Water Quality Administration developed the first sediment quality guidelines in 1973. These were adopted by the EPA and are called the Jensen Criteria. This first set of sediment quality criteria involves seven contaminants (Table 1-1). If the concentration of any of the parameters exceeds the maximum allowable value, then the sediment is classified as polluted. Very few other sediment quality guidelines exist.

In 1973, the EPA published criteria and regulations for managing marine-dredged sediment (Federal Register 38 (1973), *Ocean Dumping: Final Regulations and Criteria*) (Anon, 1973). Other early sediment quality guidelines were developed jointly by the EPA and the Corps of Engineers. The guidelines regulated the disposal of dredged sediments. When coupled with site-specific sediment bioassays, the joint EPA-Corps of Engineers regulations have been the standard reference for regulating contaminated sediment. For example, Region V of the EPA developed guidelines to evaluate Great Lakes Harbor sediments using this combination (Table 1-2). These regulations and guidelines are still in effect although they do not necessarily reflect current thinking or regulatory direction. They also do not address bioavailability, a major consideration in today's regulatory trends. Recently, several agencies developed additional sediment quality criteria. The Wisconsin Department of Natural Resources has developed interim criteria for some metals, PCBs, and a few pesticides but has not been implemented (Table 1-3). The Washington State Department of Ecology has developed and implemented Sediment Management Standards for some metals and polynuclear aromatic hydrocarbons (Table 1-4). In the absence of established criteria, EPA recommended additional approaches (USEPA, 1989j).

It appears that the current regulatory trend is to define sediment quality using criteria that directly measure biological effects. Excellent discussions of these criteria are provided by Chapman (Chapman, 1989), Baudo (Baudo, et al., 1990), and Fitchko (Fitchko, 1989). Several of these methods are shown in Table 1-5. These methods are described in detail in Sediment Classification Methods Compendium (USEPA, 1989j).[2]

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[2] Final EPA document no. 823-R-92-006 (September, 1992).

TABLE 1-1. FEDERAL WATER QUALITY ADMINISTRATION CRITERIA FOR MAXIMUM ALLOWABLE CONCENTRATIONS IN DREDGED MATERIAL

Parameter	Criteria wt% (dry)
Volatile solids	6.0
Chemical oxygen demand	5.0
Total Kjeldahl nitrogen	0.10
Oil and grease	0.15
Mercury	0.0001
Lead	0.005
Zinc	0.005

Source: Federal Register 38 (1973) (Anon, 1973).

Regulatory Issues

The Clean Water Act and Comprehensive Environmental Response, Compensation and Liability Act mandate the U.S. Coast Guard and EPA to ensure safe cleanup of hazardous waste discharges and contaminated sediment. Congress has recently authorized legislation for EPA to lead an effort to survey the extent of the contaminated sediment problem (Water Resources Development Act, 1992). Several coastal pollution measures have provisions addressing sediment pollution. EPA is working toward the development of nationally applicable sediment-quality criteria for coastal waters. However, a coordinated Federal effort to address the problem is still in its infancy.

The U.S. Army Corps of Engineers issues disposal permits for dredged material using human health and marine impact guidelines developed by EPA. During the selection of sites, the permitting process and through EPA's management and monitoring programs, environmental aspects are considered. Contaminated sediment may be sent for disposal in aquatic, near-shore, or upland containment sites. Relatively clean sediment can be discharged into unconfined aquatic sites. Historically, the ocean has been used to dispose of waste. Over 90% of the material dumped into the ocean consists of sediment dredged from U.S. harbors and channels (USEPA, 1989f). It was assumed that the ocean waters had an inexhaustible capacity to assimilate waste without harming their resources. That assumption has gradually changed to recognize that the ocean's assimilative capacity is finite. Pursuant to the Ocean Dumping Ban Act of 1988, all ocean dumping of sewage sludge and industrial wastes ended in December 1991.

TABLE 1-2. EPA GUIDELINES FOR CLASSIFICATION OF GREAT LAKES HARBOR SEDIMENTS

	Not polluted	Moderately polluted	Heavily polluted
Volatile solids	<5%	5%-8%	>8%
COD	<40,000	40,000-80,000	>80,000
TKN	<1,000	1,000-2,000	>2,000
Oil and grease	<1,000	1,000-2,000	>2,000
Lead	<40	40-60	>60
Zinc	<90	90-200	>200
Mercury	--	--	≥1.0
Ammonia	<75	75-200	>200
Cyanide	<0.10	0.10-0.25	>0.25
Phosphorous	<420	420-650	>650
Iron	<17,000	17,000-25,000	>25,000
Nickel	<20	20-50	>50
Manganese	<300	300-500	>500
Arsenic	<3	3-8	>8
Cadmium	--	--	>6
Chromium	<25	25-75	>75
Barium	<20	20-60	>60
Copper	<25	25-50	>50
Total PCB*	--	--	≥10

All concentrations as mg/kg, dry weight.

* Present practice considers 1 mg/kg as a screening guideline.

Source: USEPA, 1977.

TABLE 1-3. WISCONSIN DEPARTMENT OF NATURAL RESOURCES INTERIM CRITERIA FOR IN-WATER DISPOSAL OF DREDGED SEDIMENTS

Contaminant	Guideline ppm (dry)
Arsenic	10.00
Cadmium	1.00
Chromium	100.00
Copper	100.00
Lead	50.00
Mercury	0.1
Nickel	100.00
Zinc	100.00
Hepachlor	0.05
Endrin	0.05
Aldrin	0.01
Chlordane	0.01
PCBs	0.05
Dieldrin	0.01
Toxaphene	0.05
Lindane	0.05

Source: Sullivan, et al., 1985

In general, Resource Conservation and Recovery Act (RCRA) or Toxic Substances Control Act (TSCA) regulations apply to treatment or disposal of sediment if it is any of the following:

RCRA - ignitable, corrosive, reactive, or toxic per 40 CFR 261.20-261.24
RCRA - contains any amount of RCRA-listed substance per 40 CFR 261.30 - Appendix IX
TSCA - contains PCBs in excess of 50 ppm

TABLE 1-4. WASHINGTON STATE DEPARTMENT OF ECOLOGY MARINE SEDIMENT QUALITY STANDARDS-CHEMICAL CRITERIA[1]

Chemical parameter	mg/kg dry weight (ppm dry)
Arsenic	57.00
Cadmium	5.10
Chromium	260.00
Copper	390.00
Lead	450.00
Mercury	0.41
Silver	6.10
Zinc	410.00
Chemical parameter	**mg/kg organic carbon (ppm carbon)[2]**
LPAH[3]	370.00
Naphthalene	99.00
Acenaphthylene	66.00
Acenaphthene	16.00
Fluorene	23.00
Phenanthrene	100.00
Anthracene	220.00
2-Methylnaphthalene	38.00
Chemical parameter	**mg/kg organic carbon (ppm carbon)**
HPAH[4]	960.00
Fluoranthene	160.00
Pyrene	1,000.00
Benz(a)anthracene	110.00
Chrysene	110.00
Total benzofluoranthenes[5]	230.00
Benzo(a)pyrene	99.00
Indeno(1,2,3-c,d)pyrene	34.00
Dibenzo(a,h)anthracene	12.00
Benzo(g,h,i)perylene	31.00
1,2-Dichlorobenzene	2.30
1,4-Dichlorobenzene	3.10

TABLE 1-4. (Continued)

Chemical parameter	mg/kg organic carbon (ppm carbon)
1,2,4-Trichlorobenzene	0.81
Hexachlorobenzene	0.38
Dimethyl phthalate	53.00
Diethyl phthalate	61.00
Di-n-butyl phthalate	220.00
Butyl benzyl phthalate	4.90
Bis(2-ethylhexyl)phthalate	47.00
Di-n-octyl phthalate	58.00
Dibenzofuran	15.00
Hexchlorobutadiene	3.90
N-Nitrosodiphenylamine	11.00
Total PCBs	12.00
Chemical parameter	**µg/kg dry weight (ppb dry)**
Phenol	420.00
2-Methylphenol	63.00
4-Methylphenol	670.00
2,4-Dimethyl phenol	29.00
Pentachlorophenol	360.00
Benzyl alcohol	57.00
Benzoic acid	650.00

[1] Where laboratory analysis indicates a chemical is not detected in a sediment sample, the detection limit shall be reported and shall be at or below the criteria value shown in this table. Where chemical criteria in this table represent the sum of individual compounds or isomers, and a chemical analysis identifies an undetected value for one or more individual compounds or isomers, the detection limit shall be used for calculating the sum of the respective compounds or isomers.

[2] The listed chemical parameter criteria represent concentrations in parts per million, "normalized", or expressed, on a total organic carbon basis. To normalize to total organic carbon, the dry weight concentration for each parameter is divided by the decimal fraction presenting the percent total organic carbon content of the sediment.

[3] The LPAH criterion represents the sum of the following "low molecular weight polynuclear aromatic hydrocarbon" compounds: naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene. The LPAH criterion is not the sum of the criteria values for the individual LPAH compounds as listed.

[4] The HPAH criterion represents the sum of the following "high molecular weight polynuclear aromatic hydrocarbon" compounds: fluoranthene, pyrene, benzo(a)anthracene, chrysene, total benzofluoranthenes, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene. The HPAH criterion is not the sum of the criteria values for the individual HPAH compounds as listed.

[5] The total benzofluoranthenes criterion represents the sum of the concentrations of the "B", "J", and "K" isomers.

TABLE 1-5. SEDIMENT QUALITY ASSESSMENT METHODS

	Type			
Method (Chapter)	**N**	**D**	**C**	**Concept**
Bulk Sediment Toxicity		X		Test organisms are exposed to sediment which may contain unknown quantities of potentially toxic chemicals. At the end of a specified 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 to characterize interstitial water toxicity, identify the suspected toxicant, and confirm 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 U.S. 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.
International Joint Commission*			X	Contaminated sediments are assessed in two steps: 1) an initial assessment that is based on macro-zoobenthic community structure and concentrations of contaminants in sediments and biological tissues, and 2) a detailed assessment that is based on a phased sampling of the physical, chemical, and biological aspects of the sediment, including laboratory toxicity bioassays.

* The IJC approach is an example of a sequential approach, or "strategy" combining a number of methods for the purpose of assessing contaminated sediment in the Great Lakes.

N - Humic type
D - Descriptive type
C - Combination type

Source: Sediment Classification Methods Compendium (USEPA, 1989j)

Movement is underway to include contaminated sediment in the mainstream of the regulatory structure. For example, the interaction among several regulations has been addressed in the *CERCLA Compliance with Other Laws Manual* (USEPA, 1989b). EPA is planning to develop sediment contamination controls for businesses, and is applying Superfund regulations to fifteen underwater areas to limit sediment pollution.

The laws that are potentially applicable to contaminated sediment include the following:

- Clean Water Act (CWA)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
- Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
- Marine Protection, Research, and Sanctuaries Act (MPRSA)
- National Environmental Policy Act (NEPA)
- Resource Conservation and Recovery Act (RCRA)
- Rivers and Harbors Acts of 1989
- Toxic Substances Control Act (TSCA)
- Water Resources Development Acts
- International Law
- State Law

The Clean Water Act (CWA)--

Five sections of the Clean Water Act are relevant to contaminated sediment. They are Sections 115, 118, 307, 401, 404. Of these, the most significant is Section 404.

<u>Section 115</u>--Section 115 of the Clean Water Act provides a powerful, but generally unused, tool for cleaning up contaminated sediment. Unlike legislation that primarily regulates placement of dredged material or provides limited authorization to remove it for economic purposes, Section 115 specifically authorizes cleaning up pollutants. It authorizes EPA to identify near shore contaminated hot spots and to contract with the Corps of Engineers to clean them up.

<u>Section 118</u>--Section 118 is the Great Lakes Amendment to the Clean Water Act. Among other provisions, it authorizes the EPA Great Lakes National Program Office (GLNPO) to carry out a five-year study and demonstration project on the control and removal of contaminated sediment in the Great

Lakes. The Assessment and Remediation of Contaminated Sediments (ARCS) Program is underway. The ARCS program includes demonstrating methods for assessing in-place pollutants and decision-making on remedial action alternatives. The ARCS program selected sediment treatment technologies demonstrations on a bench- and pilot-scale at five areas of concern in the Great Lakes during 1991 and 1992. Areas singled out for special attention include Saginaw Bay, Michigan (Lake Huron); Sheboygan Harbor, Wisconsin (Lake Michigan); Grand Calumet River, Indiana (Lake Michigan); the Ashtabula River, Ohio (Lake Erie); and the Buffalo River, New York (Lake Erie).

Section 307--Section 307 of the Clean Water Act requires that any source introducing pollutants into a publicly owned treatment works (POTW) establish pretreatment standards for the source category with the designated control authority. The pretreatment standards prevent the discharge of pollutants that may interfere with, pass through, or otherwise be incompatible with the treatment works. Several proposals have been made to discharge confined disposal facility effluents to POTWs. This section of the act allows the designated control authority to establish limits on the pollutants.

Section 401--Section 401 of the Clean Water Act requires anyone applying for a federal permit to conduct any activity resulting in discharges to U.S. waters obtain certification from the state in which the activity will be conducted. This means that the state water quality agency must certify that the proposed disposal of the material will not violate state water quality standards, and will not cause significant water quality degradation. States can require design changes or safeguards in any project before issuing a permit. The 401 certification ensures that states are involved in sediment disposal.

Section 404--Section 404 of the Clean Water Act regulates the discharge of dredged and fill material into waters of the United States, and establishes a permit program to ensure that such discharges comply with environmental requirements. This program is administered at the federal level by the U.S. Army Corps of Engineers and the EPA. The Corps of Engineers has the primary responsibility for the permit program and is authorized, after notice and opportunity for public hearing, to issue permits for the discharge of dredged or fill material. EPA has primary roles in several aspects of the Section 404 program including developing environmental guidelines to evaluate permit applications, reviewing proposed permits, prohibiting discharges with unacceptable adverse impacts, approving and overseeing the state's assumption of the program, establishing jurisdictional scope of waters of the United States, and interpreting of Section 404 exemptions. Enforcement authority is shared between EPA and the Corps of Engineers.

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)--

This 1980 federal law addresses the problem of hazardous waste sites. It authorizes the EPA to investigate and respond to releases of hazardous wastes. When contaminated sites are discovered, EPA evaluates them. If listing criteria are exceeded, EPA can place them on the National Priority List (NPL) for cleanup. Several contaminated sediment sites appear on the NPL (see Appendix C).

When ranking sites for addition to the NPL, EPA generally gives the greatest weight to the potential for direct human exposure to contaminants such as through contaminated drinking water. Indirect exposure such as eating contaminated fish or exposure from volatilization of toxics from a water surface is considered a less serious threat.

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

EPA reviews and registers all pesticides sold in the United States. It examines data concerning their toxicity and behavior in the environment to determine the need for restrictions governing the chemicals' use and disposal. The EPA testing procedure examines the chemicals' persistence in sediment and soils.

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

The Marine Protection, Research, and Sanctuaries Act of 1972, better known as the Ocean Dumping Act, regulates ocean dumping of any material that may adversely affect human health, the marine environment, or the economic potential of the ocean. EPA and the Corps of Engineers are responsible to administer the Act, the National Oceanic and Atmospheric Administration (NOAA) is responsible to monitor the effects of ocean dumping, and the U.S. Coast Guard is responsible to enforce the Act. Title 3 gives the Secretary of Commerce the authority to establish marine sanctuaries. MPRSA applies to the ocean and coastal waters, but not to estuarine waters, which are covered by the Clean Water Act. MPRSA also governs ocean dumping of dredged material. MPRSA authorizes the Corps of Engineers to choose sites for dredged material dumping and to issue permits to dump at those sites.

National Environmental Policy Act (NEPA)--

Under the National Environmental Policy Act (NEPA) of 1969, all federal agencies must prepare an Environmental Impact Statement (EIS) for proposed actions that may have a significant effect on the environment. 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. All Corps of Engineers EISs are submitted to the Environmental Review Branch of the appropriate regional EPA office for review and response.

Resource Conservation and Recovery Act (RCRA)--

RCRA provides for the classification of hazardous waste, the definition of solid and liquid waste, and the permitting of hazardous and nonhazardous waste landfills. Sediment classified as nonhazardous waste may be disposed in landfills approved under Subtitle D of RCRA; sediment classified as hazardous must be disposed in landfills approved under Subtitle C. Liquid wastes, as defined by the Paint Filter Liquid Test (40 CFR 264.314(c)), may not be sent to landfills in the United States.

Application of RCRA to contaminated sediment is not completely defined. Dredged sediment containing listed hazardous waste requires treatment in accordance with 40 CFR §268 and disposal at a permitted facility meeting the RCRA Minimum Technology Requirements (MTR). Sediment exhibiting a hazardous waste characteristic requires treatment to the extent that the residue no longer exhibits the hazardous waste characteristic, or meets applicable treatment standards under 40 CFR §268; <u>OR</u> disposal in a RCRA facility meeting MTR.

Under the proposed RCRA Subpart S, provisions for corrective action can be applied to any RCRA-permitted facility if a release of a hazardous substance has occurred or is suspected to have had occurred. EPA requires including corrective action provisions with RCRA permits since the passage of HSWA in 1984.

The Rivers and Harbors Act--

The Rivers and Harbors Act of 1899 authorizes the Corps of Engineers to build harbors and other projects related to waterborne commerce and to keep these harbors and channels open for traffic. Section 10 of the Act prohibits the unauthorized obstruction or alteration of any navigable water in the

United States. Under the Rivers and Harbors Act, the Corps of Engineers has the authority to issue permits for all private dredging or fill projects in navigable waterways.

The law originally required a local government sponsor to share the costs of constructing a confined disposal facility (CDF). In the absence of a local sponsor, the Corps of Engineers maintains its authority to construct the CDF as part of its Federal navigation maintenance routine. The Corps of Engineers is responsible for all aspects related to the integrity of the CDF's design and construction, including prevention of adverse environmental effects.

Toxic Substances Control Act (TSCA)--

Regulations under TSCA, enacted in 1976, require written approval by the regional EPA administration for disposal of contaminated sediment containing PCBs in concentrations higher than 50 ppm. When the Corps of Engineers intends to dredge an area with sediment containing PCB concentrations above 50 ppm, it must apply to the EPA Regional Administrator for a TSCA permit. EPA can withhold the permit if the dredging and disposal plan presents any unreasonable risk for landfilled materials or inadequate protection for alternate disposal methods. Under TSCA regulations, any material with PCB concentrations higher than 50 ppm must be incinerated or sent for disposal in a RCRA-approved facility. TSCA requirements do not apply to PCB concentrations less than 50 ppm. The TSCA anti-dilution provisions, wherein PCBs are treated as if they were at the original material's concentration, do not apply to EPA actions at CERCLA sites. However, dredged materials containing PCB concentrations greater than 50 ppm may be disposed by alternate methods approved by the EPA Regional Administrator. It must be demonstrated that disposal in an incinerator or chemical waste landfill is not reasonable and appropriate, and that the alternate disposal method will provide adequate protection to human health and the environment (USEPA, 1990e).

Water Resources Development Act of 1990[3]--

Section 312 of this Act authorizes the Corps of Engineers to dredge outside navigational channel boundaries to effect environmental cleanup. This act requires a non-federal local sponsor's participation, and that sponsor must provide half of the dredging costs and 100 percent of the disposal costs for the material removed from outside the navigation project.

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[3] WRDA was also reauthorized in 1992.

International Law--

International regulations addressing dumping wastes into the marine environment were written at the 1972 London Dumping Convention on The Prevention of Marine Pollution by Dumping of Wastes and Other Matter. Additionally, the Boundary Waters Treaty of 1909 between the United States and Canada committed the two countries to avoid pollution of the others' waters.

State Law--

In addition to the federally-mandated 401 certification, a state may require additional permits for dredge and disposal projects. Each state has its own set of laws, regulations, and procedures that pertain to activities affecting water quality and the quality of the environment. A subcommittee of state environmental administrators, working through the Council of Great Lakes Governors, is developing new state in-place pollutant programs to ensure consistency among state regulations.

SECTION 2

CHARACTERIZATION CONSIDERATIONS

Surface waters of the United States receive discharges from sources containing a variety of liquid and solid materials. Although the compositions and quantities of these discharges are not known with certainty, many may contain toxic and hazardous chemicals. Because of their physicochemical properties these toxic chemicals may remain in sediment for long periods of time.

A great deal of monitoring data are available from surveillance and monitoring required by the Clean Water Act (CWA). However, these data primarily concern effluents and water quality. Since many contaminants have very low water solubilities, monitoring the water may not reveal the presence of contaminants in sediment. Navigational dredging and permitting processes under the CWA generate a significant volume of data, but they do not readily characterize sediment. The data are confined to sediment in navigational channels and proposed disposal sites. Several current programs require sediment monitoring that will eventually provide sediment quality data, such as those under the Great Lakes Water Quality Agreement (GLWQA). In addition, the CWA and the Marine Protection, Research, and Sanctuaries Act (MPRSA) oversee aquatic disposal projects and require extensive data collection. These data will help to identify the contaminants associated with sediment, and appropriate disposal techniques. The National Oceanic and Atmospheric Administration's (NOAA) Status and Trends Monitoring Program will provide sediment information for coastal areas.

SITE CHARACTERISTICS AFFECTING TREATMENT CHOICES

Characterization and evaluation of the site are necessary to select an appropriate remedy and identify the source and nature of the contaminants. Industrial plants and other potential point sources of contamination near the site aid in identifying the type and levels of contaminants.

The location of the site and its physical characteristics can affect sediment dredging activities. Access difficulties may prevent delivery of the proper treatment equipment. Congested navigation channels can make dredging impractical. If the water body is a source of drinking water, dredging may require either extra precautions to prevent contaminant spread or an alternate water supply.

A description of the water body is necessary to select a remedial action. Some important water body information is presented in Table 2-1. Additional sources of water-body information are listed in Table 2-2. This information helps the Project Manager select both the most appropriate dredging method and the most suitable remedy. Remedial selection also requires definition of the nature of the water column such as its turbidity, total dissolved solids, total dissolved organic matter, and chemical composition. The use of a water body, such as navigation, recreation, industrial, or municipal discharge, or a combination of these, determines whether institutional control of the waterway is feasible. The waterway uses affect the nature of restrictions that may be needed during remediation.

SEDIMENT CHARACTERISTICS AND BEHAVIOR

Sediment particles reach water bodies by various routes. They vary in chemical composition and in physical properties. The constituents of sediment such as clay, organic matter, hydrated iron, manganese oxides, and associated characteristics (e.g., particle size distribution, pH, oxidation-reduction condition, and salinity of the water body) all affect the interaction of the sediment particles with the contaminants. For example, fine-grained sediment often contains more contaminants and natural organic matter because of its higher surface-area-to-weight ratio than coarse-grained material. Verschueren (1983) reports that the organic carbon content of sediment influences the adsorption capacity of contaminants such as PCBs. Means (1980) reports that the sorption of pyrene, 7-12-dimethylbenz(a)anthracene, 3-methylchloranthracene, and dibenzanthracene is correlated with the organic matter content of sediment.

Sediment particle size influences the association of the contaminants with the sediment and the potential for contaminant migration. Smaller diameter particles remain suspended for longer periods of time, easily resuspend in high tides and floods, and travel farther in the current from the contamination source. Transport properties of sediment are discussed in detail in a number of articles and books by Bennett (undated) and Yalin (1977). Although it is recognized that contaminants in a confined water body, such as a lake, are usually found in fine particles, their distribution is not necessarily uniform. They often occur in pockets of limited area and in deeper areas of lakes. Also, the contaminant profile of sediment is affected to a large extent by the benthic organisms occurring in the water body. These aspects of the sediment behavior are discussed extensively in *Sediments*

TABLE 2-1. WATER BODY AND SEDIMENT INFORMATION REQUIREMENTS AND SOURCES

Information factor	Application	Sources
Depth to contaminated bottom materials (water column), or of water body or water channel (minimum, maximum, mean)	Ability of dredges to reach/remove contaminated materials.	Navigation chart. Direct measurement. Remote sensing (sonar).
	Ability to operate/maneuver dredging equipment.	Navigation chart. Table 2-2. Remote sensing (sonar).
	Accessibility of site for dredging equipment.	
	Predicted movement of discharged substances or sediment.	
	Potential for capping/CAD	
Width of water body or water channel (minimum, maximum, mean) or configuration of channel or water body	Ability to operate/maneuver dredging equipment.	Navigation chart. USGS topographic chart. Table 2-2. Remote sensing (sonar).
	Accessibility of site for dredging equipment.	
	Predicted movement of discharged substances or sediment.	Navigation chart. Table 2-2. Direct measurement/observation.
Water current direction and velocity (surface, subsurface)	Ability of dredging equipment to operate.	
	Predicted movement of discharged substances or sediment.	
Wave height	Ability to operate/maneuver dredging equipment.	Table 2-2.
	Potential for capping/CAD	
Suspended particulate concentration	Adherence of contaminants to particulates rather than settling as sediment.	Table 2-2. Observation (general estimate).
	Need for containment.	
	Containment method selection.	

TABLE 2-1. (continued)

Information factor	Application	Sources
Water temperature profile	Ability of discharged material to solubilize while setting to sediment. Ability of discharged material to settle out.	Table 2-2.
Salinity profile	Solubility of discharged material while settling to sediment. Sediment treatment options.	Table 2-2.
Seasonal considerations (drought, snow melt, storm, flood)	Physical characteristic alterations in the water body that affect ability to operate/maneuver dredging equipment. Prediction of contaminant movement.	Table 2-2. Direct measurement observation.
Sediment type and particle size	Selection of dredging equipment. Selection of sediment treatment and disposal methods. Containment method selection.	Table 2-2. Sampling and analysis. Remote sensing (in-situ nuclear density probe).
Sediment organic carbon content	Adhesion of contaminants to sediment. Bioavailability. Treatment surfactant choice.	Table 2-2. Sampling and analysis.
Sediment inorganic content (nitrates, phosphates, heavy metals)	Availability of oxygen and treatment method solution.	
Sediment/water partition coefficient	Assess extent of contamination based on compound distribution between sediment and water.	*Handbook: Responding to Discharges of Sinking Hazardous Substances* EPA/540/2-87/001.
Octanol/water partition coefficient	Prediction of contaminant/water interaction.	*Handbook: Responding to Discharges of Sinking Hazardous Substances* EPA/540/2-87/001.

TABLE 2-2. ADDITIONAL INFORMATION SOURCES FOR WATER BODY DATA

Source	Information available
U.S. Coast Guard District Offices	Historical spill data; local meteorological data; oceanographic data.
U.S. Geological Survey	Topographic maps; data on the geologic and hydrologic features of the site; topographic data.
U.S. National Weather Service	Meteorological and nautical data.
U.S. Army Corps of Engineers	Historical water uses of the site; predicted flow patterns for the area; navigational charts.
U.S. National Oceanic and Atmospheric Administration	Nautical and meteorological data; visual reconnaissance capabilities; modeling of contaminant trajectory.
U.S. Department of Interior and State Department of Natural Resources	Identification and location of endangered species and habitats.
Scripps Institute of Oceanography and Woods Hole Oceanographic Institute	Data on currents, waves, and tides.
State Water Departments	Data concerning all water systems with a state.
State Coastal Department	Data on currents, waves, and tides.
Local Municipalities and Universities	Historical knowledge of area; environmental and geologic knowledge of area.
Ephermeris and Nautical Almanac	Prediction of tidal movements and other planetary influences.

of Southern Lake Huron (USEPA, 1980), and *Sediments: Chemistry and Toxicity of In-Place Pollutants* (Baudo, et al., 1990).

Particle size and organic matter content significantly affect the selection of a remedy. Fine textured sediments such as silt and clay have a much greater affinity for all classes of contaminants. Organic matter content, including humic material 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. Many technologies cannot effectively remove contaminants that are strongly bound to small particles, while others have difficulty physically processing fine particles. The mineralogy of the particles affect technology selection. For example, it is likely that sediment from Lake Michigan confined by limestones will act differently, and will attach to contaminants differently than sediment from Lake Superior confined by granites and volcanic rock.

Since this document focuses on procedures to select remedial options, minimum attention is given to sampling and analytical techniques. Reasons for sediment sampling and analysis include determination of distribution of specific contaminants, sediment contaminant mobility, existing impacts on aquatic benthic fauna, disposal alternatives, and treatment alternatives. Such techniques are described in *Removal and Mitigation of Contaminated Sediments* (SAIC, 1985), *Procedures for the Assessment of Contaminated Sediment Problems in the Great Lakes* (International Joint Commission, 1988), *Handbook of Techniques for Aquatic Sediment Sampling* (Mudroch, et al., 1991), *Test Methods for Evaluating Solid Waste* SW-846 (USEPA, 1986c), *Sediments: Chemistry and Toxicity of In-Place Pollutants* (Baudo, et al., 1990), *Sediment Classification Methods Compendium* (USEPA, 1989j, 1992) and *Confined Disposal of Dredged Material* (USACE, 1987a).

CONTAMINANT CHARACTERISTICS AND THEIR BEHAVIOR IN SEDIMENT

Contaminants typically found in sediment can be grouped as follows:

- Polynuclear aromatic hydrocarbons (PAHS)
- Pesticides
- Chlorinated hydrocarbons
- Mononuclear aromatic hydrocarbons (benzene and its derivatives)
- Phthalate esters
- Metals
- Nutrients
- Miscellaneous such as cyanides and organo-metals

These contaminants enter the water body from various sources and contact the sediment particles by direct sinking, and subsequent adsorption on the sediment particles.

In most aquatic systems, the suspended sediment and the top part of the sediment bed contain higher contaminant concentrations than dissolved in the overlying water column. Consequently, sediment becomes a reservoir of contaminants that redissolves and migrates into the water column. Sediment-bound contaminants can also undergo various reactions, thereby altering the behavior and nature of the original chemicals. For example, oxidation of organic matter in sediment frequently creates conditions favorable to the release of bound metals into the water as their more soluble species (Luand, 1977). For example, insoluble metal sulfides may release their metals if the sediment becomes oxidized during removal and treatment. Other bound trace metals, especially mercury, can be methylated or converted to other organo-metallic forms by microorganisms. These organo-metals can bioaccumulate in fish (Fujita, 1981).

The octanol/water partition coefficient of organic chemicals has proved useful in predicting soil adsorption. The octanol/water partition coefficient, K_{ow}, is the ratio of the equilibrium concentration, C, of a dissolved substance in a two-phase system consisting of two immiscible solvents, such as n-octanol and water:

$$K_{ow} = \frac{C_{octanol}}{C_{water}}$$

The partition coefficient, theoretically, depends only on temperature and pressure. It is a constant without dimensions.

Unfortunately, K_{ow} values for many compounds of environmental concern are not readily available. The water solubilities of these compounds are usually available from many sources. Experimental data show that water solubility, S, and the K_{ow} of an organic compound are correlated by the following equation (Verschueren, 1983):

$K_{ow} = 5.00 - 0.670 \log S$

where S is the aqueous solubility in micromoles per liter, or

$K_{ow} = 4.5 - 0.75 \log S$

where S is in ppm

Figure 2-1 shows the relationship between the aqueous solubilities of various organic compounds and the corresponding K_{ow} values. Table 2-3 uses these data to give an absorption rating. In the absence of quantitative information, the remedial manager can use Table 2-3 to the advantage of knowing either the K_{ow} value or water solubility of the contaminant of concern. A thorough discussion of the partition coefficient and its use is given in Verschueren (Verschueren, 1983).

The tendency of an organic compound to adsorb onto a sediment particle is related to its solubility in water: the lower the solubility, the greater the tendency of the organic compound to adsorb. Studies using natural sediment from Coyote Creek, California, show that organic compounds are rapidly adsorbed from aqueous streams by suspended solids and bottom sediments.

For inorganic contaminants, no technique similar to those of the organic contaminants is presently available. Hence, actual chemical analyses and toxicity tests must be performed to evaluate the potential hazards of inorganic contaminants. However, recent work on the development of sediment criteria for metal contaminants suggests that measurements of the acid volatile sulfide (AVS) content of sediment is valuable in assessing the toxicity of divalent metals bound to sediment. It is anticipated that AVS normalization will provide the basis for development of sediment criteria for metal contaminants in anoxic sediment.

DATA REQUIREMENTS FOR TREATMENT EVALUATION

Site, sediment, and contaminant-specific physical and chemical data are needed to evaluate technology performance. One important source of these data is the information collected during treatability studies. Such data can help identify any pretreatment and posttreatments, optimize the technology's efficiency, and gather cost and preliminary design data. A source of data types required to evaluate a technology is presented in the *Guide for Conducting Treatability Studies Under CERCLA* (USEPA, 1989k). Tables 2-4 and 2-5 present an abbreviated list of characterization parameters for selected technologies.

Use of the Data

All treatment processes are sensitive to variability in the physical and chemical composition of the sediment feed stream. Therefore, knowledge of the characteristics of the sediment can be used to quickly identify the options that are most likely to succeed or fail in treating the particular stream.

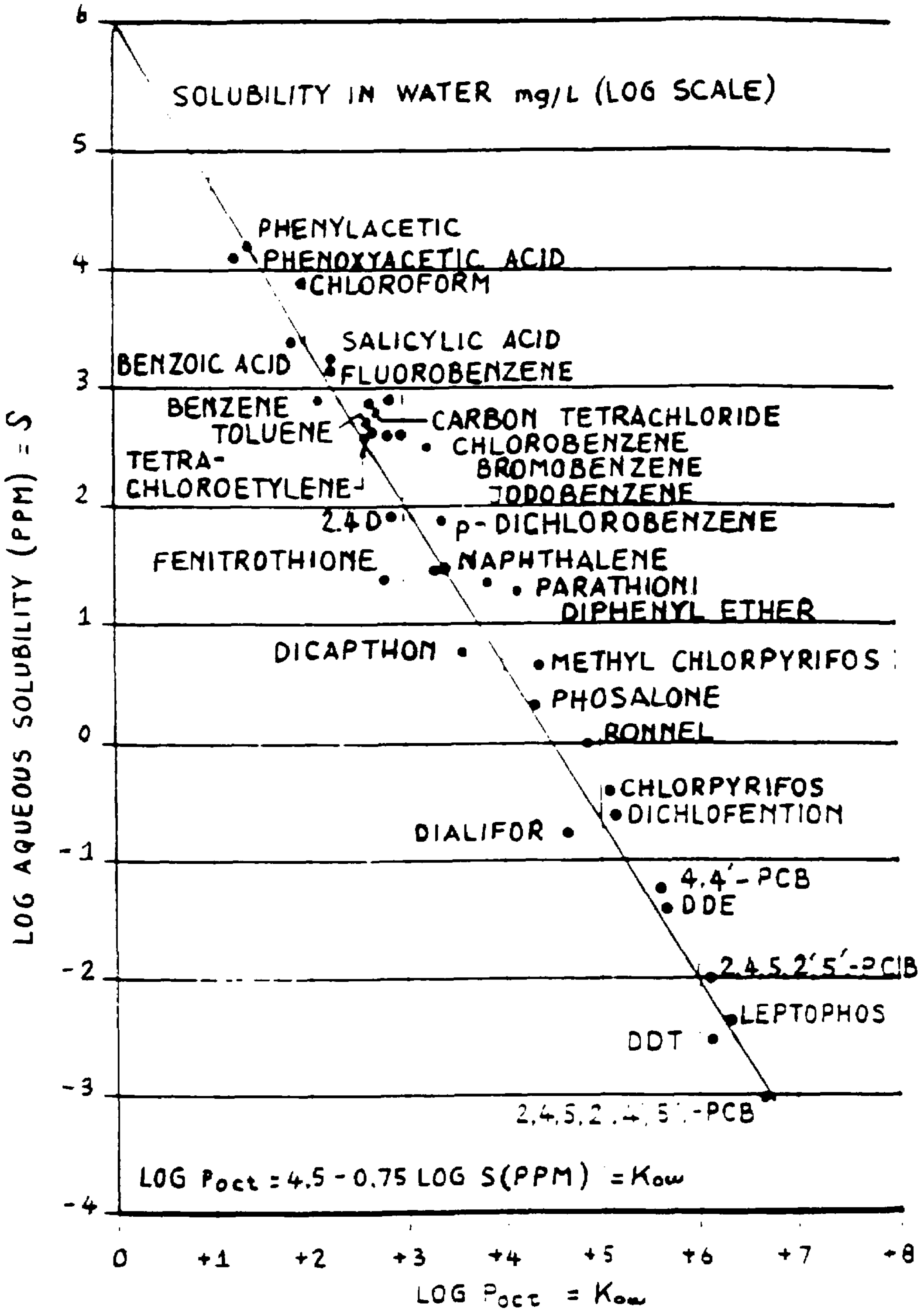

Figure 2-1. Partition coefficients and aqueous solubilities of various organic chemicals.

Source: Verschueren, 1983.

TABLE 2-3. ABSORPTION RATINGS

Rating	Octanol/water partition coefficient (K_{ow})	Based on sediment adsorption	Persistence
L (low)	<3	Absorbs weakly	95% degradation in 6 months or less
M (moderate)	$\geq 3 < 5$	Absorbs moderately	95% degradation in 2 yrs or less
H (high)	≥ 5	Absorbs strongly	95% degradation in 10 yrs or less
E (extreme)	---	---	<95% degradation in 10 yrs or more

TABLE 2-4. TECHNOLOGY DATA REQUIREMENTS FOR TREATMENT OF DREDGED SEDIMENT

Treatment technology	Matrix	Type	Parameter	Purpose and comments
Biological	Sediment/soil	Physical	Moisture content Field capacity pH Temperature Oxygen availability Water solubility Particle size	Determine the treatability of the material and the treatment process of choice.
		Chemical	Total organic carbon (TOC) Redox potential	Determine the treatability of the material and the treatment process of choice.
			Carbon/nitrogen: phosphorus ratio	Determine mineral nutrient requirements.
			Priority pollutant analysis	Determine presence of biological toxins.
		Biological	Soil biometer tests	Determine biodegradation potentials and quantify biodegradation rates of contaminants.
			Electrolytic respirometer tests	Measure oxygen uptake and biodegradation.
			Culture studies	Identify the indigenous microflora and specifically adapted microflora to be injected during the enrichment procedures.
			Bacterial enumeration tests (e.g., spread-plate techniques)	Measure the bacterial population density in the inoculum.
			Microbial toxicity/growth inhibition tests	Determine biological activity in the laboratory.
	Liquids	Chemical	pH Dissolved oxygen (DO) Chemical oxygen demand (COD)	Determine the treatability of the material and the treatment process of choice.
		Biological	Biological oxygen demand (BOD)	Determine the treatability of the material and the treatment process of choice.
			Culture studies	Identify the indigenous microflora.
			Microbial toxicity/growth inhibition tests	Measure biological activity in the laboratory.

TABLE 2-4. (continued)

Treatment technology	Matrix	Type	Parameter	Purpose and comments
Extraction - Aqueous - Solvent	Sediment/soil	Physical	Type, size of debris	Determine need for pretreatment.
			Particle-size distribution	Determine volume reduction potential, pretreatment needs, solid/liquid separability.
			Clay content	Determine adsorption characteristics of soil.
			Moisture content	Measure conductivity of air through soil.
			Equilibrium partition coefficient	Aid in selection of extraction medium.
		Chemical	Dioxins/furans, radionuclides	Determine special waste-handling procedures.
			Organic concentration	Determine concentration of target or interfering constituents, pretreatment needs, extraction medium.
			Metals (total) concentration	Determine concentration of target or interfering constituents, pretreatment needs, extraction medium.
			Metals (leachable) concentration	Determine mobility of target constituents, posttreatment needs.
			Total organic carbon (TOC), humic acid	Determine presence of organic matter, adsorption characteristics of soil.
			Cation exchange capacity (CEC)	Determine adsorption characteristics of soil.
			pH	Determine pretreatment needs, extraction medium.
			Cyanides, sulfides, fluorides	Determine potential for generating toxic fumes at low pH.
			Priority pollutant analyses	Determine waste complexity.
		Contaminant characteristics	Vapor pressure Solubility Henry's Law constant Partition coefficient Boiling point Specific gravity	Aid in selection of extraction medium.

TABLE 2-4. (continued)

Treatment technology	Matrix	Type	Parameter	Purpose and comments
Dechlorination	Sediment/soil	Physical	Moisture content	Identify reagent requirements.
		Chemical	Aromatic halides	Determine concentration of target constituents, reagent requirements.
			Metals	Measure concentration of other alkaline-reactive constituents, reagent requirements.
			pH	Determine reagent requirements.
			Priority pollutant analysis	Determine presence of incompatible compounds.
Solidification/ stabilization (S/S)	Sediment/soil	Physical	Description of materials	Determine waste handling methods (e.g., crusher, shredder, removal equipment).
			Particle size analysis	Determine surface area available for binder contact and leaching.
			Moisture content	Quantify the amount of water addition/removal in S/S mixing process.
			Density testing	Evaluate changes in density between untreated and treated waste.
		Strength test	Unconfined compressive strength	Evaluate changes in response to overburden stress between untreated and treated waste (e.g., material response to stress from cap).
			Flexural strength	Evaluate material's ability to withstand loads over large area.
			Cone index	Evaluate material's stability and bearing capacity.
			Durability testing	Evaluate durability of treated wastes (freeze-thaw and wet-dry durability).
		Chemical	pH	Evaluate changes in leaching as functions of pH.
			Alkalinity	Evaluate changes in leaching as functions of alkalinity.
			Total organic carbon, VOCs, and SVOCs, oil and grease, halides, inorganic salts, cyanides, phenols, sodium arsenate, borates, phosphates, iodates, sulfide/sulfate, carbohydrate, coal/lignite	Evaluate viability of S/S process. (Interfering compounds impede fixation reactions, cause chemical reactions, generate excessive heat. Interfering compounds vary with type of S/S.)
			Indicator compounds	Evaluate effectiveness of S/S (e.g., leaching tests).
			Leach testing	Evaluate effectiveness of S/S.
			Heat of hydration	Measure temperature changes during mixing.

TABLE 2-4. (continued)

Treatment technology	Matrix	Type	Parameter	Purpose and comments
Thermal	Sediment/soil	Physical	Moisture content	Affects heating value and material handling.
			Ash content	Determine the amount of ash that must be sent for disposal or further treatment.
			Ash fusion temperature	Prevent high-temperature slagging problems using inorganic salts having low melting points.
			Particle-size distribution	Avoid feeding problems that may result from large or fine particles.
			Heating value	Additional energy required by low heating value materials.
		Chemical	Volatile organics, semivolatile organics	Allows determination of principal organic hazardous constituents (POHCs).
			POHCs	Allows determination of destruction removal efficiency (DRE).
			Total chlorine, fluorine	Determine air pollution control devices needed for control of acid gases.
			Total sulfur, total nitrogen	Identify required air-pollution control devices (emissions of SO_x and NO_x are regulated).
			Phosphorus	Prevent refractory attack and slagging problems from organic phosphorus compounds.
			Polychlorinated biphenyls (PCBs), dioxins (if suspected)	Determine the feasibility of incineration. (99.9999% DRE required for PCBs; safety considerations; incineration is required if greater than 50 ppm PCBs present.)
			Metals	Determine special treatment needs. (Volatile metals (Hg, Pb, Cd, Zn, Ag, Sn) may require flue-gas treatment; other metals may concentrate in ash. Trivalent chromium may be oxidized to hexavalent chromium, which is more toxic. Presence of inorganic alkali salts, especially potassium and sodium sulfate, can cause slagging.)

Source: USEPA, 1989k.

TABLE 2-5. TECHNOLOGY DATA REQUIREMENTS FOR IN SITU TREATMENT OF SEDIMENT

Treatment technology	Matrix	Type	Parameter	Purpose and comments
Biological **- Aerobic**	Sediment/ soil	Physical	Permeability of soil	Determine ability to deliver nutrients to oxygen and to allow movement of microbes.
		Chemical/ biological	Contaminant concentration and toxicity, SOD, nutrients	Determine viability of microbial population in the contaminated zone.
- Anaerobic	Sediment/ soil	Physical	Permeability of soil	Determine ability to allow movement of microbes.
		Chemical/ biological	Contaminant concentration and toxicity	Determine viability of microbial population in the contaminated zone.
Solidification/ stabilization	Sediment/ soil	Physical	Presence of subsurface barriers (e.g., drums, large objects, debris, geologic formations)	Assess the feasibility of adequately delivering and mixing the S/S agents.
			Depth to first confining layer	Determine required depth of treatment.

Source: USEPA, 1989k.

SECTION 3

SELECTION OF REMEDIAL OPTIONS

INITIAL SCREENING USING GENERIC SITE CONDITIONS

The Federal Water Pollution Control Act and CERCLA direct the U.S. Coast Guard and the Environmental Protection Agency to ensure safe cleanup of hazardous chemical discharges, including sediment, in United States waters. In addition, the Corps of Engineers is charged with keeping the commercial waterways navigable by removal of sediment, which may or may not be contaminated.

Certain remedial actions are routinely taken by the Corps of Engineers; others are currently under investigation by EPA. Both the traditional options selected by the Corps of Engineers -- such as confined disposal facilities, confined aquatic disposal, *in situ* capping, ocean disposal, etc. -- as well as the soil/sludge remediation techniques being investigated by EPA under Superfund or enforcement may be applicable to cleanup of sediment.

The first step in the selection process is characterizing the site and sediment. These data enable the remedial manager to decide whether the sediment is contaminated and whether it poses a potential threat to human health or the environment. If the sediment does not pose a threat, then no action is required. If the sediment is contaminated and does pose a threat to human health or the environment, then some action is required.

Selecting the Most Effective Options/Identifying Marginal Options/Determining Ineffective Options

Section 1 provides several sediment quality criteria to assist the remedial manager in determining whether or not sediment is contaminated. For contaminated sediment, Figure 3-1 displays conventional techniques and new treatments that may be potentially applicable, based on RODs dealing with contaminated sediment (see Appendix C). Table 2-4 indicates the principal parameters that are needed to properly evaluate a technology. Finally, Appendices A and B contain relevant case studies and treatability studies, respectively.

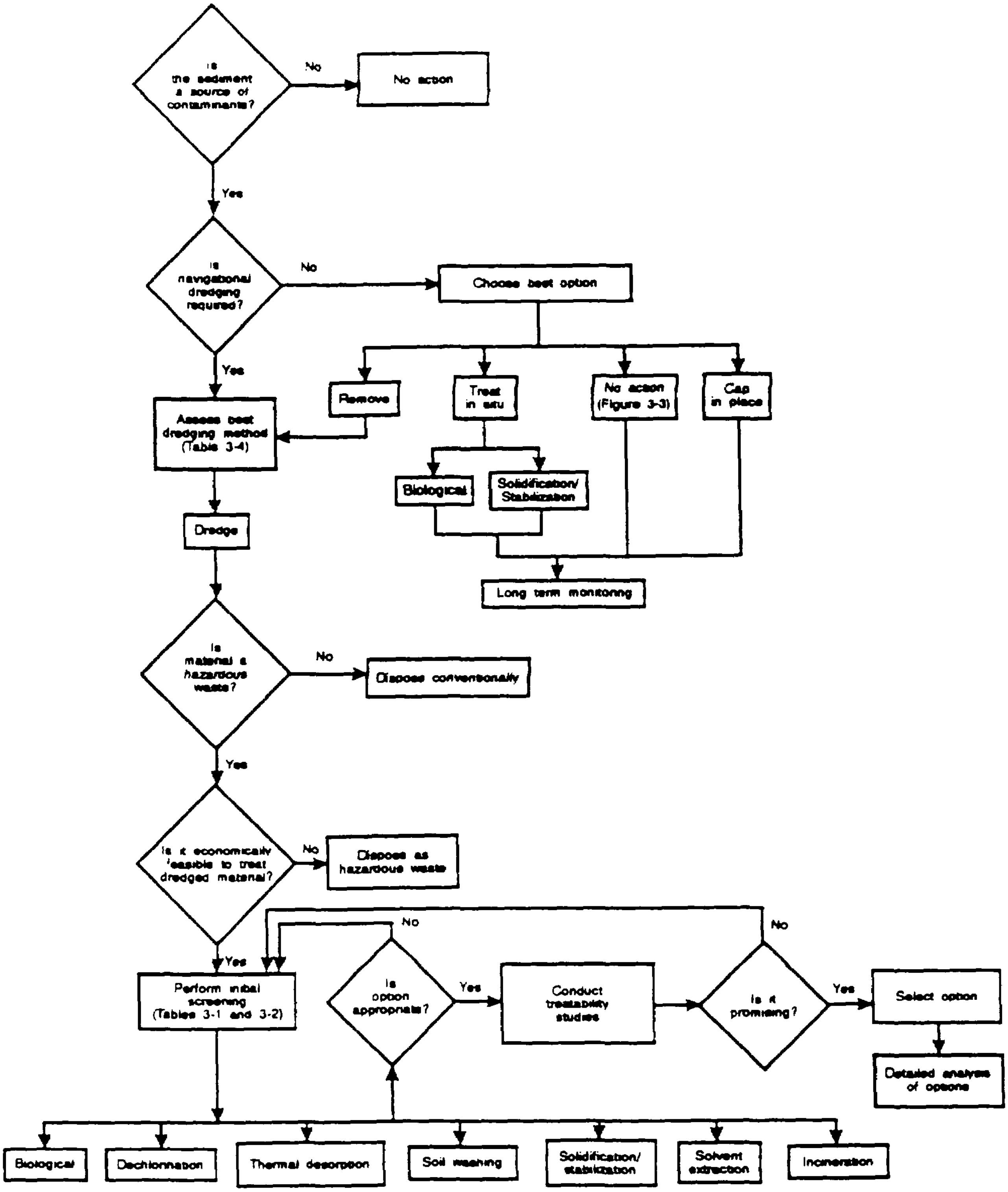

Figure 3-1. Applicable remedial options.

Tables 3-1 and 3-2 assist the remedial manager to screen out less appropriate remedial methods. The remaining methods can then be pursued in detail in the feasibility study. At present it is difficult to assign numeric values to the low, medium, and high categories presented in Table 3-2. When available, qualitative and quantitative values are listed in Table 3-3 to further assist the remedial manager. Additional parameters can be found in the text under the section describing the specific technology. Using Figure 3-1, the remedial manager can determine whether conventional options or innovative technologies or some combination are appropriate to the site. Table 3-4 is a worksheet to assist the remedial manager in evaluating the parameters in Tables 3-1 and 3-2. Once completed, the worksheet will indicate one of four general conditions:

> A **preferred technology choice**, indicating that the selected technology may be appropriate for the site-specific conditions.
>
> A **less than clear-cut choice**, indicating that some parameters must be adjusted to fit the technology to the site conditions.
>
> An **array**, indicating that the site conditions are so varied that several technologies may be required to remediate the site.
>
> The **absence of a choice**, indicating that none of the listed technologies is appropriate to the site.

The remedial manager can then move toward technology selection. The selection process is outlined below. Relevant examples are detailed in Section 4 of this guide.

- Use Tables 1-1 through 1-4 to aid in determining if sediment is contaminated.
- Refer to Figure 3-1 to preliminarily screen the treatment options.
- Review Table 2-4 for the principal parameters affecting technology performance.
- Screen less appropriate technologies using Tables 3-1 and 3-2.
- Use Table 3-4 as a worksheet for your specific site.
- Determine an appropriate overall treatment system from the technology description sections of the text.

TABLE 3-1. INITIAL SCREENING BY CONTAMINANT GROUP

Contaminant group	Biological treatment	Dechlorination	Soil washing	Solvent extraction	Solidification/ stabilization	Incineration	Thermal desorption
Organics							
Halogenated volatiles	O	O	+	O	x	+	O
Nonhalogenated volatiles	O	x	+	O	x	+	O
Halogenated semivolatiles	+	+	O	O	x	+	O
Nonhalogenated semivolatiles	+	x	O	O	x	+	O
PCBs	O	+	O	+	O	+	+
Pesticides	O	O	O	O	O	O	O
Dioxins/furans	x	+	O	O	x	+	O
Organic corrosives	x	x	O	O	+	O	x
Organic cyanides	+	x	O	O	O	O	O
Inorganics							
Nonvolatile metals	x	x	O	x	+	x	x
Inorganic corrosives	x	x	O	x	+	x	x
Inorganic cyanides	O	x	O	x	+	O	x

Legend

+	Demonstrated effectiveness: Successful treatability test at some scale completed.
O	Potential effectiveness but not demonstrated: Expert opinion that technology will work.
x	No expected effectiveness
U	Unspecified. Insufficient data available for adequate evaluation.

Source: USEPA, 1988b, 1990c, d, h, i, j, k, l, m

TABLE 3-2. INITIAL SCREENING BY GENERAL PARAMETERS

Parameter[1]	Biological treatment	Dechlorination	Soil washing	Solvent extraction	Solidification/ stabilization	Incineration	Thermal desorption
Clay content							
Low	+	+	+	+	+	+	+
Medium	O	O	O	O	+	O	O
High	O	x	x	x	O	x	x
Humic content							
Low	+	+	+	+	+	+	+
Medium	+	O	O	O	+	+	+
High	+	O	O	O	+	+	+
Metals content							
Low	x	x	+	x	+	+	+
Medium	x	x	O	x	+	O	O
High	x	x	x	x	+	x	x
Particle size							
Small	+	O	x	O	x	O	O
Medium	+	+	O	+	+	+	+
Large	O	x	+	+	O	O	O
pH							
Low	x	x	O	O	+	O	O
Medium	+	+	+	+	+	+	+
High	x	+	O	O	O	+	+
Salinity	U	+	O	O	O	+	+
Silt content							
Low	+	+	+	+	+	+	+
Medium	+	+	O	+	+	O	O
High	+	O	O	x	+	x	x

TABLE 3-2. (continued)

Parameter[1]	Biological treatment	Dechlorination	Soil washing	Solvent extraction	Solidification/ stabilization	Incineration	Thermal desorption
Solids content							
Low	+	O	O	O	O	O	x
Medium	+	+	+	+	+	+	O
High	+	+	+	+	+	+	+
Waste composition	+	+	+	+	+	+	+
Homogeneous	O	+	O		+	+	+
Heterogeneous							
Water content							
Low	O	+	+	O	+	+	+
Medium	+	O	+	x	+	O	O
High	O	x	O	x	O	x	x

[1] Ranges for the selected parameter are discussed in the technology section.

Legend

+	Favorable to process
O	No effect on process expected
x	May impede process
U	Unspecified. Insufficient data available for adequate evaluation.

TABLE 3-3. PARAMETER EFFECTS

Parameter	Biological treatment	Dechlorination	Soil washing	Solvent extraction	Solidification/ stabilization	Incineration	Thermal desorption
Clay content	No known effect	Increases reaction time	Impedes contaminant removal	Affects solvent use and efficiency	No known effect	No known effect	Can effect removal efficiency
Humic content	No apparent effect	Increases reaction time	Inhibits contaminant removal	No apparent effect	If >45% (wt) can affect bonding	No effect	No known effect
Metals content	Can be toxic to microorganisms	Increases use of reagent	Does not remove insoluble metals	Does not removal insoluble metals	Does not remove leachable metals	Volatile metals can vaporize	Volatile metals can vaporize
Particle size	If non-uniform can affect activity	No apparent effect	Fines difficult to remove from wash solution	Must be < 1/4"	If < 200 mesh or > 1/4" can affect bonding	Fines can be carried through the process	Fines can be carried through the process
pH	Most effective range 4.5-8.5	Must be > 2	Affects choice of reagents	Affects choice of solvent	pH is automatically adjusted	If low, can cause acid attack	If outside 5 to 11 can cause corrosion
Salinity	Microorganisms must be adapted to high salt concentration	Affects reagent use	No apparent effect	No known effect	May affect bonding	No known effect	No known effect
Silt content	No apparent effect	No known effect	Affects efficiency	Affects efficiency	May affect bonding	Can be carried through process	Can be carried through process
Solids content	Depends on the process type	Affects reagent use	No apparent effect	No apparent effect	If < 15%, requires higher reagent use	Most efficient as content increases	Most efficient as content increases
Waste composition	If heterogeneous can affect sustained activity	Certain chlorinated aliphatics may produce potentially explosive compounds	Affects waste solution formulations	Affects choice of solvents	If heterogeneous, can affect bonding	Can affect energy requirements if heterogeneous	Can affect energy requirements if heterogeneous
Water content	Content outside 40-80% inhibits activity	If > 20% requires higher reagent use	No effect	Affects choice of solvent	No known effect	If high, affects feed handling and energy requirements	Affects energy use

TABLE 3-4. INITIAL SCREENING WORKSHEET

Parameter	Range	Biological treatment	Dechlorination	Soil washing	Solvent extraction	Solidification/ stabilization	Incineration	Thermal desorption
Contaminant								
Clay content								
Humic content								
Metals content								
Particle size								
pH								
Salinity								
Silt content								
Solids content								
Waste composition								
Water content								

REMOVAL AND TRANSPORT

The first step in the remedial selection process is to determine whether to treat the sediment *in situ*. Most often, sediment is excavated/dredged, and contained. 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.

A primary 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.

Removal of Contaminated Sediment

Most contaminated sediment research and regulatory emphasis have focused on dredging and disposal. The choice of whether to dredge depends on the nature of the sediment, the types of contaminants, the depth to bottom, the thickness and volume of sediment, the distance to next operation (e.g., disposal sites), and the available machinery. Dredging and transport are appropriate: when the environmental effects of the no action alternative are unacceptable; when environmental conditions such as wave action, flooding, or erosion transport prohibit leaving the sediment in place; or when sediment lies in navigation waterways that must be dredged. Dredging costs for all types of sediment range from $1.00 to $25.00/cubic yd, while costs for dredging contaminated materials typically range from $5.00 to over $25.00/cubic yard.

Dredging costs depend on the volume of material removed, the location of the material (contiguous areas as opposed to isolated hot spots), the type of waterway (navigation channel, constricted natural river, etc.), the time restrictions placed on dredging, the type of dredge, and any special restrictions placed on the operation (e.g., the use of silt curtains, special equipment, hours of operation, etc.)

Dredging causes resuspension of sediment. However, the spread of resuspended sediment can be limited through the use of silt curtains. Silt curtains create an underwater obstacle that extends below the water's surface, sometimes to the bottom. Oil booms lie on the surface and block material moving on top of the water.

Dredging methods are divided into three major categories: mechanical, hydraulic, and pneumatic. The water content of the sediment is an important variable in the design, operation, and handling costs of contaminated material. Mechanical dredging produces a material with a water content near that of *in situ* sediment. The high solid content reduces the size requirements for transport, treatment, and disposal equipment. Although mechanical dredging offers the advantage of high density recovery, it generates high resuspension of bottom sediment, particularly in the fine-grained range. Since the fine-grained sediment is often highly contaminated, the higher resuspension can cause increased contaminant release. The expected levels of suspended sediment must be compared to the background levels of suspended material in the water. Higher velocity currents can transport particles as large as 10 mm diameter to greater distances. The significance of any effects from this resuspended material must be considered in the context of other activities that may cause similar resuspension, such as ship traffic and storm events.

Mechanical Dredges--

Mechanical dredges include clamshells, dippers, bucket ladder dredges, draglines, and conventional earthmoving equipment. They remove bottom sediment through directly dislodging and excavating material at almost *in situ* density. Such techniques have been used extensively.

Clamshells--A clamshell is a highly precise digging tool efficient in close quarters such as dock and pier areas. Hinged clamshells range in capacity from 1 to 20 cu yd. They can recover all types of material except highly consolidated sediment, and can excavate to practically any depth, restricted only by the crane lifting capacity. Clamshell dredges operate at 20 to 30 cycles per hour, depending on working depth and sediment characteristics. Because they excavate a high percentage of solids, they can lower the cost of subsequent dewatering. If the sediment will be deposited in a confined facility, lower water content will promote rapid settling and reduce the escape of sediment with effluent water.

The clamshell is attached by a cable to a crane mounted on a flat-bottomed barge. The anchors can move the barge short distances after it is in position, but must be moved by a tug during any longer trips. The crane operator drops the clamshell into the water in the open position. After the bucket hits bottom, the operator closes the bucket, scooping up the sediment. The operator then raises the bucket of contaminated sediment through the water column and above the water, swings it over a barge or scow, opens the jaws, and dumps the sediment. If properly operated, conventional clamshells can remove sediment with minimal loss of sediment. Modifications to the conventional clamshell, known as a closed-bucket clamshell, use welded plates and rubber gaskets to improve the seal when bucket closes. Closed-bucket clamshells are routinely used in contaminated sediment dredging projects by the Corps of Engineers in the Great Lakes, and reduce the amount of resuspended material by 30 to 70 percent (McLellan, 1989).

Draglines--Draglines employ the same basic equipment as the clamshell dredge, the major differences being the control cable arrangement, the excavating bucket, and the method of operation. The dragline bucket is loaded by being pulled by a drag cable through the material being excavated and toward the crane. Dragline dredges generally offer a longer reach than clamshell dredges operated by the same crane (Merritt, 1976). Draglines have limited production rates and a high degree of sediment resuspension caused by agitation and bucket leakage.

Bucket Ladder Dredges--A bucket ladder dredge is composed of a submersible ladder which supports a continuous chain of buckets that rotate around two pivots. As the buckets rotate around the bottom of the ladder, they scoop up the material to be dredged and transport it back up the ladder to be discharged into a storage area on the dredge. Bucket ladder dredges are most commonly used abroad in mining operations such as sand and gravel production. Although production rates are higher than for other mechanical dredges, the bucket ladder generates considerable turbidity due to mechanical agitation of sediments and leakage out of the buckets. Therefore, it is not recommended for dredging of hazardous materials or contaminated sediments (Hand, et al., 1978).

Conventional Earthmoving Equipment--Conventional earthmoving equipment such as backhoes and front-end loaders have limited applications in the removal of contaminated sediments. Backhoes are normally used for trench and other subsurface excavation and are capable of reaching 40 ft or more below the level of the machine (Merritt, 1976 and Church, 1981). Backhoes can be barge-mounted or operated from land, although the lateral reach is limited, as is the vertical reach, by the boom length.

Loaders are normally used to excavate loose or soft materials in a narrow vertical range of operation a few feet above and below grade. Loaders must be in close proximity, both horizontally and vertically, to the materials being excavated, and shore-based and barge-mounted operations are not practical. Operations in shallow water may be practical if sediments are sufficiently loose or soft.

Dippers--The dipper is a powered shovel designed for digging out rock and other very hard, compacted material. It operates with a violent digging action, and tends to drop small particles. Dipper capacities range from 8 to 12 cu yd. Dippers usually achieve a production rate of between 30 to 60 cycles per hour. They are well suited to excavation of soft rock and highly consolidated sediment within a working depth of 50 ft. Since this technique allows extensive contaminant releases, its application to most contaminated sediment is limited.

Hydraulic Dredges--

Hydraulic dredges are usually barge-mounted systems that use centrifugal pumps to remove and transport the sediment/water mixture. Pumps may be either barge-mounted or submersible. Standard hydraulic dredging commonly produces slurries of 10 to 20% solids by wet weight. Economic operating depths range between 50 and 60 ft.

Hydraulic dredges generally exhibit higher production rates and lower resuspension than mechanical dredges. They are also capable of removing liquid contaminants. However, they are susceptible to damage by debris and clogging with weeds. Hydraulic dredges include portable dredges, hand-held dredges, plain suction dredges, cutterhead dredges, dustpan dredges, and hopper dredges.

<u>Portable Hydraulic Dredges</u>--Portable hydraulic dredges are defined as dredge vessels that can be moved easily over existing roadways without major dismantling. Dredging capabilities range from 10 to 50 ft. Vessel draft is generally less than 5 ft (many less than 2 ft). Production rates average between 50 to 500 cu yd/hr depending on model, size, and site conditions. These dredges are particularly useful for projects in isolated water bodies, such as lakes and inland rivers, because they an be easily moved to sites over land. Their shallow drafts make them effective in shallow water. Portable dredges cannot operate in waves higher than 1 ft or in water shallower than 2 ft.

<u>Hand-Held Hydraulic Dredges</u>--Hand-held hydraulic dredges are assembled using readily available equipment designed for other applications. They can be operated either underwater or above-water. Underwater hand-held dredges are normally operated by divers, which can operate to depths of 1,000 ft with an excavation rate of 250 cu yd/hr. Above-water hand-held dredges can be operated from above the water surface in water bodies less than 4 ft deep with sufficiently firm bottom materials to allow wading by workmen. Hand-held dredges cannot be operated in strong currents or high-flow velocities.

<u>Plain Suction Dredges</u>--Plain suction dredges are the simplest form of hydraulic dredges, relying solely on the suction created by a centrifugal pump to dislodge and transport sediments. The dredge head is attached to the end of a ladder and its position is controlled vertically and horizontally by the

movement of cables attached to the ladder. Plain suction dredges are most effective in the removal of relatively free-flowing sediments such as sands, gravels, and unconsolidated material. Hard and cohesive materials such as clays or firm native bottom soils are not readily removed by plain suction, as no mechanical dislodging devices are employed. Slurries of 10 to 15 percent solids by weight can be achieved in appropriate applications. Production rates average between 1,000 and 10,000 cu yd/hr. Vessel draft is on the order of 5 to 6 ft.

Hopper dredges--A hopper dredge is a self-propelled ship with excavating equipment mounted amidships. Two hinged suction pipes, called drag arms, extend down and back from the sides of the vessel. Intakes at the lower ends of these pipes scrape along the bottom scooping up sediment that is then drawn up into open hoppers on board. Product rates range from 500 to 2,000 cu yd/hr, at depths up to 60 ft. Vessel drafts range from 12 to 31 ft. The vessel can operate in waves up to 7 ft. When the hoppers are full the hopper dredge takes the accumulated sediment to a disposal site. Hopper dredges are used in heavily trafficked environments, or in open water where waves are too high for stationary dredges. Their advantages are self-containment, mobility, and seaworthiness.

Hopper dredges have a number of drawbacks. The intake head is inefficient and imprecise, leaving behind large amounts of uncollected, resuspended sediment. The turbulence created by the ship's propeller increases resuspension. The on-board hoppers are often allowed to overflow as a means of eliminating excess water, adding more turbidity and contaminant to the water column. This procedure is inappropriate for contaminated sediment.

Cutterhead Dredges--The configuration and principle of operation of the cutterhead dredges are similar to those of the plain suction dredge with the exception of the addition of a mechanical device for dislodging material; this device is called a cutterhead. The cutterhead is located at the intake of the suction pipe and rotates to dislodge sediment, allowing sediment to be removed by suction through the suction pipe. Slurries up 10 to 20 percent solids by weight are typically achieved. Production rates vary according to pump size and can be as large as 2,500 cu yd/hr. Vessel draft is between 3 and 5 ft. Cutterhead dredges are capable of reaching materials up to 50 ft below the water surface. They are highly efficient in removing all types of materials, including very hard and cohesive sediments.

Dustpan Dredges--The dustpan dredge is also similar in configuration and operation to the plain suction dredge. The dustpan has a widely flared head containing high-pressure waterjets which dislodge sediments. The dustpan dredge works best in free-flowing granular material and is not suited for use in fine-grained clay sediments. Slurries of 10 to 20 percent solids by weight are typically achieved. Production rates range between 200 and 15,000 cu yd/hr, depending on the discharge pipe diameter and the discharge velocity. Vessel draft varies between 5 and 14 ft.

Pneumatic Dredges--

Pneumatic dredges use compressed air and/or hydrostatic pressure to remove sediments. Pneumatic dredges are commonly barge-mounted. They produce slurries of higher solid concentrations than hydraulic dredges and cause less resuspension of bottom materials. Common pneumatic dredges include airlift dredges, the "Pneuma" (developed in Italy) and the "Oozer" (developed in Japan). Pneumatic dredges have been used extensively in Europe and Japan; they have only limited availability in the United States. Pneumatic dredges also require a minimum of 7.5 ft of water -- deeper than for mechanical or hydraulic dredges -- to function properly.

Airlift Dredges--Airlift dredges used compressed air to dislodge and transport sediments. Compressed air is introduced into the bottom of an open vertical pipe that is usually supported and controlled by a barge-mounted crane. As the air is released, it expands and rises, creating upward currents which carry both water and sediment up the pipe. The applied air pressure must be sufficient to overcome the hydrostatic pressure at operating depths. Higher air pressures and flow rates result in higher transport capacity. Air can also be introduced through a special transport head which can be vibrated or rotated to further dislodge more cohesive sediments. Slurries of 1:3 solid/water ratio can typically be achieved with airlift dredges (Hand, et al., 1987). Airlift dredges are usually operated from barges with drafts between 3 and 6 ft. Airlift dredges are used primarily in underwater mining of sand and gravel and are well-suited to deep dredging applications for excavating loose granular materials, primarily sand. Any depth for which sufficient pipe and air pressure can be provided can be dredged by this method.

Pneuma Dredges--The Pneuma dredge is a pump which is lowered by a crane to be in direct contact with the sediments being dredged. The pump is driven by compressed air and operates by positive displacement. The body of the pump contains three cylindrical vessels, each with an intake opening on the bottom and air port and a discharge outlet on top. The air ports can be opened to the atmosphere through air hoses and valves. The three discharge outlets join in a single discharge hose. When operating, the pump is lowered into the sediment with its intakes buried. An air port valve is opened, creating a pressure differential between the sediment (at hydrostatic pressure) and the cylinder (at atmospheric pressure) and inducing flow of sediment and water into the cylinder. When the cylinder is nearly full, compressed air is introduced into the cylinder, closing a check valve at the intake opening and forcing the slurry through the discharge outlet in the discharge hose. The three cylinders operate in parallel, each one-third cycle ahead and behind the other two cylinders and are controlled by an air distributor located on the control vessel (Richardson, et al., 1982).

Pneuma dredges are most applicable to loosely packed sediment. Pneuma dredges are normally suspended from a crane cable and pulled into the sediments being dredged by a second cable. Vessel draft is between 5 and 6 ft. Production rates range between 60 and 300 cu yd/hr.

Oozer Dredges--The Oozer dredge is a pump that is similar in concept to the Pneuma; significant differences are as follows:

- The pump body consists of two cylinders.
- A vacuum is applied to the cylinders to increase the differential pressure and flow between the sediment and the cylinders.
- The pump is usually mounted at the end of a ladder.
- The dredge tracks in a cutterhead-swing-type motion, alternating speeds.
- Sediment thickness detectors are attached close to the suction mouth.
- Underwater television cameras and a turbidimeter are attached near the suction mouth for monitoring turbidity.
- Suspended oil can be collected by a hood attached on the suction mouth.
- Cutters can be attached for dislodging hard soils.

The Oozer dredge is capable of operating at depths up to 60 ft and pumping slurries of 30 to 70 percent solids (near in situ densities) at rates of 500 to 800 cu yd/hr, while keeping resuspension of sediments low (Barnard, 1978).

Comparison of Dredge Advantages/Disadvantages--

The three types of dredges discussed above vary in capabilities according to the types of sites in which they operate most efficiently, their production rates, sediment resuspension rates, and operating depths. Table 3-5 compares these major characteristics. *Handbook: Responding to Discharges of Sinking Hazardous Substances* (USEPA, 1987b), *Field Studies of Sediment Resuspension Characteristics of Selected Dredges* (McLellan, et al., 1989), *Literature Review and Technical Evaluation of Sediment Resuspension During Dredging* (Herbich, et al., 1991) and *Contaminated*

TABLE 3-5. DREDGE COMPARISONS

Type	Functional advantages	Functional drawbacks	Production rate (cu yd/hr)	Max use depth (ft)
Mechanical	Handles small volumes of sediment; good in confined areas or near structures; good for harbors and interior waterways; good for removal of bottom debris and non-consolidated sediment; provides high solids content; widely available.	Low production rates; cannot excavate highly consolidated sediment or solid rock (specialized types can overcome this drawback); higher resuspension of sediment.	30 - 700	30 - 100
Hydraulic	Handles moderate to high volumes of water and sediment; good for lakes and inland rivers; can operate at shallow depths; provides low solids content; moderate resuspension of sediment.	Moderate production rates; cannot operate in rough, open water; susceptible to debris damage; adds substantial amounts of water to material.	10 - 10,000	50 - 70
Pneumatic	Good for nonconsolidated solids; use in interior waterways; provides low solids content low resuspension of sediment.	Moderate production rates; may obstruct traffic; do not operate well in shallow (<10 ft) depths.	60 - 800	Up to 150

Source: USEPA, 1987b.

Dredged Material - Control, Treatment, and Disposal Practices (Cullinane, et al., 1990) discuss and illustrate dredge types, capacities, and capabilities.

Transporting the Sediment

The method of transportation for dredged material depends on the distance between the dredging and treatment sites. Selection of transport options will be affected by both dredge selection and pretreatment and treatment decisions. The primary emphasis during transport is towards spill and leak prevention. During transport, spills occur during the loading and unloading of sediments and special care should be taken during these operations; pipelines also leak sometimes. The principal transportation methods for moving dredged materials include the following:

Pipelines: Commonly used to transport dredged materials over relatively short distances (up to 3 mi for navigation dredging; as long as 15 mi for commercial land reclamation and fill operations).

Barges or scows: The most widely used method of transporting large quantities of dredged material over long distances. They use controls to prevent the spread of contamination: decontamination of equipment; fugitive emissions control; procedures for loading and unloading; route and navigation precautions against hazards.

Railroads: Normally used when distances to disposal sites exceed 50 mi. Control of dust during transport is essential.

Trucks: Appropriate when the distance to the disposal site lies between 15 and 50 mi. Federal, state, and local regulations control the movement of hazardous materials via truck. The high water content of contaminated sediment adds weight and cost to trucking.

Hopper dredges: Mobile dredges that transport sediment dewatered during filling of the dredge. Clean excess water can overflow the hopper, leaving space for additional sediment. Equipment is routinely used to dredge contaminated materials.

A more thorough discussion of contaminant control during dredging and transport is given in *Contaminated Dredged Material - Control, Treatment and Disposal Practices* (Cullinane, et al., 1990).

Selecting a Compatible Dredge and Transport System

Two additional factors to consider when selecting appropriate dredge and transport system are distance to the disposal/treatment site and compatibility with disposal/ treatment processes. For example, if the technology is more effective with dewatered material, and if the material does not drain readily, then mechanical dredging, which produces a drier sediment slurry than hydraulic dredging, would probably be selected. The drier, mechanically dredged material would then be transported by barge and/or truck, rather than by pipe.

PRECONDITIONING/PRETREATING THE SEDIMENT

Several technologies may be able to treat contaminated sediment partially. However, it is unlikely that a single treatment scheme will totally remediate a particular contaminated sediment. More often, treatment stages are required. For example, most sediment will require dewatering followed by particle classification (which removes oversize material). The remedial manager must now accommodate three components, any of which may or may not be contaminated: the sediment, the oversized materials, and the separated water. In addition to discussing the treatment options for the separated sediment component, it is necessary to address dewatering, and water effluent treatment. Figure 3-2 summarizes the major activities that are undertaken in treating contaminated sediment.

Dewatering Techniques

Dewatering is normally required to reduce the moisture content of sediment, enhancing the handling characteristics, and preparing the sediment for further treatment and disposal. The water generated during dewatering generally contains low levels of contaminants and require treatment. Dredged material dewatering is traditionally accomplished in ponds or CDFs, which rely on seepage, drainage, consolidation, and evaporation. This is generally effective and economical, but slow. Common industrial methods of dewatering slurries or sludges include centrifugation, dewatering lagoons, filtration, and gravity thickening.

Some of these are appropriate to dewater sediment. Method selection depends on the volume of sediment, land space available, solid content of the waste stream, and the degree of dewatering required. A good compendium on dewatering techniques is given in *Handbook: Responding to Discharges of Sinking Hazardous Substances* (USEPA, 1987b). Sediments vary in percent solid, depending on location and dredging technology. Mechanical and pneumatic dredges remove sediment

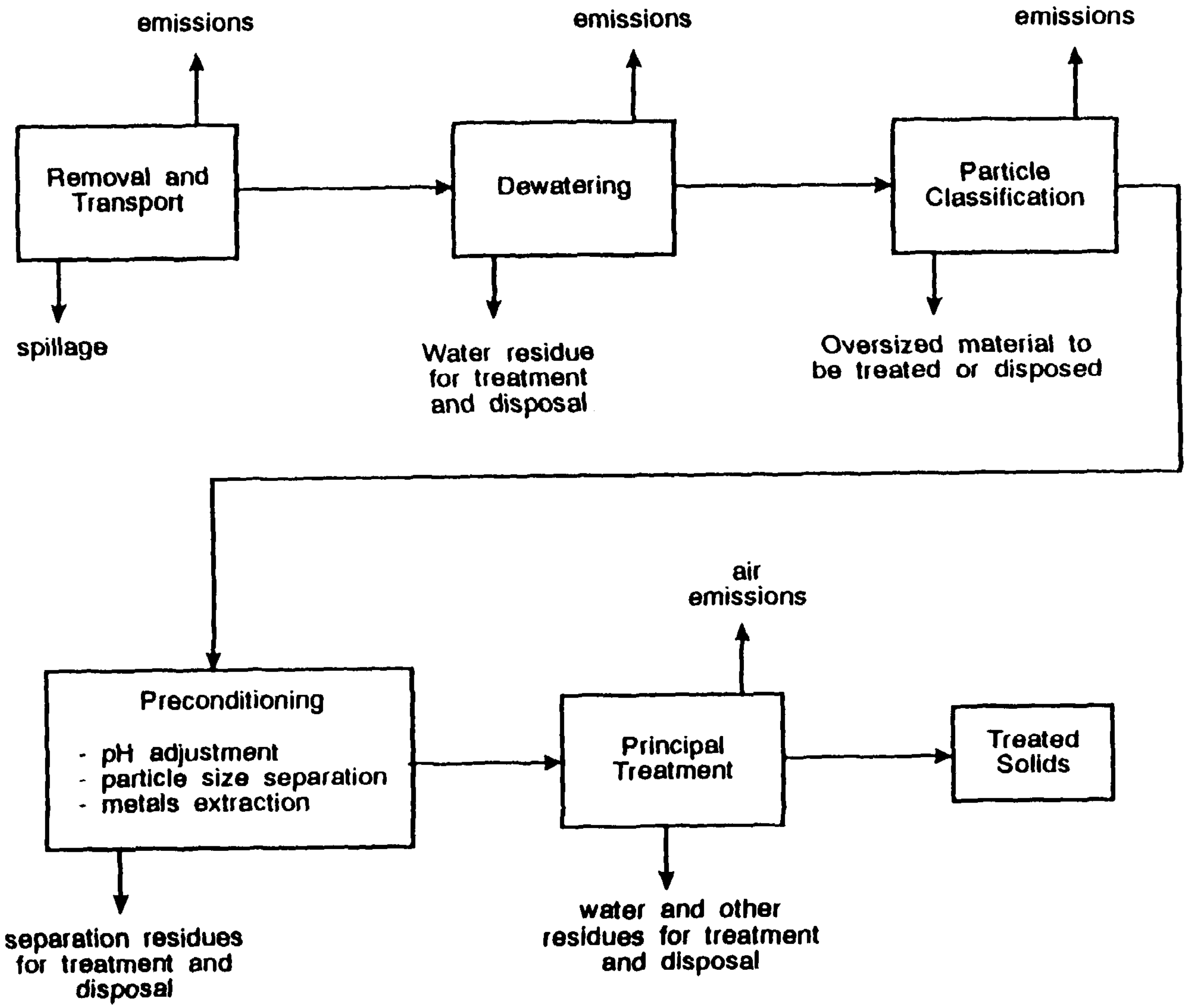

Figure 3-2. Overview of dredged material treatment.

at or near *in situ* solid concentrations, while hydraulic dredges remove sediments in a liquid slurry 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.

Centrifugation--

Centrifugal dewatering uses the force developed by fast rotation of a cylindrical drum or bowl. Solids and liquids separate by density differences under the influence of centrifugal force. Centrifuges are relatively compact and are therefore well suited to areas with space limitations. They can achieve a product composed of 10 to 35 percent solids, but removal efficiencies are drastically reduced for particles less than 10 micron. Centrifuges are unsuitable for streams containing tars, small particle sizes, low density particles, large objects, or fibrous materials thereby possibly limiting their application to contaminated sediment. They are not as effective as filtration or dewatering lagoons/CDFs, and have high operating costs, energy use, and maintenance. Costs for centrifugation have been reported to include $500,000 capital and $85,000/yr operating expenses at a 50 lb/hr (dry) throughput (USEPA, 1986d).

Dewatering Lagoons/CDFs--

Industrial dewatering lagoons can remove sediment from gravel size to fine silt measuring 10 to 20 micron, if flocculation is used. They correspond closely to CDFs. Particles settle according to their own settling velocity, which varies according to the particle diameter and specific gravity. These lagoons/CDFs also provide temporary storage for dredged materials. They can use a gravity or vacuum-assisted underdrainage system to remove water. This system can achieve up to 40 percent solids content after 10 to 15 days. Vacuum-assisted systems may produce a dry cake in a shorter retention time. Vacuum-assisted dewatering lagoons reportedly increase the rate of dewatering by about 50 percent.

Dewatering lagoons have high capital costs. They require a large land area and involve a long construction time. Settled solids accumulate on the bottom basins where they are temporarily stored. As the volume of accumulated solids increases, the capacity of the basin decreases, reducing its effectiveness and efficiency. Accumulated solids must be periodically removed and treated.

Filtration--

Filtration is a physical process in which liquid is forced through a permeable medium, retaining dewatered solids on the membrane. Filtration dewaters fine-grained sediment over a wide range of solids concentrations. Effectiveness depends on the type of filter, the particle size, and the solids concentration in the influent.

Three commonly used types of filter systems are belt press filtration, vacuum filtration, and pressure filtration. Belt presses process slurries from 1 to 40 percent solids by weight, and generate solid streams with 12 to 50 percent solids by weight. They can process up to 25 t/hr. Vacuum filters can process streams of 10 to 20 percent solids by weight, and capture 85 to 99 percent of the solids material. Because information on the use of filtration for dewatering sediment is limited, it is difficult to predict its effectiveness in such applications. Typical ranges of solids concentrations in dewatered municipal wastewater treatment sludges are as follows (USEPA, 1987b):

Belt press filtration - 15 to 45 percent
Vacuum rotary filtration - 12 to 40 percent
Pressure filtration - 30 to 50 percent

Gravity Thickening--

Gravity thickening concentrates solids in a tank similar to a conventional sedimentation tank or clarifier. They concentrate dredged material slurries of any grain size, at nearly any flow rate, and produce a solids concentration ranging from about 2 to 15 percent. Thickened material is then further dewatered using other methods to reduce the hydraulic load on other process stages. Gravity thickening is not cost effective when the solids concentration exceeds 6 percent. Therefore, gravity thickeners have very limited potential application to contaminated sediments, only in rare cases when solids content is very low in hydraulic dredging operation.

Particle Classification

Particle classification separates sediment particles based on one or more physical properties, such as differences in size, density, mass, magnetic characteristics, etc. Particle classification technologies include sieves and screens, hydraulic and spiral classifiers, cyclones, settling basins, and clarifiers. Particle classification separates sediments according to grain size or removes oversize material that is incompatible with subsequent processes. Classification by grain size is important in managing contaminated dredged material when contaminants adsorb onto or are held in fine-grained sediment such as clay and organic matter. The small grain solids of a specific size or less can be treated while the relatively non-contaminated, coarser sediments can be disposed of with minimal or no additional treatment.

> **Grizzlies** are vibrating or fixed separation units, reliable for the removal of oversized material. They improve the reliability and efficiency of subsequent solids separation technologies and reduce maintenance costs of downstream equipment.
>
> **Moving screens** provide large capacity throughput and high efficiency. They can be arranged to permit progressively finer separation with less area requirements. Vibrating screens separate particles from 1/8 to 6 in. dia. High speed models range from 4 to 325 mesh. These screening techniques are best suited to dry materials; modifications to handle wet materials are costly.
>
> **Stationary screens** differ from moving screens in that they have no moving parts. One stationary screen that has potential application to solids separation at hazardous waste sites is the wedge-bar screen. They operate easily with little maintenance, and require only a small operating area. Wedge-bar screens are less efficient than the moving screen since the oversized materials that are discharged contain a considerable amount of fines. They may be operated preceding the moving screen to provide more efficient solid separation than either process alone.
>
> **Hydraulic classifiers** remove and classify sand and gravel from slurries. They can remove and classify solids ranging in size from 3/8 in. to 105 micron (150 mesh) to 74 micron (200 mesh). They are not suited for removal of particles larger than 1.0 in., or smaller than 74 micron. Their solids-handling capabilities are generally limited to 250 to 300 t/hr.

> **Spiral classifiers** use rotating screws mounted in an inclined vessel to wash, dewater, and classify sand and gravel up to 3/8 in. dia. Maintenance requirements are minimal, and operation is easy to learn.
>
> **Hydrocyclones** are widely used to separate solids from water, especially in situations with limited space. They remove particles in the 10 to 2000 micron range. In general, hydrocyclones do not effectively separate slurries with a solids concentration greater than 30 percent.
>
> **Conventional clarifiers** are used in domestic sewage and industrial wastewater treatment. They can remove particles down to 10 to 20 micron with the use of flocculants, and produce sludge with a solids content of 4 to 12 percent. They are best suited for small to moderate scale cleanup operations. They cannot remove solids with a diameter less than 10 micron. Clarifiers are not suitable for locations with space limitations.

A good compendium of screening techniques is given in *Handbook: Responding to Discharges of Sinking Hazardous Substances* (U.S. EPA, 1987b).

REMEDIAL OPTIONS COMMONLY APPLIED TO SEDIMENT

No remedial alternative can remove, contain, or treat contaminated sediment without some disturbance and consequent release of contaminants. Disturbing sediment causes resuspension of contaminants in the water column. The remedial option must minimize the contaminant release.

The conventional sediment handling methods are removal and disposal. This option is desirable: when it will not result in adverse environmental effects; when conditions such as currents, wave action, etc. make in-place treatment or capping ineffective; or when removal is necessary for other purposes. If the sediment presents environmental problems, it can be contained (e.g. capped in place), left in place, treated *in situ*, dredged and treated, placed in a CDF, or some combination of these technologies. An excellent discussion of contaminant control and treatment using these techniques is given in *Review of Removal, Containment, and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett, Daniel E.; Perry, Bret D.; Torrey, Elizabeth J.; and Miller, Jan A., 1990), Miscellaneous Paper EL-90-24, U.S. Army Engineer Waterways Experiment

Station, Vicksburg, Mississippi. A companion document stressing management strategies and conventional methods of dredged material disposal is given in *Management Strategy for Disposal of Dredged Material: Contaminant Testing and Controls* (USACE, 1985).

No Action

No action consists of leaving the contaminated sediment in place with the hope that natural sedimentation will bury or contain pollutants. The no-action option is appropriate when the pollutant discharge source has been halted, burial or dilution processes are rapid, sediment will not be remobilized by human or natural activities, and environmental effects of cleanup are more damaging than allowing the sediment to remain in place. This option relies on natural processes such as the input of uncontaminated sediments from the drainage basin and their integration with in-place contaminated material through dispersion, mixing, burial, and biological degradation. The greatest advantages of the no action option are low cost and the low risk of contaminant spread. A monitoring program should be established to insure that the rates of contaminant release and the area of influence of the contaminants are not accelerating. Some guidance on the no-action option is presented graphically in Figure 3-3.

Subaqueous Capping

Current interest has focused on subaqueous containment, called contained aquatic disposal (CAD), which uses underwater capping (covering) of contaminated sediments with cleaner, less contaminated sediments with or without lateral walls. Although it is technically feasible to cap contaminated sediments in-place, at their original location, conflicting uses such as navigation may dictate that contaminated sediments be moved from their original site of deposition. Capping is appropriate if:

- The no action alternative does not provide sufficient protection.
- Point source discharges have been halted.
- The costs and environmental effects of moving/treating contaminated sediment are too great.
- Suitable capping materials are available.
- Hydrologic conditions will not disturb the site.
- Bottom will support the cap.
- The area is amenable to dredging.

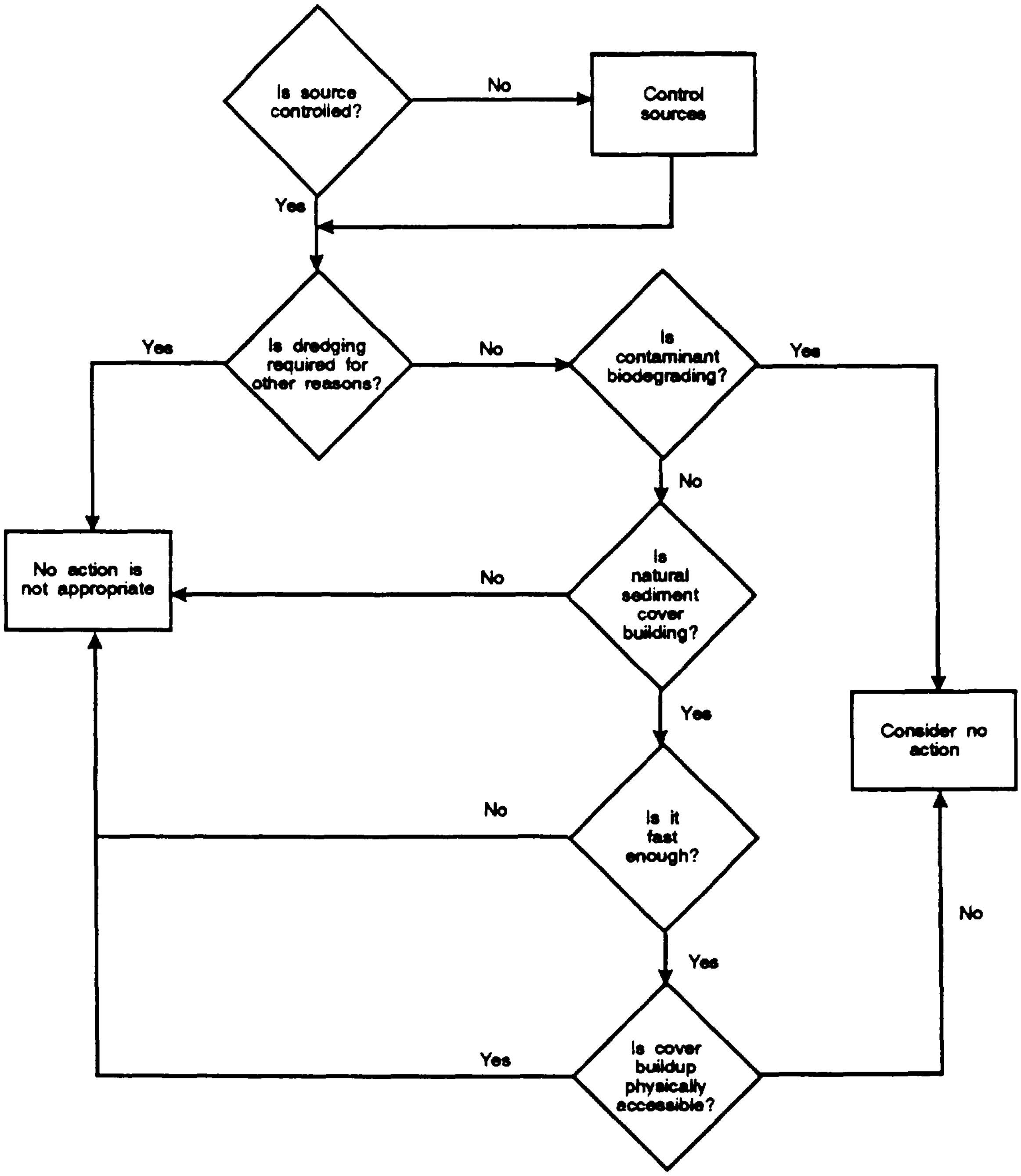

Figure 3-3. Flow Chart for Screening No Action

If dredging is necessary it may be possible simply to deposit sediments in the bottom of a natural depression or to dig a hole in the bottom and place the sediment in it. The preferred deposition methods are by hydraulic pipeline with or without a submerged diffuser, direct placement with a clamshell, or release from a bottom-dump scow. The success of capping operations is dependent on the following:

Selecting the dredge equipment - Subaquatic placement is controlled through careful selection and operation of the dredging equipment. Although either mechanical or hydraulic methods may be used to dredge and place contaminated sediments into the underwater hole, each case should be evaluated based on sediment and capping material characteristics and disposal site considerations. While mechanical dredging and placement can result in the deposition of a highly consolidated mass of materials, there is a certain amount of sediment resuspension into the overlying water column as the materials fall through the water column. Hydraulic pipelines which are outfitted with diffuser discharge heads provide minimum discharge velocities, and, therefore, rapid settling of the discharge solids and their associated contaminants.

Transportation of the contaminated material to the disposal site - It is advantageous to avoid multiple sediment handling steps. If possible, the sediment should be transported in the same device from which it will be discharged.

Choice of the disposal and capping site - The effects of the water body at the site (such as currents, water depth, bottom contours, etc.) can affect the placement accuracy and the integrity of the mound. Bed slope (e.g., slope sloughing) needs to be considered to prevent site failure and contaminant release. There is a tendency for sediments to flow because of the momentum generated during placement and slope impacts. Basic current information should be collected at disposal sites to identify site-specific conditions. However, based on observations at several sites, Bokuniewicz, et al., (1978), concluded that the principal influence of currents in the receiving water is to displace the point of impact of the descending jet of material away from the bottom by a calculated amount. They stated that even strong currents observed at a Great Lakes site need not be a serious impediment to accurate placement, nor do they result in significantly greater dispersion during placement. Long-term effects of currents at the site may still need to be investigated, and little information is available on the transport of sediment from disposal mounds. Water velocity which results from wind-driven currents decreases with depth. High velocity currents are theoretically sufficient to transport discrete particles as large as 10 mm in diameter, but discrete particle movement is frequently masked by the effects of cohesive forces among particles. Aside from the effect of **water depth** on currents, there appears to be little additional short-term influence on disposal. The initial thickness of the spreading surge above the bottom has been shown to be a function of water depth.

Selection of capping material - Compatibility of the capping material with the sediment, its thickness and integrity, and its capability to fall quickly and directly over the material to be capped, all affect the efficiency of the procedure.

Placement techniques for the contaminated material and cap - The accuracy of placement is directly dependent on the techniques used for placement. If the material is bottom dropped from a scow, the sediment could resuspend and travel in the water column, affecting the efficiency of the capping operation. Site conditions might require more direct placement, such as with a submerged diffuser, which allows for careful placement of hydraulically dredged material while limiting water column impacts.

Effectiveness of monitoring methods - Monitoring the cap is essential to ensure that its integrity has not been compromised by water body and other effects.

A sufficient number of completed capping projects have proven that the concept is technically and operationally feasible. Table 3-6 describes some features of capping projects reported in the literature. Note that 70 feet deep sites were most often chosen; clamshell dredges were selected for dredging, and scows used for placement. Thickness of the caps ranged from 1 to 13 feet. However, the remedial manager must evaluate the capping site, dredge, placement method, and cap thickness based on the characteristics of the specific site and dredged material. Figure 3-4 presents a flow chart for screening CAD.

Confined Disposal Facility (CDF): Upland, near-shore, and in-water

CDFs are engineered structures designed to retain dredged material. The Corps of Engineers use CDFs to hold about 30% of the dredged material produced by the navigation program (USEPA, 1989g). They can be constructed entirely away from the water, partially in water near the shore, or completely surrounded by water. Costs for disposing dredged material in CDFs in the United States

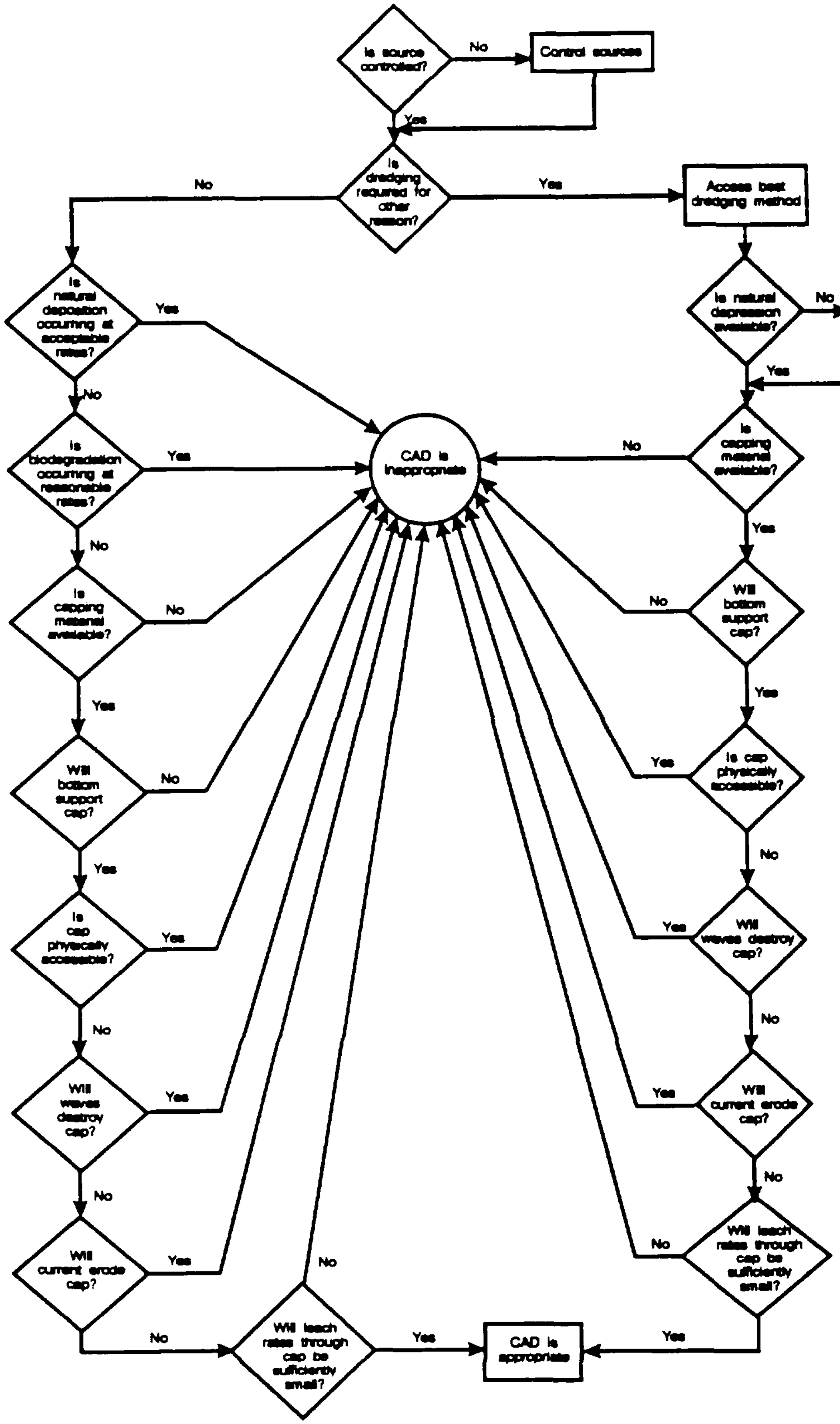

Figure 3-4. Flow Chart for Screening CAD.

range from $5.00 to $20.00/cu yd. A thorough discussion of CDF siting considerations, construction techniques, and costs is given in *Standards for Confined Disposal of Contaminated Sediments* (Parametrix - undated) and *Confined Disposal of Dredged Material* (USACE, 1987a).

The primary goal of CDF design is containment and solids retention. 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. The walls for a diked disposal area can be made from most types of soil materials (USACE, 1987a). In the Great Lakes, the dikes that form the CDF walls are usually made of limestone covered by boulder-size stones to protect the core of the dike from waves. Inside the dikes the typical CDF has a large cell for disposal of material, and adjoining cells for retention and decantation of turbid, supernatant water. As with any structure in water, near shore and in water CDFs are subject to movement from wind and waves. CDFs are almost always constructed as permeable dikes -- not as sealed, impermeable landfills. Water loss is therefore inherent in the structure. Some facilities have tried fabric and plastic liners to prevent seepage through the dike walls, with little success. Sand, soil, or sediment linings can reduce permeability, and sediment particle migration into the dike interstices can also act as a seal. Clay or bentonite-cement slurries are the most effective seal. Caps are the most effective way to minimize contaminant loss from CDFs through contaminant volatilization and plant and animal uptake.

Upland disposal sites are located away from the water body and outside the influence of tidal fluctuations. They usually require overland transport of the dredged material. The primary opportunities for contaminant loss occur during dredging, during transport and rehandling, and during containment by migration through the media. Upland sites allow sediment to settle and compact in a natural dewatering process.

Near-shore disposal facilities are located at sea level and within the area water body influence. Sediment may lie above or below the water table. Near-shore sites usually receive dredged sediment transported directly from a nearby site. Sediment can be deposited to a depth that promotes long-term anaerobic conditions. Contaminants migrate principally through the confinement media, groundwater, tidal movements, and surface runoff. Near-shore disposal sites have several advantages such as smaller transport distances, reduced water-column contamination during emplacement, accurate emplacement, and easier monitoring.

Siting CDFs is becoming more difficult because of the lack of suitable space in the midst of major ports and harbors, problems in acquiring permits, transportation expenses, the potential for contaminant migration into groundwater and surface drainage of contaminated water, and plant and animal uptake of contaminants.

CDFs offer an attractive, cost effective method of dredged material disposal. If properly located and constructed, they can isolate contaminated sediment from the environment fairly well. Some treatments can be effected in the CDF, such as biodegradation.

TABLE 3-6. DESCRIPTIONS OF CAPPED DISPOSAL PROJECTS

Project**		Contaminated material			Capping material			
Location (date)	**Site characteristics**	**Volume of material yd^{3*}**	**Dredging method**	**Placement method**	**Volume, yd^{3*} (type)**	**Thickness of cap, ft**	**Placement method**	**Positioning method**
Duwamish Waterway Seattle, WA (1984)	Existing subaqueous depression ~70 ft deep	1,100	Clamshell	Scow	3,600 (sand)	1-3	Sprinkling from scow	Surveying instruments
Rotterdam Harbor, The Netherlands (1981-1983)	Phase I: Botlek Harbor Excavated to ~98 ft deep	1,200,000	Trailing suction hopper	Pumpout-submerged diffuser	-- (clay)	2-3	Scow, then leveled over site	Surveying instruments
	Phase II: 1st Petroleum Harbor Excavated to ~80 ft deep	620,000	Matchbox suction	Pipeline submerged diffuser	-- (clay)	2-3	Scow, then leveled over site	Automated dredge and suction head positioning equipment
Hiroshima Bay, Japan (1979-1980)	Contaminated bottom sediment overlaid in situ with capping material ~70 ft deep	N/A	N/A	N/A	-- (sand w/shell)	1.6	Conveyor to gravity-fed submerged tremie; suction/pumpout thru submerged spreader bar	Surveyed grid and winch/anchor wires
New York Bight (1980)	Generally flat bottom ~80-90 ft deep	860,000 (mounded to 6 ft thick)	Clamshell	Scows	1,800,000 (majority fine sand)	Average 3-4 Maximum 5-9	Scow, hopper dredge	Buoy, real-time navigation electronics
Central Long Island Sound Disposal Area (1979)	Stamford-New Haven, North Generally flat bottom ~65 ft deep	34,000 (mounded 3-6 ft thick)	Clamshell	Scows	65,400 (sand)	Up to 7-10	Hopper dredge	Buoy, Loran-C coupled positioning system

TABLE 3-6. (continued)

Project**		Contaminated material			Capping material			
Location (date)	**Site characteristics**	**Volume of material yd^{3*}**	**Dredging method**	**Placement method**	**Volume, yd^{3*} (type)**	**Thickness of cap, ft**	**Placement method**	**Positioning method**
Central Long Island Sound Disposal Area (1979)	Stamford-New Haven, South Generally flat bottom ~70 ft deep	50,000 (mounded 4-6 ft thick)	Clamshell	Scows	100,000 (cohesive silt)	Up to 13	Scow	Buoy, Loran-C coupled positioning system
Central Long Island Sound Disposal Area (continued) (1981)	Norwalk Generally flat bottom ~65 ft deep	92,000 (multiple mounds up to 8-12 ft thick)	Clamshell	Scows	370,000 (silt and sand)	Up to 6-7	Scow	Buoy
(1982-1983)	Mill-Quinnipiac Generally flat bottom ~65 ft deep	40,000	Clamshell	Scows	1,300,000 (silt)	Multiple broad area placement. Estimated final average 6-10.	Scow	Buoy
(1983)	Cap Site No. 1 Generally flat 60 ft deep	33,000 (mounded 3 ft thick)	Clamshell	Scows	78,000 (silt)	Incomplete coverage	Scow	Buoy, Loran-C
(1983)	Cap Site No. 2 Generally flat ~56 ft deep	40,000 (low mound, 2 ft thick)	Clamshell	Scows	40,000 (sand)	Irregular - maximum 4.5, areas as little as 0.6	Scow	Buoy, Loran-C

* All volumes are approximate, usually based on estimate in-scow measurements. Dash entries indicate volume of capping either unknown or not required.

** Data sources are found in the primary document (USACE, 1987).

Source: USACE, 1987b.

TREATMENTS POTENTIALLY APPLICABLE TO SEDIMENT

Several remedial options have the potential to treat contaminated sediments, but have limited supporting field data. The options selected for discussion in this guide are as follows:

- *In situ* treatment
- Biological treatment
- Dechlorination
- Soil washing
- Solvent extraction
- Solidification/stabilization treatment
- Incineration
- Thermal desorption

The remedial options discussed in this guide are presented in terms of the process description, applicability and limitations, performance data, and costs. Many of these process options are not stand-alone processes, but may be components of a system that involves multiple treatment steps to address multiple contaminant problems. The type of remedial actions selected for 103 CERCLA sites are shown in Table 3-7, and are summarized in Appendix C.

In Situ Treatments

In situ sediment treatments include capping, solidification/stabilization, biological treatment, chemical treatment methods, and ground freezing. Capping, as discussed earlier in this section, has been the focus of considerable research in recent years. The major advantage of *in situ* treatment is that these methods eliminate the need to remove contaminated sediments. *In situ* treatment methods are most effective to low flow streams where the flow can be diverted while the treatment takes place. The primary disadvantages of chemical and biological treatment methods are the possibility for secondary contamination and the difficulty of ensuring complete mixing of the treatment reagents with the contaminated sediments. Ground freezing can be used to isolate and remove contaminated sediments. The high cost of implementing it will greatly limit the use of this method.

TABLE 3-7. REMEDIATION TECHNOLOGIES FOR CONTAMINATED SEDIMENT

Remediation technology	Number of sediment CERCLA sites selecting the technology
Biological treatment	
Biodegradation	7
Landfarming	1
Physical/chemical treatment	
KPEG dechlorination	2
Solvent extraction	2
Soil washing	6
Solidification/stabilization	19
Thermal treatment	
Incineration	26
Thermal desorption	3
Vitrification	1
Containment	
Off-site disposal	14
On-site disposal	18
On-site storage	2
No action	11

Solidification/Stabilization--

In situ solidification/stabilization treatments immobilize sediment and contaminants by treating them with reagents to solidify or fix them. These fixatives neutralize or bind the pollutants to reduce contaminant mobility, usually via leaching. Another method covers sediment with barriers or sorbents to reduce transfer of the pollutants to water and biota.

Several problems associated with *in situ* solidification/stabilization are inaccuracies in reagent placement, erosion, long-term monitoring requirements, the inability of the procedure to remove/detoxify contaminants, and the difficulty in adjusting solidification mixtures/agents for subaqueous settings. Little is known about the costs of large-scale treatments, their effectiveness, or their possible toxic by-products. This technique has not yet been proven or accepted for treatment of contaminated sediment. It would not be feasible in any area where the solidified mass cannot be tolerated (e.g., future construction or dredging).

Biological Treatment--

Biological treatment can effectively treat a wide range of organic contaminants, but it does not clean up inorganics. Partial degradation products (for example, degradation of trichloroethene, resulting in the formation of vinyl chloride) may be more soluble or toxic than the original contaminants making these limited in application. The degradation process can be impeded by high organic concentrations, oxygen deficiency, lack of nutrients, and low temperature. An excellent discussion of biological degradation can be found in *Sediments: Chemistry and Toxicity of In-Place Pollutants* (Baudo et al., 1990) and *Biological Remediation of Contaminated Sediments with Special Emphasis on the Great Lakes* (Jafvert, et al., 1991).

Aerobic biological treatment has effectively treated soils contaminated with organic materials. The aerobic organisms require oxygen and nutrients to survive. Nitrogen and phosphorous are the most common nutrient sources. Other possible nutrients include iron, trace metals, magnesium, potassium, calcium, sodium, sulfur, and manganese. Aerobic biodegradation requires that the sediment have a continuous supply of oxygen. Hence, this is not feasible for bottom sediments in areas where organic concentrations and oxygen demands are high.

Anaerobic biological treatment uses organisms that survive in an oxygen-deficient environment. The primary mechanism in anaerobic degradation of halogenated organics is removal of chlorine atoms by reductive dehalogenation. A redox potential of -250 mv or less, presence of nitrates and sulfates but the absence of oxygen, are required. Most *in situ* sediment is anaerobic; it can degrade contaminants under ambient conditions (USEPA, 1989f). Anaerobic degradation is slower than aerobic, and applies to fewer compounds.

Some compounds, such as PCBs, can be most effectively treated in a system that provides both aerobic and anaerobic conditions. Fortunately, nature provides both processes -- often in close juxtaposition.

Chemical Treatment--

In situ chemical treatment is an area of emerging new technologies. The *in situ* methods that are most applicable to treating contaminated sediments include neutralization, precipitation, oxidation, and chemical dechlorination. Several potential problems are associated with the use of these chemical methods. Table 3-8 summarizes the problems specific to each of these treatment methods. All *in situ* chemical methods have the potential for secondary impacts, whether it be as a direct result of toxic treatment reagents or as a result of potentially toxic degradation products. Consequently, *in situ* treatment is limited to situations where the contaminated area can be contained during treatment or where stream flow can be diverted for the duration of treatment. Another problem with all *in situ* methods is the problem of ensuring that the treatment reagents are completely mixed with the contaminated material. Because of the above-mentioned problems, chemical treatment without stream diversion have limited application.

Ground Freezing--

Ground freezing has been successfully used for years in construction of dams and tunnels in order to cut off water and support loads. It has recently come into consideration as a potential technique for containing and facilitating the removal of contaminants in sediments. The process involves placing refrigeration probes in the sediments at close intervals and cooling them from a portable refrigeration unit. Ice crystals grow until they coalesce and form a wall of frozen sediment. The process is extremely slow because each probe can freeze only a small zone about 1.5 feet in diameter. This method is also costly because of high energy requirements. These limitations would preclude the use of ground freezing for large volumes of contaminated sediments (USEPA, 1985a).

TABLE 3-8. SUMMARY OF IN SITU CHEMICAL TREATMENT

Treatment method	Waste types amenable	Treatment reagents	Potential problems
Neutralization	Acids and bases	• Weak acids and bases • To neutralize acids: calcium carbonate, sodium carbonate, or sodium bicarbonate; limestone or greenstone may be applied as active cover material.	• Toxicity to pH-sensitive benthos if not properly placed on the spill • Use of ferric sulfate under aerobic conditions may result in the formation of hydrous iron oxides which can scavenge heavy metals from water and may coat the gills of bottom feeders.
Precipitation	Inorganic cations and anions	• Sulfide precipitation is most promising since metal sulfides are the least soluble metal compounds likely to form over a broad pH range. Calcium sulfide, iron sulfide, or sodium sulfide may be used.	• Potential for formation of H_2S gas; likelihood increase as the reactivity of sulfide and metals decrease. • Effective only under reduced conditions, oxidation to more soluble sulfide species could occur under aerobic conditions.
Oxidation	Wide range of organics; highly chlorinated compounds and nitro-aromatics are not well suited	• Oxygen and/or ozone and hydrogen peroxide.	• Oxidation can result in more mobile degradation products. • Both ozone and hydrogen peroxide may react with organics in the water column or sediments which are not target compounds, thereby reducing effectiveness. • Compounds which are sorbed to sediments may be difficult to oxidize. • Ozone will decompose back to oxygen rapidly in the presence of organics; stability of hydrogen peroxide is not well known.
Chemical dechlorination	Highly chlorinated organics (e.g., PCB, dioxins)	Polyethylene glycol and potassium hydroxide	• Treatment system can tolerate some water but limits have not been established. • Degradation is temperature dependent and may proceed slowly at ambient temperatures.

Source: USEPA, 1985.

EX SITU TREATMENT

Biological Treatment

Process Description--Biological treatment is the bio-oxidation of organic matter by microorganisms. This technology uses bacteria, fungi, or enzymes to break down PCBs, pesticides, and other organic constituents into less toxic or innocuous compounds. Slurry-phase and solid-phase treatments are effective on soils, sludges, and sediment. Biological processes can generate residue streams that may require additional treatment (e.g., wastewater and air emissions). Products of biodegradation may be more soluble and toxic than the original materials.

Slurry Phase Biological Treatment--

Process Description--The term "slurry phase treatment" describes the biological treatment of contaminated soil or sludge in a large, mobile bioreactor. While the system maintains intimate mixing and contact of microorganisms with the hazardous compounds, it also creates the environmental conditions required for optimal microbial degradation. Slurry phase treatment has the potential to treat a wide range of contaminants such as pesticides, fuels, creosote, PCP, PCBs, and some halogenated volatile organics. However, the presence of heavy metals can inhibit microbial metabolism. Soil washing and metal extraction, using weak acids and chelating agents, can be combined with biological treatment by coupling two separate slurry-phase reactors in series.

A typical soil slurry feedstock contains about 50 percent solids by weight. The slurry is mechanically agitated in a reactor vessel to keep the solids suspended and to maintain the appropriate environmental conditions. Nutrients, oxygen, and acid or alkali are added to maintain optimum conditions. The toxicity of heavy metals and chlorides may inhibit microbial metabolism.

Applicability and Limitations--Slurry phase reactors operate from 59° to 167°F. Control of the activity of organisms responsible for contaminant destruction is resolved by maintaining adequate moisture (40-80%) pH in the range of 4.5 to 8.5, the dissolved oxygen content at near saturation with air (approximately 8 mg/L), and nutrients (C:N:P = 100:10:1 to 100:1:0.5) (Table 3-9). Microorganisms, added initially to seed the bioreactor, may be supplemented continuously to maintain the correct biomass concentration. The residence time in the bioreactor varies with the soil or sludge matrix, the physical and chemical nature of the contaminant, and the biodegradability of the

TABLE 3-9. FACTORS AFFECTING SLURRY-PHASE BIOLOGICAL TREATMENT

Factor	Effect	Typical range
Contaminant solubility	Low solubility components more difficult to biodegrade	--
Heavy metals, highly chlorinated organics, some pesticides, inorganic salts	Can be toxic to microorganisms	--
Moisture content	A moisture content of greater than 80% affects bacterial activity and availability of oxygen. A moisture content below 40% severely inhibits bacterial activity.	40-80%
Nutrients	Affects activity if lacking nutrients (C-N-P)	C:N:P 100:10:1-100:1:0.5
Oxygen	Lack of oxygen is rate limiting.	~8 mg/L
Particle size	If nonuniform, can affect contact with microorganisms	--
pH	Inhibits biological activity outside range.	4.5-8.5
Temperature	Larger, more diverse microbial population present in this range.	59°-167°F
Variable waste composition	Inconsistent biodegradation caused by variation in biological activity.	--
Microbial population	Insufficient population results in low biodegradation rates.	--

contaminants and typically range from hours to days. Once the contaminants have biodegraded, the treated slurry is dewatered. The residual water may require further treatment before disposal.

Performance Data--Several firms market slurry-phase biological treatment systems. The **MoTec** technology has treated pentachlorophenol and creosote wastes, oil field and refinery sludges, and pesticide wastewaters. **Ecova** applied its full-scale slurry-phase bioremediation to soil containing pesticides and diesel fuel, and its pilot-scale system to soil contaminated with PAHs (USEPA, 1988b). ECOVA's application to treat PCP-contaminated wastes has resulted in a 99 percent reduction in PCP concentrations over a period of 24 days. **Biotrol** conducted treatability studies on soils contaminated with oil, pentachlorophenol, and creosote from wood preserving sites (Arkwood, Inc., AR, Coleman Evans Site, FL, and MacGillis and Gibbs Site, MN) (USEPA, 1989h). At Arkwood, Inc., Arkansas, after 98 days of treatment, the PCP and PAHs were not detected in TCLP leachate from biologically treated solids (ERM, 1990). **Detox Industries, Inc.** applied its pilot-scale treatment to PCBs. Approximately 0.75 tons of sludge containing 2,000 ppm PCBs were reduced within four months, to below 4 ppm -- a 99.8 percent removal (USEPA, 1989e). **Remediation Technologies, Inc.'s (ReTec)** full-scale slurry biodegradation system was used to treat wood preserving sludges at a site in Tennessee. The system achieved greater than 99 percent removal efficiency for PCP and PAHs (USEPA, 1990c).

Cost--Cost for slurry-phase treatment ranges from $80 to $150 per cu yd (USEPA, 1989e).

Solid-Phase Biological Treatment--

Process Description--This above-grade process treats soils using conventional soil management practices to enhance the microbial degradation of contaminants. The system uses a treatment bed lined with cleanup sand over a high-density liner. A drainage system collects water. Contaminated material is distributed over the prepared bed. Nutrients such as nitrogen and phosphorous are added, and the soil tilled 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.

Solid-phase treatment is one of the oldest and most widely used technologies for hazardous waste treatment. Its success has been demonstrated throughout the United States, especially at petroleum refinery sites treated under RCRA, and at wood preserver sites with creosote-contaminated sludges and soils (Torpy, 1989).

__Applicability and Limitations__--This technology can treat soils, sludges, and sediments contaminated with pesticides, fuels, creosote, PCP, PCBs, some halogenated volatile organics, non-halogenated organics such as gasoline, aliphatics, aromatics, chlorinated aromatic organic compounds.

Process residuals for most biological treatment systems include the treated solids, process water, which may be treated in a conventional water treatment system, and possible air emissions.

__Performance Data__--Theoretically, biological organisms will digest organics until no food source (contaminant) is left. However, efficiencies depend on the presence of appropriate microorganisms, adequate concentrations of essential nutrients, contaminant effects on microbial population activity, etc.

Ecova has used solid-phase biodegradation at full-scale to treat soil containing PCP and PAHs at a wood preserver site (Josyln Manufacturing and Supply Co., Redmond, WA).

__Cost__--Cost for the solid-phase treatment ranges from $50 to $80 per cu yd (Torpy, 1989).

__Dechlorination__

__Process Description__--The KPEG dechlorination process is potentially effective in detoxifying specific types of aromatic organic contaminants, particularly dioxins and PCBs. The process heats and mixes contaminated soils, sludges, or liquids with an alkali metal-hydroxide-based polyethylene glycol reagent in a batch reactor. Figure 3-5 presents a schematic flow diagram of a typical KPEG process.

The mixture of contaminated medium and reagent forms a homogeneous slurry. The reagent contains potassium or sodium hydroxide (KOH or NaOH) and polyethylene glycol (PEG). The addition of other reagents, such as dimethyl sulfoxide (DMSO) or sulfolane (SFLN) may improve the efficiency of the process. When simultaneously heated to between 212°F to 302°F and mixed, the slurry's halogenated contaminants decompose into less toxic glycol-ethers and water-soluble chloride compounds. Residence time in the reactor ranges from 0.5 to 2 hours -- depending on the contaminant type, its initial concentration, water content, humic and clay content, and the required removal efficiency. Water is vaporized in the reactor and collected in a condenser. Additional treatment of sediment may be required to desorb both reaction by-products and reagent. This treatment churns the dehalogenated sediment and water in successive washing cycles. The residual wastewater may

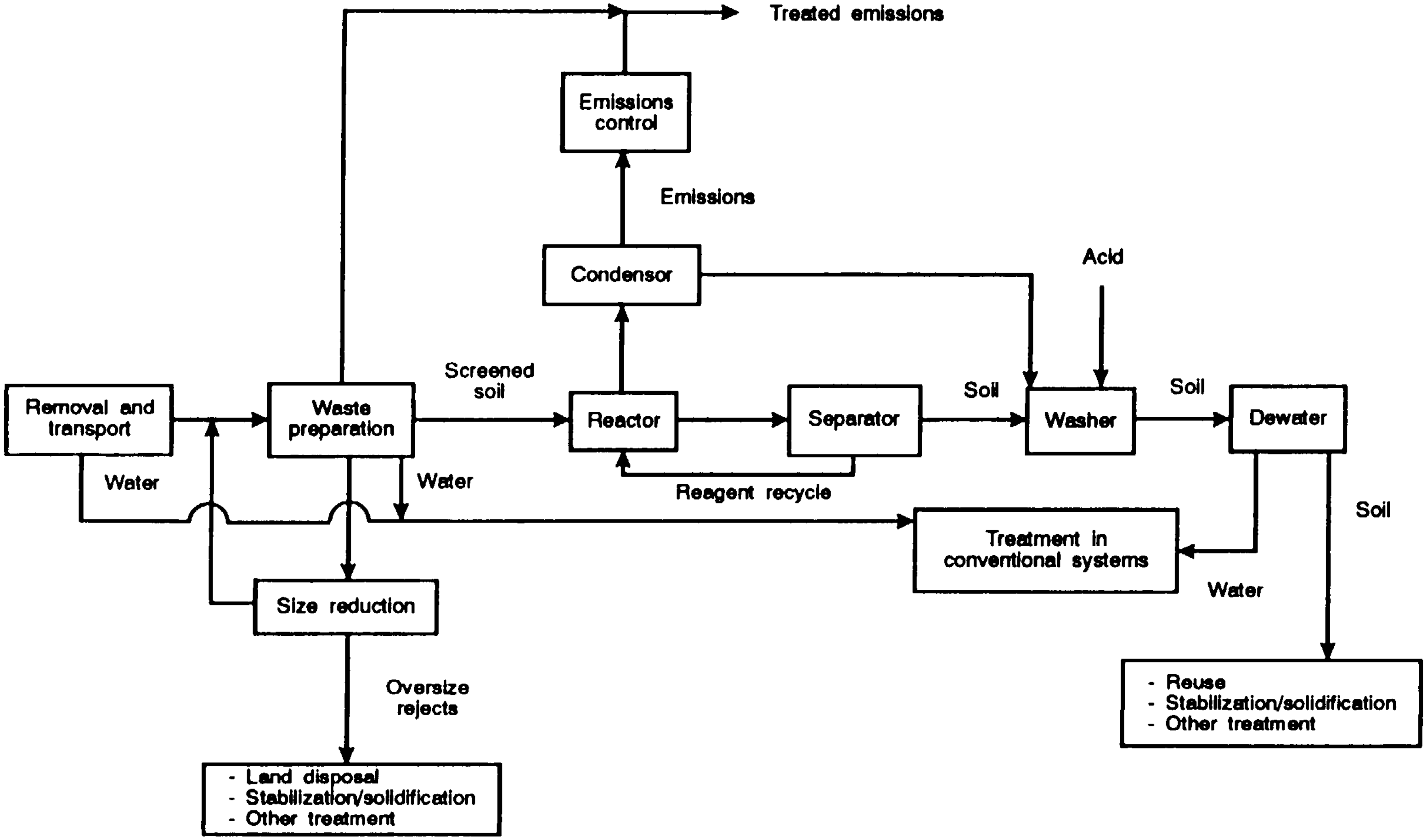

Figure 3-5. Dechlorination process.

Source: Adapted from McCoy and Associates, 1989.

require treatment before disposal. Further post-dechlorination options include biodegradation, precipitation, or incineration (USEPA, 1989c).

In considering development of a treatment system, the remedial manager can refer to Figure 3-3 to determine the system components needed to pre-treat, treat, and post-treat the sediment. In combination with the factors affecting the technology's performance (Table 3-10), an overall conceptual treatment system can be developed. For the dechlorination process, the following steps might apply:

- Removal and transport. This step can generate a water stream that can be combined with the process water residue for further treatment.

- Waste preparation can include screening to remove oversize debris, particle size separation, dewatering, and pH adjustment. At this point, the remedial manager may consider pre-treatment to remove metals. This is a case where another technology such as soil washing may be used as a pretreatment step. Each of the pretreatment steps generates additional residue streams that should be combined with other process streams for final treatment and disposal.

- The principal treatment includes mixing, reacting, separating, washing, and dewatering the sediment to remove the contaminant. The air emissions generated during treatment can be captured and treated. The treated soil can be reused if it is clean, or if contaminated it may be solidified or treated further before land disposal. Water can usually be treated in a conventional treatment system, and oversize materials can be disposed or solidified for disposal.

<u>Applicability and Limitations</u>--Dechlorination techniques are primarily used to treat and destroy halogenated aromatic compounds such as dioxins, PCBs, and chlorobenzenes. If additional contaminants are present, other options should be considered.

The reaction time needed in the dechlorination process depends on contaminant type and initial concentrations, water content, humic/clay content, and the presence of other reactive materials. It is retarded by the presence of aliphatic organics and inorganics such as metals. It cannot process highly concentrated contaminants. A water content less than 20 percent, a pH above 2, and chlorinated organics concentrations <5 percent facilitate the process.

TABLE 3-10. FACTORS AFFECTING DECHLORINATION PERFORMANCE

Factor	Effect	Range
Aliphatic organics, inorganics, metals	Proves most effective with aromatic halides (PCB, dioxins, chlorophenols, chlorobenzenes)	--
Aluminum and other alkaline reactive metals	Requires increased use of reagent; can produce H_2 gas	--
Chlorinated organics	Requires use of excessive reagent	<5%
Clay and sandy soils	Increases reaction time	--
Humic content	Increases reaction time	--
Moisture content	Uses excessive reagent with higher water content	<20%
pH	Process not effective when pH <2; pretreat to raise pH	>2

Source: USEPA, 1988b.

TABLE 3-11. DECHLORINATION SYSTEMS

Vendor/Site	Technology description
Galson Remediation Corporation (GRC)	Successful full-scale glycolate dehalogenation at two PCB-contaminated waste oil sites.
	Full-scale reactor batch capacity: 80 cu yd. Designed to treat 160-200 cu yd/day.
	Treatment costs: $200 to $500/cu yd. Actual costs contingent upon site-specific characteristics (USEPA, 1990h).
P.W.C. Guam	Mobile glycolate dehalogenation unit field tested on soils contaminated with Aroclor 1260 (concentrations from 300 ppm to 2,200 ppm treated to levels below 2 ppm within 5 hours).

Performance Data--With efficiencies greater than 98 percent reported, PCB removal to less than 1 ppm has been routinely achieved. Several factors limit the effectiveness of KPEG chemical dechlorination: highly concentrated contaminants (greater than 5%), high water content, low pH, high humic content, and the presence of other alkaline-reactive materials such as aluminum. Treatability tests will determine the effectiveness of the KPEG process for specific site conditions. Factors affecting performance are listed in Table 3-10. Two applications of the dechlorination process are shown in Table 3-11.

Cost--Costs for the dechlorination technology range from $200 to $500/cu yd (USEPA, 1990h).

Extraction Technologies

Solvent Extraction--

Process Description--Solvent extraction does not destroy wastes. It separates the hazardous contaminants from soil, sludge, and sediment, thereby reducing the volume of the hazardous waste that must be treated. This volume reduction technique leaches contaminants from the sediment with organic solvents. Figure 3-6 shows a schematic diagram of a typical solvent extraction process. This process has been effective in treating semivolatile organic compounds (SVOCs) such as PCBs, volatile organic compounds (VOCs), halogenated solvents, and petroleum wastes. It is not generally effective for inorganic contaminants. It is often selected as a pre-treatment technique for use with other processes. Solvent extraction uses organic chemicals as solvents, and therefore differs from soil washing, which uses water or water with additives. Suitable solvents include kerosene, hexane, methanol, ethanol, isopropanol, furfural, dimethyl formamide, dimethyl sulfoxide, ethylene diamine, and freon and supercritical fluids, such as carbon dioxide, propane, and butane. Success in extracting organic pollutants depends strongly on the nature of the solvent. Treatability tests can determine which solvent, or combination of solvents, is best suited for the site-specific contaminants. Most processes require multiple extraction cycles to achieve high removal efficiencies. A key advantage of an extraction process is the recovery and reuse of the solvent. Its toxicity must also be considered.

Solvent extraction generates three main product streams: concentrated contaminants, separated solvent/water, and treated sediment. The extract retains a smaller volume of concentrated solvent-free contaminants for post-treatment. Depending on the presence of metals or other inorganic contaminants additional treatment of the sediment by another technique may be necessary. The

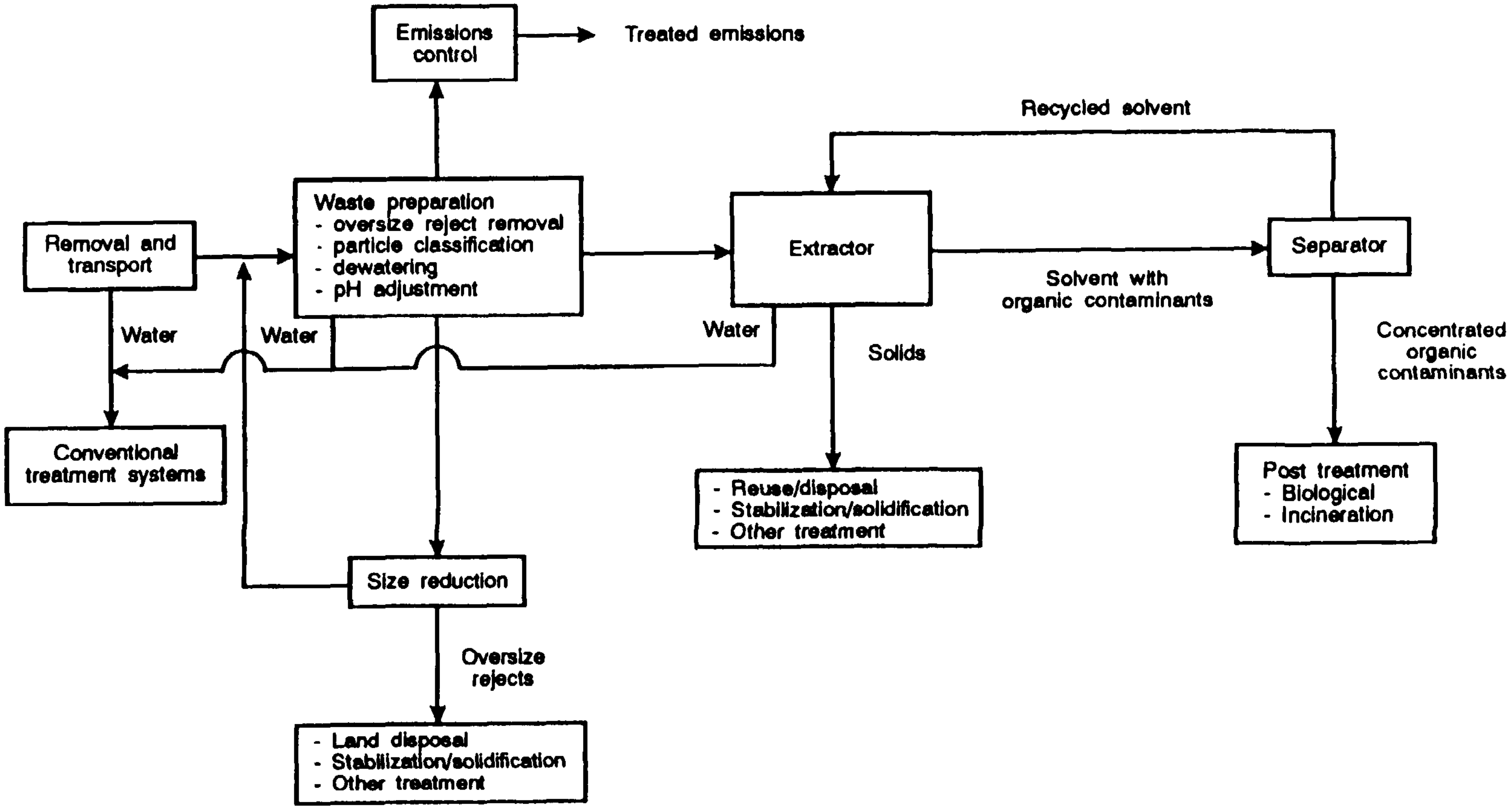

Figure 3-6. Solvent extraction process.

Source: Adapted from USEPA, 1990l.

separated water must be analyzed to determine whether treatment is necessary before discharge (USEPA, 1990l).

Using Figure 3-2 as a guide to identify the components of a possible treatment system for overall remediation using solvent extraction, and referring to Table 3-12 to determine the factors affecting technology performance, the remedial manager can develop a conceptual treatment system. The system may contain the following major components:

- Removal and transport. This step generates a water side stream that needs to be combined with other water residue streams and sent to a conventional water treatment system for treatment.

- Waste preparation includes the pretreatment steps needed to condition the feed stream to optimize system performance. For solvent extraction, this can include removal of oversize material and debris, particle classification, dewatering, and pH adjustment. Each of these steps requires additional equipment, and generates streams of solids and liquids that can be recycled to the principal treatment, combined with other residue streams being treated down-stream, or post-treated for disposal.

- The extraction stage may be most efficient if metals are removed prior to organics extraction. Additional solids, water, and concentrated organics streams are generated in these steps. The solids stream may be clean enough to be reused as fill, or if still contaminated may be solidified for land disposal. The organics stream will need further treatment using biological methods or incineration.

System components will vary depending on the waste composition, site specific contaminants, and the waste matrix.

Applicability and Limitations--Solvent extraction techniques are suitable for treatment of PCBs, volatile organics, halogenated solvents (such as TCE, trichloroethane, petroleum waste), and aromatics (such as benzene, toluene, cresol, chlorinated phenols).

Pumpable feed streams with less than 40 percent (wt) oily organics and greater than 20 percent (wt) solids are favorable. (CF Systems and the B.E.S.T.™ process can treat materials up to 20 percent solids; most others require more thorough dewatering). Particles with a diameter greater than 1/4 in. must be screened because the equipment is incapable of handling large diameter particles. The process does not efficiently extract inorganics and metals. In many cases, multiple extraction cycles are needed to achieve high removal efficiencies.

TABLE 3-12. FACTORS AFFECTING SOLVENT EXTRACTION TECHNIQUES

Factor	Effect	Range
Complex waste mixtures	Affects solvent selected	--
Metals	Does not remove metals	--
Particle size	Equipment used in the process not capable of handling large particle size	<1/4"
pH of waste	Must be in range compatible with extracting solvent (e.g., B.E.S.T.™ process, pH $\geq$10)	--
Separation coefficient	Requires multiple extraction steps if contaminant is strongly bound	--
Volatiles	May require multiple extraction steps if present in high concentrations	--
Oil concentration	Adversely affect oil/water separation	<40%

Source: USEPA, 1988b.

Performance Data--Pilot-scale study at Bedford Harbor, MA showed that PCB concentration in the dredged sediment can be reduced by 90-98 percent. Factors affecting performance are listed in Table 3-12.

Solvent extraction systems are at various stages of development. The CF System and the B.E.S.T.™ process are being evaluated under the USEPA SITE Program. A brief review of six systems is given in Table 3-13.

TABLE 3-13. SOLVENT EXTRACTION SYSTEMS

Vendor/Site	Technology description
CF Systems	● Uses liquefied carbon dioxide and hydrocarbon gases such as propane and butane as solvents to separate organic contaminants from soils, sludges, and sediment. ● Heavy metals and inorganics are not amenable to this treatment. ● Feed material is generally pretreated through the addition of water to ensure its pumpability. ● pH may be adjusted to maintain the metallurgical integrity of the system. ● Feed material is typically screened to remove particles with a diameter greater than 1/4 in. ● Large particles may be reduced in size and then returned to the extraction unit for processing. ● In 1988, it was demonstrated under the auspices of EPA's SITE program at a Superfund site in New Bedford Harbor, Massachusetts. ● Contaminated sediment was treated in a unit with a design capacity of 1.5 gal/min. A mixture of liquefied propane and butane was used as the extraction solvent. PCB extraction efficiencies of 90-98% were achieved for sediment originally containing from 350 to 2575 ppm. ● Projected cost of applying the technology to a full-scale cleanup at New Bedford Harbor ranges from \$148 to \$447/ton (\$200-\$600/cu yd) (McCoy and Associates, 1989).

TABLE 3-13. (Continued)

Vendor/Site	Technology description
The Resources Conservation Company (RCC) Basic Extractive Sludge Treatment (B.E.S.T.™)	● Uses aliphatic amines (triethylamine) as solvents to separate and recover contaminants. ● Feed materials are screened to remove particles of greater than 1 in. diameter. ● pH is adjusted to an alkaline condition (pH 10). ● Process operates at or near ambient temperature and pressure. ● Solvent can be recycled from the residual liquid via steam stripping because of its high vapor pressure and low boiling point azeotrope formation. ● Process has been evaluated at the bench-scale on Indiana Harbor and New Bedford Harbor sediment. ● PCB removal efficiency for the New Bedford sediment was greater than 99 percent. ● PCB removal efficiency for the Indiana sediment was greater than 90 percent with a 0.5 ppm residual (USEPA, 1989g). ● Pilot-scale equipment has been used at a gulf coast refinery treating various refinery waste streams. ● Treated PCB-contaminated soils at an Ohio industrial site in 1989. ● Full-scale unit with a nominal capacity of 70 ton/day was used to process 3,700 tons of PCB-contaminated petroleum sludge at the General Refining Superfund Site in Savannah, Georgia during 1987. ● Cost estimates are about \$130/m^3 (\$100/cu yd) for a unit that would treat 520 m^3 (680 cu yd) a day (Sullivan, 1989).

TABLE 3-13. (Continued)

Vendor/Site	Technology description
The Low Energy Extraction Process (LEEP)	• Intended to remove organic contaminants, from either soil or sediment. • Uses common hydrophilic and hydrophobic organic solvents to extract and further concentrate organic pollutants such as PCBs. • Can conceptually process sediment containing up to 50% water. Efficiencies up to 85% can be achieved. • Successful operation of the system depends on selection of the proper solvents. • Acetone has been selected as the hydrophilic solvent for PCB removal because it is miscible with water, immiscible with kerosene, and highly efficient for removing PCBs. • Acetone has a low density and viscosity that promote efficient solids separation, has a low boiling point and retains a latent heat of vaporization that facilitates solvent recovery and it is also relatively inexpensive. • Kerosene is highly effective in removing organics and it is readily available and inexpensive. • Assuming that the PCB-contaminated solvent is incinerated and that the residual PCB concentration in sediment is five ppm, the unit operating cost would be \$58/m^3 (\$45/cu yd) of sediment processed (McCoy and Associates, 1989).
The Acurex Solvent Wash Process	• The process is said to remove 50 percent of PCBs using freon-type solvents, with each wash down to a residual level of two ppm. • Uses a proprietary solvent tailored to the waste content of the sediment. • No information is available on the amount of solvent that remains in treated sediment.

TABLE 3-13. (Continued)

Vendor/Site	Technology description
The Acurex Solvent Wash Process (continued)	● Sediment entering the treatment process can contain as much as 40 percent water. ● Fine-grained sediment causes difficulties in materials handling; many remain in the solvent after settling. ● Cost estimates range from \$130 to \$390/m^3 (\$100 to 300/cu yd). ● Pilot tests have been completed; field tests are planned (Sullivan, 1989).
The O.H. Materials Extraction Process	● Process uses methanol as a solvent. ● Sediment must be dewatered to less than 5 percent moisture and then slurried with methanol, separated, and redried. ● Solvent is cleaned for reuse using activated carbon, or it may be incinerated. ● Dried, treated sediment is spread out in the open air and periodically turned until any remnants of the methanol are degraded. ● Fine-grained materials and water in wastefeed present problems for this process. ● Claimed efficiencies are 97 percent with an estimated residual level less than 25 ppm. ● Field tests are currently underway. ● Cost estimates range from \$400 to \$514/m^3 (\$300 to 395/cu yd) including degradation and transport (Sullivan, 1989).
The Light Activated Reduction of Chemicals (LARC) Process	● Isopropanol is mixed with sediment containing 25 percent water. The liquid is decanted, and the process repeated. ● Sodium hydroxide pellets are then added to the PCB extract to form a two percent solution. The solution is placed in a reactor, hydrogen gas is added, and the mixture is subjected to ultraviolet light for up to two hours. ● Several extractions may be necessary to sufficiently reduce PCB levels.

TABLE 3-13. (Continued)

Vendor/Site	**Technology description**
The Light Activated Reduction of Chemicals (LARC) Process (continued)	• Efficiency is estimated to be greater than 99 percent. • This process has been tested only in the laboratory. • Cost estimates are about \$150/m^3 (\$115/cu yd) (Sullivan, 1989).

Cost--Costs that have been developed range from \$148 to \$447/ton (\$200 to \$600/cu yd).

Soil Washing--

Process Description--Soil washing is a water-based process for mechanically scrubbing excavated soils and sediment to remove contaminants. Figure 3-7 presents a schematic diagram of a typical soil washing process. This technology has the potential to treat a wide variety of contaminants such as heavy metals, halogenated solvents, aromatics, gasoline, fuel oils, PCBs, and chlorinated phenols. It is most effective on coarse sand and gravel and least effective on clay and silt. Fine silt tends to pass through the process, and clay strongly binds contaminants -- making soil washing inefficient. Treatability tests can determine its feasibility of for site-specific target contaminants.

Soil washing removes contaminants from sediment either by dissolving or suspending them in a wash solution, which is later treated by conventional wastewater treatment methods. It can also concentrate them into a smaller volume through particle size separation, similar to techniques used in sand and gravel operations. A combination of these processes offers the greatest promise for washing sediment contaminated with a wide variety of heavy metals and organics.

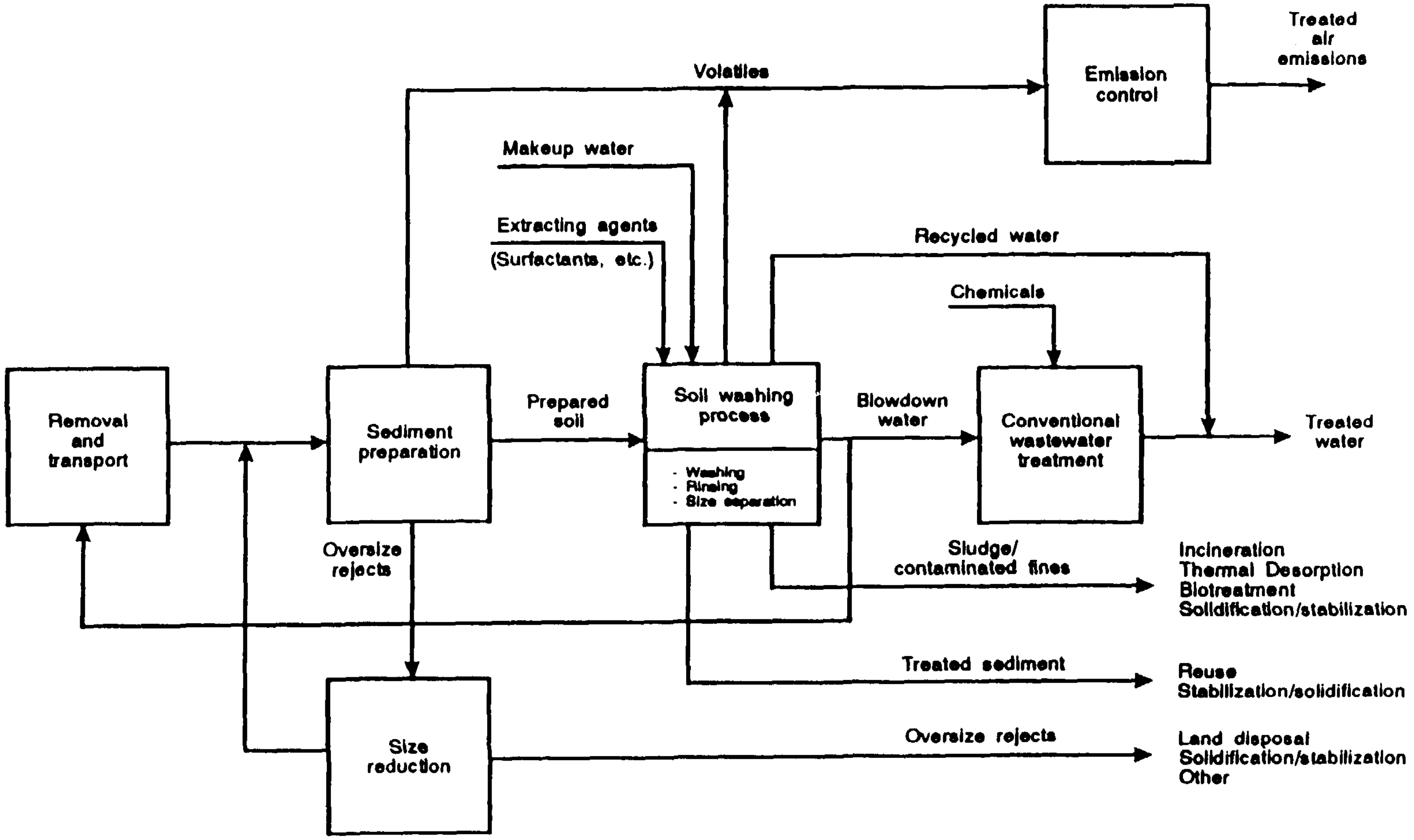

Figure 3-7. Aqueous soil washing process.

Typical soil washing fluids are composed solely of water, or of water in combination with organic solvents, chelating compounds, surfactants, acids, or bases. The concept of reducing sediment contamination through particle size separation rests on the tendency of most organic and inorganic contaminants to bind, either chemically or physically, to clay and silt particles. The clay and silt, in turn, attach to sand and gravel particles by physical processes -- primarily compaction and adhesion. Washing processes that separate the fine clay and silt particles from the coarser sand and gravel particles effectively concentrate the contaminants into a smaller volume that can be more efficiently treated or sent for disposal. The larger fraction, now clean, can be returned to the site. These assumptions form the basis for the volume-reduction concept at the root of most soil washing technologies.

Soil washing can be used either as a stand-alone technology or in combination with other treatment technologies. In some cases, the process can deliver the performance needed to reduce contaminant concentrations to acceptable levels. In other cases, soil washing is most successful when combined with other technologies. It is a cost-effective pre-treatment step in reducing the quantity of material to be processed by another technology, such as incineration. It can also transform soil feedstock into a more homogeneous material for subsequent treatment.

Soil washing generates three waste streams: contaminated solids from the soil washing unit, wastewater, and wastewater treatment residuals. Contaminated clay fines and sludges from the process may receive further treatment by incineration, solidification/stabilization, or thermal desorption. Wastewater may require treatment prior to disposal. As much water as possible should be recovered for reuse in the washing process.

The remedial manager can refer to Figure 3-2 to determine the system components needed to pre-treat, treat, and post-treat the contaminated sediment, and to Table 3-14 to determine the factors affecting the soil washing process efficiency. In doing so, the remedial manager may develop a treatment system similar to Figure 3-7, consisting of the following components:

- A removal and transport step in which sediment is excavated and moved to the treatment process. This process can generate a water side stream that can be treated along with process wastewater.

TABLE 3-14. FACTORS AFFECTING SOIL WASHING

Factor	Effect	Range
Clay content	Difficult to remove contaminants.	--
Complex waste mixtures	Affects formulations of suitable wash fluids.	--
High humic content	Inhibits contaminant removal.	--
Metals concentration	Does not remove insoluble metals. (Some metals can be solubilized and removed.)	--
Mineralogy	Can affect process behavior and contaminant binding.	--
Particle size distribution	Affects removal from wash fluid; oversize debris requires removal.)	0.063-2 mm
Separation coefficient	If highly-bound contaminant, excessive leaching required.	--
Wash solution	Solution may be difficult to recover or dispose.	--

Source: USEPA, 1988b.

- A sediment preparation stage to screen oversize debris and provide particle size separation. The oversize debris or oversized particles may be reduced and returned to the front end of the process.

- The soil washing process in which the sediment is washed with appropriate additives to enhance contaminant removal. The first stage of this process may be metals removal, followed by additional stages to remove organics. Note that several stages may be required dependent on the complexity of the contaminant mixture. The treated sediment may be reused, disposed in a landfill, or solidified/stabilized for disposal. Waste water can be treated in a conventional waste water treatment system. The contaminated sludges or fines that were separated during treatment, can be further treated using incineration, thermal desorption, biological treatment, or solidification/stabilization. Each of these technologies is discussed in this document.

Applicability and Limitations--Soil washing techniques can treat sediment contaminated with soluble metals, halogenated solvents, aromatics, gasoline, fuel oils, PCBs, chlorinated phenols, and pesticides. Insolubles such as metals and pesticides may require acid or chelating agents for successful treatment. The process cannot efficiently treat fine particles such as silt and clay, low-permeability packed materials, or sediment with high humic content. Different minerals behave differently and can affect the binding forces between contaminant and particle. A feed mixture of widely ranging contaminated concentrations in the waste feed make selection of suitable reagents necessary. Sequential washing steps may be needed to achieve high removal efficiencies. Residual solvents and surfactants can be difficult to remove after washing.

Performance Data--Soil washing has documented 90-99% removal of volatiles and 40-90% removal of semivolatiles. The factors affecting the technology's performance are listed in Table 3-14.

The vendors listed in Table 3-15 claim to have successfully applied soil washing to various waste types and offer the technology for pilot- and/or full-scale operations.

The Bureau of Mines (BOM) and EPA have been working closely to determine the effectiveness of soil washing in separating contaminants. Initial studies have concentrated on soil washing using various leachants to recover lead from waste battery scrap and contaminated soil at battery breaking operations. The BOM work could be very important in identifying soil washing as a strong candidate for use in remediating contaminated sediment. However, much work still needs to be done. The Bureau of Mines has been conducting extensive tests of the application of mineral and metal

TABLE 3-15. SOIL WASHING SYSTEMS

Vendor/Site	Technology description
MTA Remedial Resources, Inc. (MTARRI)	● Process uses technologies developed for mining and enhanced oil recovery to remove and concentrate organic contaminants from soils and sludges. ● Treatment residues consist of clean soils which are returned to site, and concentrated organics which require landfilling, incineration, or other treatment. ● MTARRI has treated various metallic compounds with acidic washing solutions. ● Company states that 5 tons (5 percent) of contaminated treatment residue is generated per 100 tons of soil treated.
BioTrol, Inc.	● BioTrol has constructed a mobile soil washing pilot-plant capable of processing 500 lb/hr of contaminated soils. ● Process is most effective on soils containing a high percentage of sand, with particles coarser than 200 mesh. ● Unit has been used to treat contaminated soil at a wood preserving site. Removal rates for pentachlorophenol range from 90 to 95 percent; removal rates for PAHs averaged greater than 95 percent. Approximately 77 percent of the feed material was recovered as wash soil. Oversized material (+14 mesh), consisting primarily of woody debris, constituted 11% of the original feed. Contaminated silt/clay formed the remaining 12 percent of the feed.
EPA	● Developed a mobile soil washing system designed for waste extraction of a broad range of hazardous materials from contaminated soils. ● Normal processing rate is 4 to 18 cu yd of contaminated soil, depending on the average particle size. ● Treatability costs range from approximately $20,000 to over $100,000 per test.

processing technologies to contaminated sediments as part of the ARCS Program and may identify lower-cost treatment or pre-treatment alternatives (Allen, 1992).

Cost--Vendor treatment costs range from $200 to 400/cu yd (USEPA, 1990k).

Thermal Desorption--

Process Description--Thermal desorption is a method of removing volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) from contaminated sediment. Figure 3-8 illustrates a typical thermal desorption process. It is not appropriate for treating inorganics. Volatile metals, however, may be removed by higher temperature thermal desorption systems. The treatment consists of heating the soil matrix at a temperature below combustion, typically 200 to 1,000F, evaporates the VOCs and some SVOCs and drives off water. The vaporized VOCs can then either by destroyed in a high temperature secondary combustion chamber, or recovered by condensation or activated carbon adsorption. This results in a large reduction in waste volume. Sediment is dredged and objects greater than 1.5 inches are removed. The sediment is heated and highly volatile components and water are driven off. Off gas from the desorption step is processed to remove particulates and to condense the volatile contaminants. The off gas is further scrubbed, as needed, before release.

This technology typically creates up to six process residual streams consisting of the treated media, oversize media rejects, condensed contaminants and water, emission gas dust, clean off gas, and spent carbon. Thermal desorption is more effective than some other processes, such as solvent extraction because it volatilizes more organics due to its higher operating temperatures. However, it is not as effective as high temperature incineration because it only evaporates the VOCs and some SVOCs, while incineration destroys all the organics.

The remedial manager can use Figure 3-2 to determine the potential components of an overall treatment system, and Table 3-16 to determine the parameters most favorable to efficient thermal desorption treatment. With these aids, the remedial manager may develop a treatment system similar to Figure 3-8, consisting of the following components:

- Removal and transport of the sediment. This step can generate a water side stream that can be treated in a conventional water treatment system.

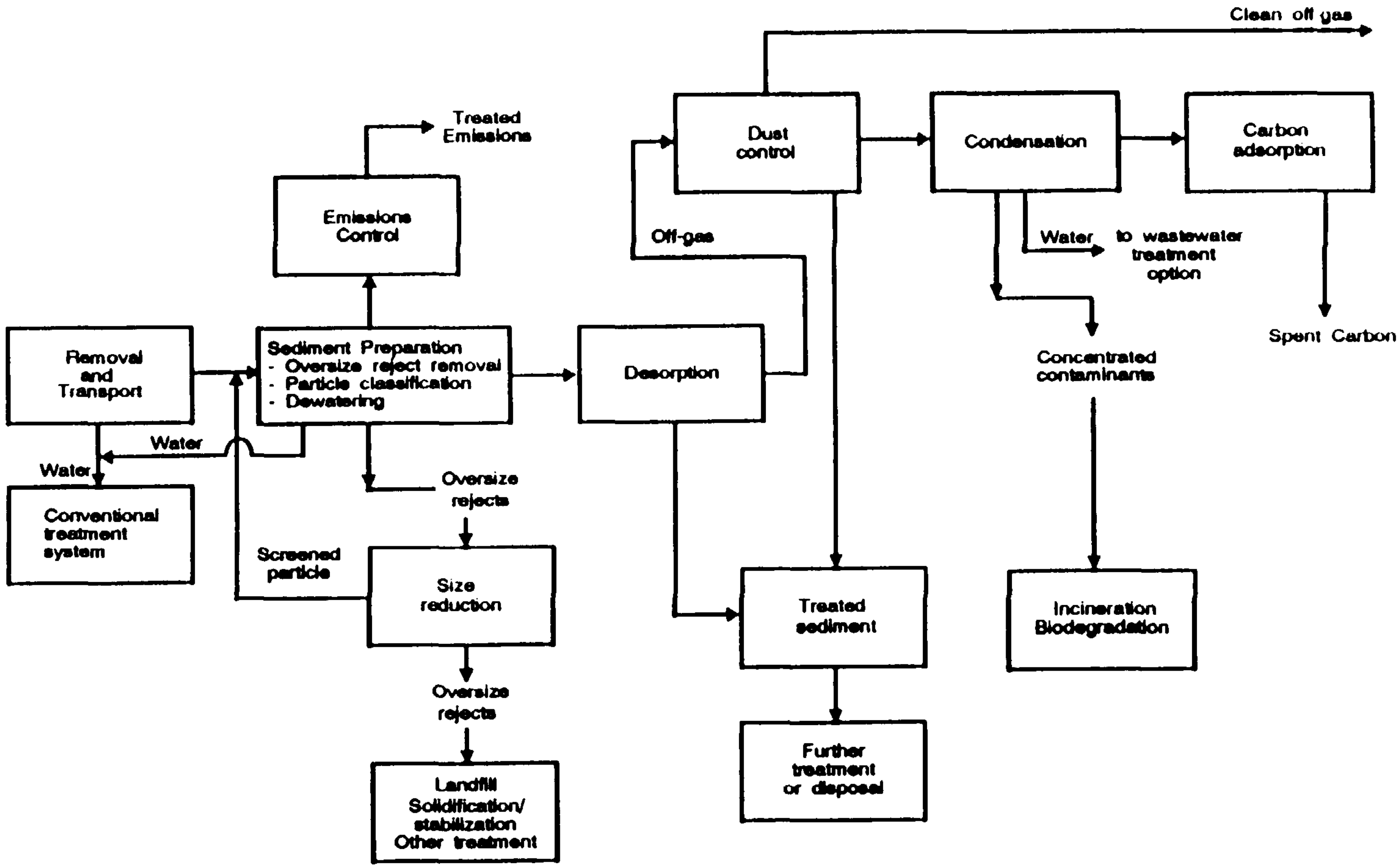

Figure 3-8. Schematic diagram of thermal desorption process.

Source: Adapted from USEPA, 1990n.

TABLE 3-16. FACTORS AFFECTING THERMAL DESORPTION

Factor	Effect	Range
Tightly aggregated particles	Can result in inadequate volatilization of contaminants.	--
Clay content	Fugitive dust emissions during handling.	--
Mercury content	Boiling point of mercury (673F) close to operating temperature for process.	--
Metals, inorganics, low volatile organics	Most effective for highly volatile organics.	Up to 800-1,000F Boiling point
Moisture content	Requires additional energy and increase treatment costs.	<60%
pH	Can cause corrosion.	5-11
Silt content	Can be carried through system resulting in high particulate loading.	--
Volatile organics	Limited by some systems although volatile organics are the primary target compound.	Up to 10%
Solid content	Facilitate placement of the waste material into the desorption equipment.	At least 20%
Particle size	Poor processing performance due to caking.	Less than 1-1.5 in.

Source: USEPA, 1988b.

- Waste preparation in which large debris is screened, and particle size separation is effected. Each operation requires separate equipment, and generates residual streams. Similar residual streams can be combined with streams from other unit operations in the system and treated together.

- Desorption is the principal treatment. It volatilizes the organic contaminants, effecting removal from the sediment. This process generates two streams: the concentrated organic vapor, and the treated sediment. The treated sediment is evaluated to ascertain the appropriateness for reuse as fill, or for further treatment or disposal. The vapor phase is treated for particulate removal and condensation or capture of the organic vapors. Solids from dust control can be combined with other system solids residual streams. Condensed organic material must be further treated using techniques such as incineration or biodegradation. Organic material captured on carbon is either incinerated or desorbed and treated further.

Applicability and Limitations--Thermal desorption is applicable to the separation of organics from refinery wastes, coal tar wastes, wood treating wastes, creosote contaminated sediment, and hydrocarbon contaminated sediment and any contaminant with boiling point up to 1,000°F.

Contaminated sediment, for material handling purposes, must contain at least 20 percent solids. Sediment that is tightly aggregated or hardpan, or that contains rock fragments or particles greater than 1 to 1.5 inches can result in poor performance. High fractions of fine silt or clay can generate fugitive dusts, causing greater dust loading on downstream air pollution control equipment.

Performance Data--Temperature control and residence time are the primary factors affecting performance in thermal desorption. Although this technology can produce treated sediment that meets BDAT treatment levels, but may not reach the desired levels in all cases. Primary factors affecting performance are listed in Table 3-16.

Thermal desorption systems by X*Trax™ Low-Temperature Treatment Process, the Low-Temperature Thermal Aeration System (LTTA) and the Low-Temperature Thermal Treatment (LT^3) System are presented in Table 3-17.

Cost--Processing cost, documented by several vendors ranges from $80 to $350/ton ($110 to $470/cu yd). Costs are very dependent on site size, quantity of waste to be processed, moisture content, organic content of the contaminated medium, and cleanup standards to be achieved.

Solidification/Stabilization Treatment

Process Description--Solidification/stabilization is a technique that mixes reactive materials with solids, semi-solids, and sludges to immobilize contaminants. Solidification produces a monolithic block of waste with high structural integrity by adding materials such as fly ash or blast furnace slag to limit the mobility or solubility of waste constituents (USEPA, 1982). Combinations of solidification and stabilization techniques are often used.

TABLE 3-17. THERMAL DESORPTION SYSTEMS

Vendor/site	Technology description
Chemical Waste Management X*TRAX™	• Company has developed the **X*TRAX™** mobile thermal desorption system. • System uses a separation process to remove volatile or semivolatile compounds from a solid matrix. • Solid feeds must be screened to a diameter less than 1-1/4 in. • Feed stream organics must contain less than 10 percent organics with boiling points less than 800°F, and less than 60 percent moisture. • System is composed of two main elements: a dryer that heats the solids and volatilizes the water and organic contaminants and a gas treatment system that condenses and collects the volatilized compounds and serves as the air pollution control portion of the system. • System operates under negative pressure in an inert environment. • The solids are treated at a temperature between 450 and 850°F. • Residence time ranges from 60 to 300 minutes. • System claims to be effective for treating contaminants with high boiling points such as PCBs. • Residuals from the process include bottom ash from the dryer, spent carbon from treatment of off-gases, condensed oil, and sludge from the phase separator. • Costs range from $200 to $470/cu yd, ($150 to 350/ton) depending on site size. • The first commercial X*TRAX™ system unit became available in 1990. It has a design capacity of 95 cu yd/day based on a feed material with 30 percent moisture.

TABLE 3-17. (Continued)

Vendor/site	Technology description
Chemical Waste Management X*TRAX™, continued	• System reports a 99 percent removal (wt) of VOCs and SVOCs (Johnson, 1989).
Canonie Environmental Services LTTA System	• Used to remediate soils containing chlorinated solvents and non-chlorinated aromatic hydrocarbons. • System removes VOCs from excavated soils by forcing heated air counter-current to the flow of the soils in a rotary drum dryer. • Was used for remediation of the Ottati and Goss Superfund site in New Hampshire. • Equipment is capable of processing between 30 to 50 tons/hr. • Costs range from \$80 to \$150/ton (\$110-\$200/cu yd) depending on soil characteristics and treatment criteria (Johnson, 1989).
Roy F. Weston LT^3 System	• Organic contaminants in the soil are stripped and incinerated without expending the energy necessary to heat the soil to combustion temperatures. • Process involves indirectly transferring heat to the wastes in a multiple screw conveyor to volatilize the contaminants. • Process is capable of accepting a wide range of soil matrices. • It has been demonstrated successfully on VOCs, semivolatile compounds, and petroleum hydrocarbons. • Treatment costs are estimated to be \$100 to \$120/ton (\$135 to \$160/cu yd) based on 20 percent moisture and 10,000 ppm organics. • It is planned to evaluate the unit for remediation of PCB-contaminated soils (Johnson, 1989).

Several variations of solidification/stabilization that are available in today's market include cement-based solidification, silicate-based solidification, and microencapsulation. Of these, cement-based and silicate-based solidification techniques have been more successful in treating hazardous wastes than thermoplastic-based or organic polymer-based techniques. The cement-based processes mix the waste directly with portland cement. In silicate-based solidification, a siliceous material such as fly ash together with lime, cement, and suitable setting agents are mixed with waste. Data suggest that silicate additives can stabilize a wider range of materials than cement. Several vendors use organophilic proprietary compounds as silicate additives to bind organics to the solid matrix. These vendors claim success treating oily sludges and solvent-contaminated sludges and soils, but solidification/stabilization technologies have been most successful to inorganic waste streams. Pretreatment adjusts the pH of the slurry or sludge to insolubilize heavy metals, thereby reducing their mobility. The highly alkaline agents neutralize acidic leachate, keeping the heavy metals in their insoluble, less mobile form.

There are many critical parameters in stabilization: the selected stabilizing agents, other additives, the waste-to-additive ratio, mixing variables, and curing conditions. They all depend on the chemical and physical characteristics of the waste. Bench-scale treatability tests must be conducted to select the additives, ratios, and curing time. Leaching and compressive strength tests determine the integrity of the product.

The short-term environmental effects of stabilizing most wastes are encouraging, and a long-term (6 years) study (Lechich and Roethel, 1988) have shown that stabilized metals, and dioxins and furans in cement blocks do not leach out even when these stabilized blocks are exposed to marine environment for prolonged periods. Any leachate produced as a result of the curing process should be collected and analyzed to determine the necessity for treatment before disposal. Gas monitoring, collection, and treatment may be necessary for wastes containing ammonium ions or volatile organics.

Applicability and Limitations--Solidification/stabilization techniques are most successful in wastes with inorganics and metals. Developers claim some success with oily sludges and solvents. S/S is not effective on volatile organics.

Maintaining an organic concentration less than 20 percent (wt), semivolatiles less than 1 percent, oil and grease concentrations less than 10 percent, cyanide concentrations less than 0.3 percent, phenols less than 5%, and PAHs less than 1 percent is favored. Fine particle sizes and halides retard setting and borates, sulfates, carbohydrates, and soluble salts of manganese, tin, zinc, copper, and lead interfere with settling. Process success is very dependent on the selection of proper stabilizing agents, their mix ratios, proper mixing, and curing. Volume increase exceeding 20 percent can result.

Performance Data--Performance of solidification/stabilization systems is usually measured by the evaluation of leachates. The technique provides virtually total containment of insoluble metals, but it's effectiveness on organics or other leachables is inconclusive. Factors for the most effective treatment are listed in Table 3-18.

Cost--Treatment costs for solidification/stabilization have been determined to be $30 to $165/cu yd (USEPA, 1986a).

Thermal Treatment

Incineration--

Process Description--Incineration is the most widely used method for destroying organic contaminants. Incineration is commercially proven and widely available from many vendors. It is effective in treating soils, sediments, sludges, and liquids containing primarily organic contaminants such as halogenated and nonhalogenated volatiles and semivolatiles, PCBs, pesticides, dioxins/furans, and organic cyanides. In incineration organic contaminants are volatilized at temperatures greater than 1000F in the presence of oxygen resulting in combustion, and destruction of the contaminants.

Varying incinerator designs use different mechanisms to attain the furnace temperature control, the exposure time, and generate the turbulence required to ensure complete combustion. Three common incineration systems are the rotary kiln, circulating fluidized bed, and infrared:

- The **rotary kiln** is a slightly inclined cylinder that rotates on its longitudinal axis. Waste feeds into the high end of the rotary kiln and passes through the combustion chamber by gravity. A secondary combustion chamber destroys organics in the flue gases.

- **Circulating fluidized bed** incinerators use high air velocity to circulate and suspend the fuel/waste particles in a combustor loop. Flue gas is separated from heavier particles in a solids separation cyclone. Circulating fluidized beds do not require an afterburner.

TABLE 3-18. FACTORS AFFECTING SOLIDIFICATION/STABILIZATION TREATMENT

Factor	Effect	Range
Coal or lignite content	Can cause defects in product.	--
Cyanides content	Can affect bonding of waste materials.	<0.3 wt%
Halide content	Retards setting; leached easily.	--
Inorganic salts content	Soluble salts of manganese, tin, zinc, copper, and lead reduce product strength and affect curing rates.	--
Leachable metals content	Not effectively immobilized.	--
Oil and grease content	Weaken bonds between waste particles and cement by coating the particles.	<10 wt%
Organic content	Can interfere with bonding of waste materials.	20-45 wt%
Particle size	Small particles can coat larger particles and weaken bonds; small insoluble particles can delay setting and curing; large particles are not suitable.	--
Semivolatile organics	Can interfere with bonding.	<1 wt%
Sodium arsenate, borates, phosphates, iodates, sulfide, carbohydrates concentrations	Retard setting and affect product strength.	--
Solids content	Requires large amounts of cement and other reagents; greatly increase the volume and weight of the end product.	>15%
Volatile organic concentrations	Not effectively immobilized.	--

Source: USEPA, 1988b.

- **Infrared** processing systems use electrical resistance heating elements or indirect fuel-fired radiant U-tubes to generate thermal radiation. Waste is fed into the combustion chamber by a conveyor belt and exposed to the radiant heat. Exhaust gases pass through a secondary combustion chamber.

Offgases from the incinerator are treated by the air pollution control equipment to remove particulates and capture and neutralize acids.

The remedial manager needs detailed information on the physical and chemical characteristics of the waste matrix to assess the matrix impact on incinerator type, its performance, size, and cost; waste preparation, handling, and feeding; air pollution control type and size; and residuals handling. Key physical parameters include the feed's physical characteristics such as type of matrix, physical form, handling properties, particle size, moisture content, and heating value. Dredged material may require particle size reduction prior to feeding incinerators. Key chemical parameters include the type and concentration of organic compounds such as PCBs and dioxins, inorganics (metals), halogens, sulfur, and phosphorous.

Heavy metals such as arsenic, lead, mercury, cadmium, and chromium are not destroyed by combustion. As a result, some will be present in the ash while others (such as arsenic, mercury) are volatilized and released into the flue gas.

Incinerator generates three major waste streams: solids from the incinerator and flue gas system, gaseous emissions from the incinerator, and water from the scrubber system (Figure 3-9). The incinerator flue gases are often treated by scrubber systems such as electrostatic precipitators or venturi scrubbers before discharge through a stack. Scrubber system solids may contain high concentrations of volatile metals, ash, and treated solids from the incinerator combustion chamber. The ash and treated solids may be contaminated with heavy metals. If these residues fail leachate toxicity tests, they can be further treated by a process such as stabilization/solidification and disposed of onsite or in an approved landfill. Liquid waste from the scrubber system may contain caustics, chlorides, volatile metals, trace organics, metal- and inorganic particulates. The liquid wastes may require neutralization, chemical precipitation, reverse osmosis, settling, evaporation, filtration, or carbon adsorption before discharge.

Figure 3-9 helps determine the potential incineration system components; Table 3-19 gives factors limiting the technology's performance. From these the remedial manager can construct a conceptual overall treatment system. A system might consist of the following components:

- Removal and transport equipment, with the attendant oversize debris removal and size reduction equipment.

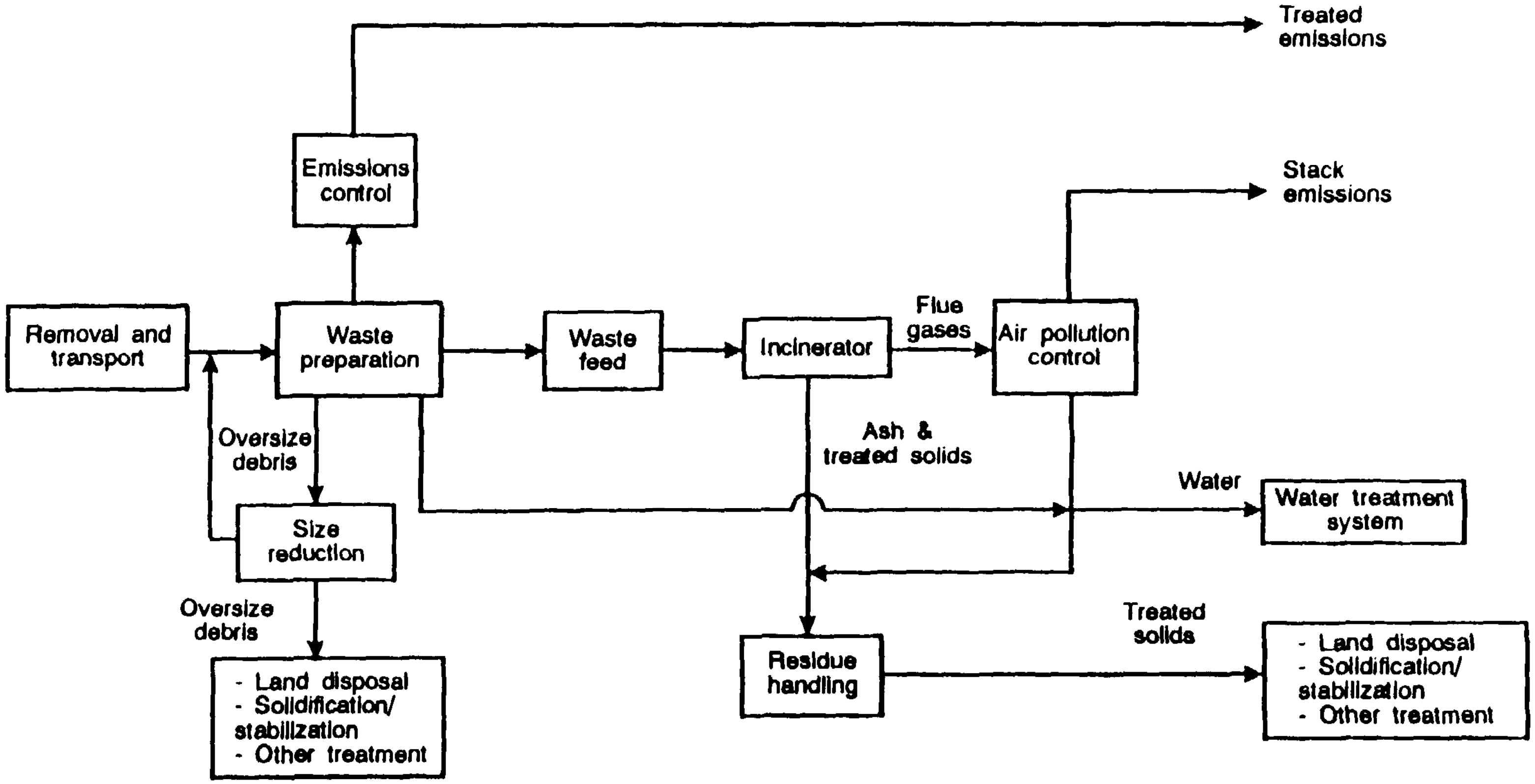

Figure 3-9. Incineration system.

TABLE 3-19. FACTORS AFFECTING INCINERATION TECHNIQUES

Factor	Effect	Range
Ash fusion temperature	Can result in melting and agglomeration.	--
Halogenated organic compound concentration	Form acid gases.	>8,000 BTU
Heating value	Requires additional energy use.	--
Metals content	Can vaporize; are difficult to remove from emissions (volatile metals (As, Cd, Zn, Ag, Hg, Pb, Sn)).	--
Moisture content	Affects feed handling and energy requirements.	Up to 50%
Organic phosphorous content	Can form acid gas (high concentrations).	--
Particle size	Cannot be processed (oversized debris); fines can be carried through the process resulting in high particulate loading.	1-2 inches
PCBs, dioxins	Must ensure sufficiently high temperature for destruction.	--
Alkaline metals such as sodium and potassium	Can cause several refractory attack.	<5% dry weight
Halogens (Cl compounds)	Can contribute to refractory attack, and slagging problems.	<8% dry weight

- Waste preparation includes screening to remove oversize debris and dewatering. Depending on the requirements of the incinerator type for sediments, various equipment is used to obtain the necessary feed size. Blending is sometimes required to achieve a uniform feed size and moisture content.

- Incineration, with its ash, water, air emissions, and treated solids residual streams. The ash and residual solids stream may be able to be land filled directly, or may require treatment before disposal. The water stream can be fed to a conventional water treatment system. The flue gases must be treated in an air pollution control device before release to the environment. The treated solids can generally be reused or landfilled.

Applicability and Limitations--Incineration techniques have been applied to halogenated and non-halogenated volatiles, semivolatiles, PCBs, pesticides, dioxins/furans, organic cyanides, and organic corrosives. It is not effective on heavy metals and is expensive.

Favorable feed stream characteristics include a particle size large enough not to pass through the system, low moisture content to prevent costly vaporization of water, materials which have a good heating value, absence of volatile metals, elevated levels of halogenated organics, sulfur, or elevated levels phosphorus compounds.

Performance Data--Incinerators typically achieve greater than 99% destruction for organics. Factors affecting the technology's performance are listed in Table 3-18.

Rotary kiln incineration by International Technology Corporation has been used at two sites (Cornhusker Army Ammunition Plant, Grand Island, Nebraska, and Louisiana Army Ammunition Plant, Shreveport, Louisiana) by the Department of Defense (DOD) to decontaminate lagoon sediments contaminated with explosives (TNT, DNT, etc.). Roy F. Weston, Inc. owns and operates a transportable incineration system (TIS) to treat solids contaminated with organic compounds and polychlorinated biphenyls (PCBs). In Beardstown, Illinois, 8,500 tons of PCB-contaminated soil from an abandoned salvage yard was successfully treated by this unit.

O.H. Materials used a Shirco Infrared unit at the Peak Oil site in Florida to treat 7,000 tons of waste (Johnson, et al., 1989). EPA conducted two evaluations of the infrared system developed by Shirco Infrared Systems. In both cases, at standard operating conditions, PCBs were reduced to less than 1 ppm in the ash, with a DRE for air emissions greater than 99.99%. Economic analysis suggests a cost range from $180/ton to $240/ton ($245 to $325/cu yd), excluding waste excavation, feed preparation, ash disposal costs, and vendor profit. Total costs including these elements may be as high as $800/ton (USEPA, 1989h).

A circulating fluidized bed incinerator developed by Ogden Environmental Services, Inc. has treated PCB-contaminated sediments from the Swanson River Oil Field, Alaska in field demonstrations.

Cost--The cost of fluidized bed incinerator depends on the technology, the type of waste treated and the size of the site. On the average, the costs can vary from $350/ton ($475/cu yd), for a large site to $1,000/ton ($1,350/cu yd) for a very small site (USEPA, 1990j).

POST-TREATMENT OF RESIDUAL STREAMS

Water Treatment

Water removed from contaminated sediments may require treatment to remove dissolved and colloidal contaminants before disposal. Some treatment techniques include activated carbon adsorption, biological treatment, ion exchange, neutralization, precipitation, flocculation, ultrafiltration, and ozonation/ultraviolet radiation. Since standard, well established wastewater treatment methods can be applied to the separated water component, they will not be addressed further in this document. A good reference to water treatment is *Handbook: Remedial Action at Waste Disposal Sites* (USEPA, 1985b).

Air Emissions Control

The remedial manager can assume that most, if not all, treatment technologies produce vapors that must be captured and treated. The potential for noxious emissions during sediment removal and treatment cannot be overlooked.

Dredging and transporting contaminated sediment, dewatering and particle classification techniques can release entrained gases. Preconditioning or pretreating the sediment can result in reactions between the treatment agents and the contaminants. Each principal treatment method, with the possible exception of the extraction technologies, can generate gases during processing. This applies to biological treatment, dechlorination methods, solidification/stabilization, incineration, and thermal desorption. As the remedial manager delves more deeply into the details of the selected technology or treatment system, each point in the process that could release or generate toxic gases must be identified and appropriate control measures taken to capture, treat, or destroy the emissions.

Solids Treatment

Solids streams from the treatment process or system must be analyzed to ensure that they meet established cleanup levels. This applies most importantly to soil washing technologies. Soil washing technologies are usually phase separation techniques and are not intended to destroy contaminants. The solids residues from these processes will probably require additional treatment before disposal. If the contaminants are PCBs, the remedial manager must ascertain that all TSCA regulations are satisfied. TSCA regulations apply to contaminants having PCB concentrations exceeding 50 ppm.

The solids residues from biological treatment, dechlorination, solvent extraction, solidification/stabilization, incineration, and thermal desorption will usually meet cleanup levels if the proper technology is selected, and operates at optimum conditions. If cleanup levels are not achieved, or heavy metals are present in the waste, a second treatment such as solidification/stabilization may be needed before disposal.

Disposal

Generally, residual solids and sludges from treatment are disposed in landfills. A landfill is a waste disposal facility where waste materials are placed in or on a controlled land area and are covered in the manner that isolates them from the environment. There are two types of landfills: sanitary and hazardous. Highly contaminated wastes must be disposed of in hazardous landfills which are designed to meet regulatory criteria. Landfilling of hazardous materials is becoming increasingly difficult and expensive due to growing regulatory control. Under TSCA, PCB-contaminated materials exceeding 50 ppm cannot be accepted unless than landfill has EPA approval for disposal of PCBs.

SECTION 4

COMBINING COMPONENTS INTO A TREATMENT SYSTEM

In order to assist the remedial manager in using this guide to select appropriate components of an adequate treatment system, four generic scenarios have been developed. These scenarios are as follows:

- A site and contamination that facilitate the section process, and provide a reasonable choice of system components.
- A site and contamination that require pretreatment of feedstock or adjustment of technology components to constitute the preferred system.
- A site and contamination that provide a poor application for this guide, indicating the need for additional information, treatment, or a technology or choice beyond those in this guide.
- A site and contamination that are outside the scope of this guide, indicating the need for research into other technologies.

DEVELOPING TREATMENT SYSTEMS USING GENERIC EXAMPLES

The four scenarios that have been chosen as examples to illustrate use of the guide's Figures and Tables are as follows:

- Scenario #1: A deep, open water body with high concentrations of complex organic contamination, and a sediment with high clay content.
- Scenario #2: A shallow, slow moving water body with Pentachlorophenol contamination and a sandy sediment.
- Scenario #3: A harbor with high traffic, waves, and tides. Contaminants are PCBs and metals in a sandy/silty sediment.
- Scenario #4: A wide, deep river. Contaminants are pesticides and nonvolatile metals in a silty, small particle size matrix.

Scenario #1

From Figure 3-1, determine the appropriate principal treatment method. If the material is to be treated *in situ*, the remedial manager can consult the text for the available, recommended methods. If dredging is chosen, selection of a treatment system begins.

From the "Materials Handling Considerations" discussion, and using Table 3-4, determine the most appropriate dredge for the site. Since this site is a deep, open water body, an appropriate dredge selection is the hydraulic type, used in lakes and inland rivers. Hydraulic dredges also have the advantage of processing high volumes of sediment, with moderate resuspension. The remedial manager is cautioned that other site-specific conditions may favor the use of a different dredge.

Next a transport method must be selected based on the distance to the treatment or disposal site, and the current costs of transport.

From Table 3-1, a technology can be selected based on the specifics of the site contaminant group. For this site, it can be determined that the technologies should be categorized as follows:

High probability	Marginal success	Not Likely to be effective
Incineration	Biological Solvent extraction Thermal desorption	Dechlorination Solidification/stabilization

Refining these selections using Table 3-2, it can be seen that the clay content further eliminates soil washing, solvent extraction, and thermal desorption, leaving incineration as the preferred choice, and biological treatment as a secondary choice. Referring to the costing worksheet, Table 4-1, the substantially higher cost of incineration makes biological treatment the favored choice.

The remedial manager can now consult the section of this document that deals with biological treatment if the site conditions are favorable, or determine what needs to be done to condition the sediment for successful biological treatment. Treatability studies will aid in determining sediment conditioning requirements and optimum operating parameters. The remedial manager should anticipate the possibility that treatability studies may prove an inappropriate choice. Then the selection process becomes iterative - selecting another technology and again performing treatability studies.

TABLE 4-1. COSTING WORKSHEET

System component	Cost range (cu yd)	Site-specific costs
Dredging	$1-$25	
Transport	TBD	
Preconditioning/pretreatment		
Dewatering	TBD	
Particle classification	TBD	
Treatment		
CDF	$5.00-$20.00	
CAD	TBD	
Biological		
In situ	TBD	
Ex situ - solid phase	$50-$80	
Ex situ - slurry phase	$200-$600	
Dechlorination	$100-$300	
Solvent Extraction	$200-$600	
Soil washing	$200-$400	
Solidification/stabilization		
In situ	TBD	
Ex situ	$30-$165	
Incineration	$475-$1,350	
Low temperature thermal desorption	$110-$470	
Posttreatment		
Water treatment	TBD	
Air emissions control	TBD	
Solids treatment	TBD	
Disposal	TBD	

Having screened a likely technology, the remedial manager can consult pre-treatment and post-treatment techniques for the chosen technology and arrange a treatment system designed to meet established cleanup goals. Although the screening process has presented a favorable principal technology, the remedial manager should be aware that certain technologies, although "screened out" may be appropriate pre-treatment or post-treatment phases of an overall system - the "treatment train" approach.

This technique is intended to be a screening process to indicate a preferred treatment or series of treatments to address site-specific conditions. The real work of verifying the screened selection, and designing, installing, and operating the final solution is really just beginning.

Scenario #2

As before, consult Figure 3-1 to determine an appropriate principal treatment.

Since the site water body is shallow and slow moving, a pneumatic dredge is chosen for its preferred operation in interior waterways and in shallow depths. Its low resuspension rate is also a plus since a fast moving water body would quickly entrain and spread contamination. The fact that pneumatic dredges can obstruct traffic may be a drawback, requiring another selection.

Now select a transport system. It is likely that we are close to shore, so a direct pumping to land transport is probable.

The major contaminant at this site is pentachlorophenol. Appendix D of the guide indicates that this compound is a halogenated semi-volatile. Reference to Table 3-1 suggests that the technologies can be categorized as follows:

High probability of success	Marginal success	Not likely to be effective
Soil washing	Biological	Solidification/stabilization
Incineration	Dechlorination	
	Solvent extraction	
	Thermal desorption	

Table 3-2 provides no further refining of the selected technology. However, referring to the text's technology descriptions for both soil washing and incineration, it can be seen that sandy sediment can be processed well by both. Again, reference to the cost work sheet, Table 4-1, indicates that incineration, though technically superior, is far more costly, leaving soil washing as the preferred technology choice. After verification of optimum technology operating parameters, dewatering, pre-treatment and post-treatment considerations can be made, based on the soil washing technology description in the text.

Scenario #3

The selection process continues for the harbor water body site with high traffic, waves and tides. Reference to the guide's materials handling section indicates that a mechanical dredge is preferred since it can operate well in harbors, in rough water, and in confined areas.

In selecting an appropriate treatment technology from Table 3-1, it can be assumed that the metals component will contain volatile and non-volatile metals. Referring to Table 3-1, it is seen that, while dechlorination, solvent extraction, and incineration are the preferred choices for PCB treatment, none is recommended for metals treatment. Biological treatment is marginally acceptable for PCBs, but not acceptable for metals. The remedial manager is therefore left with choosing among three marginal choices - soil washing, solidification/stabilization, and thermal desorption. However, the concentration of PCBs may well determine the technology of choice. TSCA provisions may apply to the site, or the EPA Regional Administrator may select an alternative that satisfies human health and environmental protection considerations. Two good sources of information on PCB regulatory issues and treatment studies are: *Guidance on Remedial Actions for Superfund Sites with PCB Contamination* (USEPA 1990a3) and *PCB Sediment Decontamination - Technical/Economic Assessment of Selected Alternative Treatments* (USEPA 1986a1).

Referring to Table 3-2, the soil washing and thermal desorption options become questionable because they cannot, as stand-alone technologies, treat all the contaminants. Solidification/stabilization, although the preferred option is also not a "strong" candidate. In such cases, the remedial manager is faced with selecting several technologies arranged in a treatment sequence to satisfy the site conditions, or researching technologies not covered in this guide.

For example, in the given scenario, soil washing can be used to separate PCBs, fines, and metals. The PCB component can then be treated, depending on the level of contamination, using dechlorination or incineration. The separated fines and metal components could use solidification/stabilization. Once the treatment train components are initially selected, treatability tests can determine preferred operating conditions. Reference to the text for each technology will determine the pre-treatment and post-treatment techniques needed to optimize the technology's performance.

Scenario #4

Again, from Table 3-4 select an appropriate dredge type. Then select an appropriate transport method.

From Table 3-1 review the potentially effective treatment technologies, remembering that several technologies may be needed to prepare, treat, and post-treat the site specific contaminants and media. Note that no clear cut choice as a preferred treatment is indicated. The selection categories are as follows:

High Probability of success	Marginal success	Not likely to be effective
None	Soil Washing Solidification/ stabilization	Biological Dechlorination Solvent Extraction Incineration Thermal desorption

Refining these selections using Table 3-2, it can be seen that the high silt content and small particle size eliminate the two selections having a marginally successful rating. This leaves the remedial manager with no choices from the listed technologies. The remedial manager must now consider if any pre-treatment can be done to make the sediment more amenable to treatment. Little can be done to change silt and small particles to more treatable conditions. This is a case in which none of the technologies discussed in this document are suitable to the contaminant/media matrix. The remedial manager is left no choice but to exit the document and begin review of other technologies outside this text.

ESTIMATING SYSTEM COSTS

Cost ranges for each component of the treatment system are given in Table 4-1. Caution is advised in using these costs out of context since they are based on varying years. Also, costs are highly variable dependent on the volumes of sediment to be processed, system efficiencies, and support equipment, utilities, and materials required.

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APPENDIX A

CASE STUDIES

APPENDIX A

CASE STUDIES

SELECTION AND EVALUATION OF TREATMENT TECHNOLOGIES FOR THE NEW BEDFORD HARBOR SUPERFUND PROJECT

The New Bedford Harbor Superfund site is located in southeast Massachusetts at the head of Buzzards Bay. Industrial process wastes containing PCBs were discharged into the Harbor between 1940 and late 1970s. Later studies showed PCB concentrations in the marine sediments ranging from below 1 ppm to over 100,000 ppm. The sediment also contained heavy metals (cadmium, copper, and lead) from less than 1 ppm to as high as 5,000 ppm (Allen and Ikalainen, 1988). Since 1979 the area has been closed to all fishing.

Sediment Characterization

The New Bedford Harbor feasibility study is divided into three geographical study areas: the hot spot, the Acushnet River Estuary, and the lower harbor and upper Buzzards Bay (Figure A-1). The hot spot is an area of approximately 4 acres on the western bank of Acushnet River. The PCB content of sediments in this area varies from 4,000 to 100,000 ppm while the metals (cadmium, copper, and lead) from less than 1 to 4,000 ppm. The potential volume of the contaminated sediment ranges between 10,000 to 15,000 cu yd.

The Acushnet River Estuary area, excluding the hot spot, is approximately 200 acres. The potential volume of sediment requiring treatment for this area varies from 600,000 to 1,200,000 cu yd.

Physical characterization tests showed that sediments from the hot spot and Acushnet River Estuary were predominantly organic silts and marine clays, 40 to 80 percent of which were finer than 200 mesh. The organic carbon content of the sediment was between 1.71 to 14.03 percent with an average of 8.94 percent. The moisture content of the sediment ranged from 30 to 60 percent.

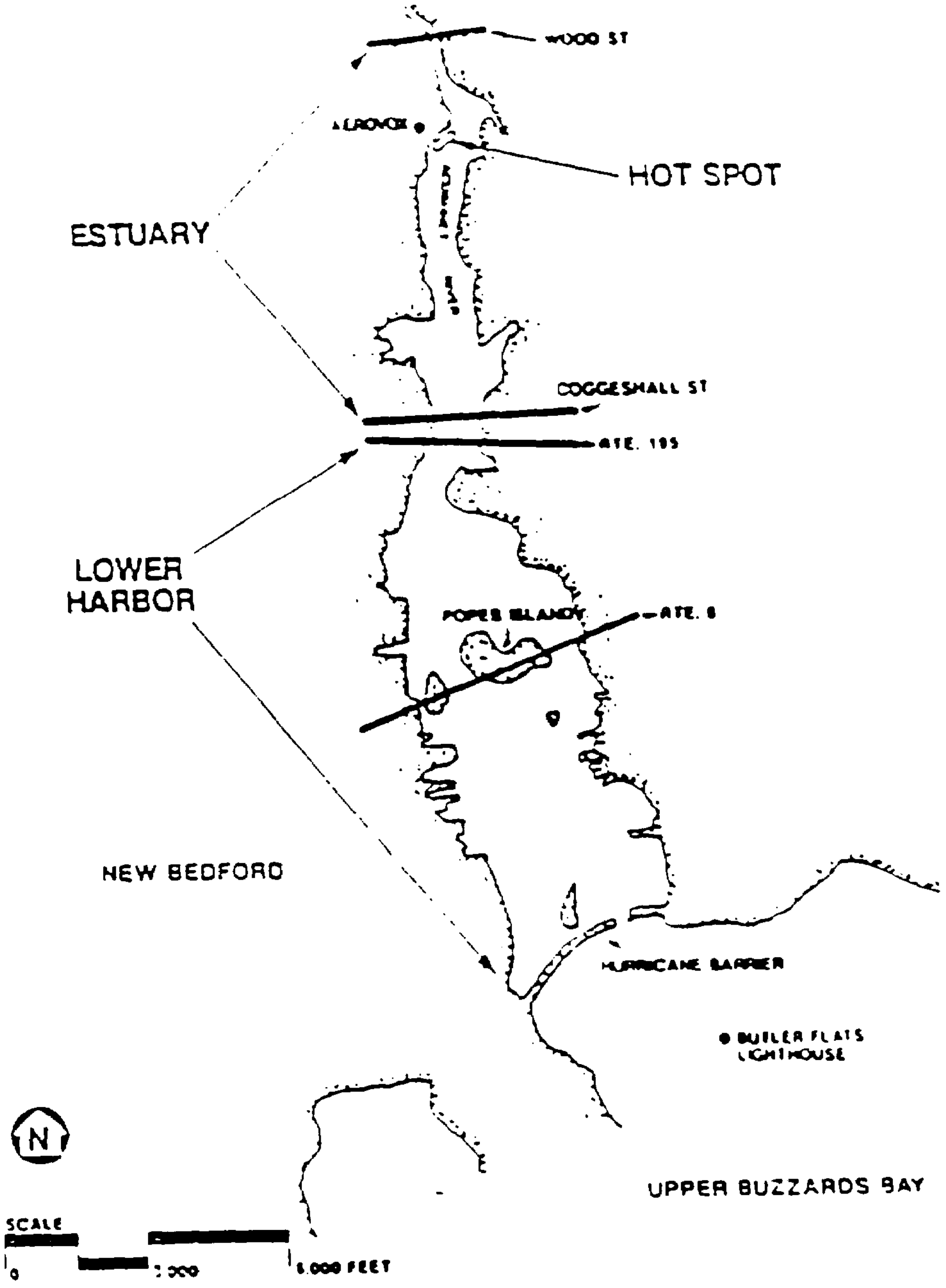


Figure A-1. Feasibility Study areas for New Bedford Harbor site.

Source: Allen and Ikalainen, 1988.

The lower harbor area's (approximately 750 acres) sediments were less contaminated -- the PCB content varied from below detection limit to over 100 ppm. Metal concentrations in the sediments ranged from below detection limit to approximately 3,000 ppm. The potential volume of the sediment requiring treatment ranged from 7,000 to 1,500,000 cu yd. The physical nature of the sediment is predominantly silty sands.

Dredging Method Selection

The USACE, at the request of EPA, conducted an engineering study to evaluate the feasibility of dredging and to select disposal alternatives for the contaminated sediments at this site.

The technical approach for the engineering feasibility study (EFS) included field data collection, literature reviews, laboratory studies, and analytical and numerical modeling techniques to assess the feasibility and to develop conceptual alternatives for dredging and dredged material disposal. This approach was built around the contaminant testing and controls presented in the USACE "Management Strategy for Disposal of Dredged Material." Technical and engineering issues addressed by the EFS included baseline mapping, geotechnical investigations, hydrodynamics, sediment resuspension and transport, contaminant releases to surface and groundwater, dredged material confinement in disposal areas, effluent treatment, and cost estimates.

The results of the EFS were presented in a series of 12 reports. Reports 1 to 11 presented detailed results of field investigations, laboratory studies, and engineering analyses (Averett and Otis, 1990).

In the report, USACE recommended that a cutterhead dredge be used for removing contaminated sediment based on the cutterhead's ability to minimize sediment resuspension. USACE also suggested monitoring the CDF and CAD cells that were constructed and filled with contaminated sediments during the pilot-scale study.

USACE also conducted a bench-scale solidification/stabilization treatability study (Allen and Ikalainen, 1988) using the New Bedford Harbor sediment. Three stabilization technologies were tested as follows:

- Portland cement
- Portland cement along with Firmex - a proprietary additive
- Silicate Technology Corporation's FMS silicate additive

The sediments studied contained two levels of PCBs -- 7,500 and 2,167 ppm. The results of the study show that all three processes reduced PCB leachability by factors of 10 to 100. The leachability of cadmium and zinc were reduced significantly, but copper and nickel were not immobilized -- their leachability was increased by factors of 3 to 27 and 7 to 41, respectively. The bench-scale treatability tests were performed on sediment samples using distilled-deionized water.

ABB Environmental (formerly E.C. Jordan, Eastern Region/C-E Environmental), under EPA, completed the hot spot feasibility study in July 1989. In this study, several organizations were involved with different responsibilities. The attached organization chart (Figure A-2) shows the major feasibility study (FS) components and information flow for New Bedford Harbor.

In the FS document, 56 treatment technologies (Table A-1) were identified for initial screening. After the initial screening, 14 technologies (Table A-2) were retained for detailed evaluation. Following the detailed evaluation, six technologies (Table A-3) were retained for bench-scale testing.

Because of the PCB and metal content of the sediment, several permits were needed to perform these bench-scale tests. Although Massachusetts does not regulate PCBs as RCRA hazardous waste, both TSCA and RCRA regulations apply to the New Bedford Harbor sediment because of the heavy metal content. As a result of these requirements, the CF Systems Corporation (who lacked TSCA R&D permits) elected not to participate in this treatability study program. The bench-scale studies were delayed six months while the selected vendors applied for the TSCA permits.

Only four technologies: solvent extraction, alkali metal dechlorination, advanced biological treatment, and vitrification were tested (ABB Journal, 1990). Only solvent extraction (B.E.S.T.™ process), was retained as a viable treatment technology. Alkali metal dechlorination was not retained because of poor recoveries of reagent and sediment solids. The vitrification process was not considered further because of lack of demonstrated performance at the pilot-scale. The results of the advanced biological treatment study showed that considerable process development will be necessary before this technology can be used for treating PCB-contaminated sediments.

EPA eventually selected incineration as the best alternative (for the hot spots) because of the balance of effectiveness, reliability, availability, cost, and level of PCB destruction. The USEPA's official Record of Decision (ROD) documenting the remedy was signed in April 1990. The overall remedial option process is summarized in Figure A-3.

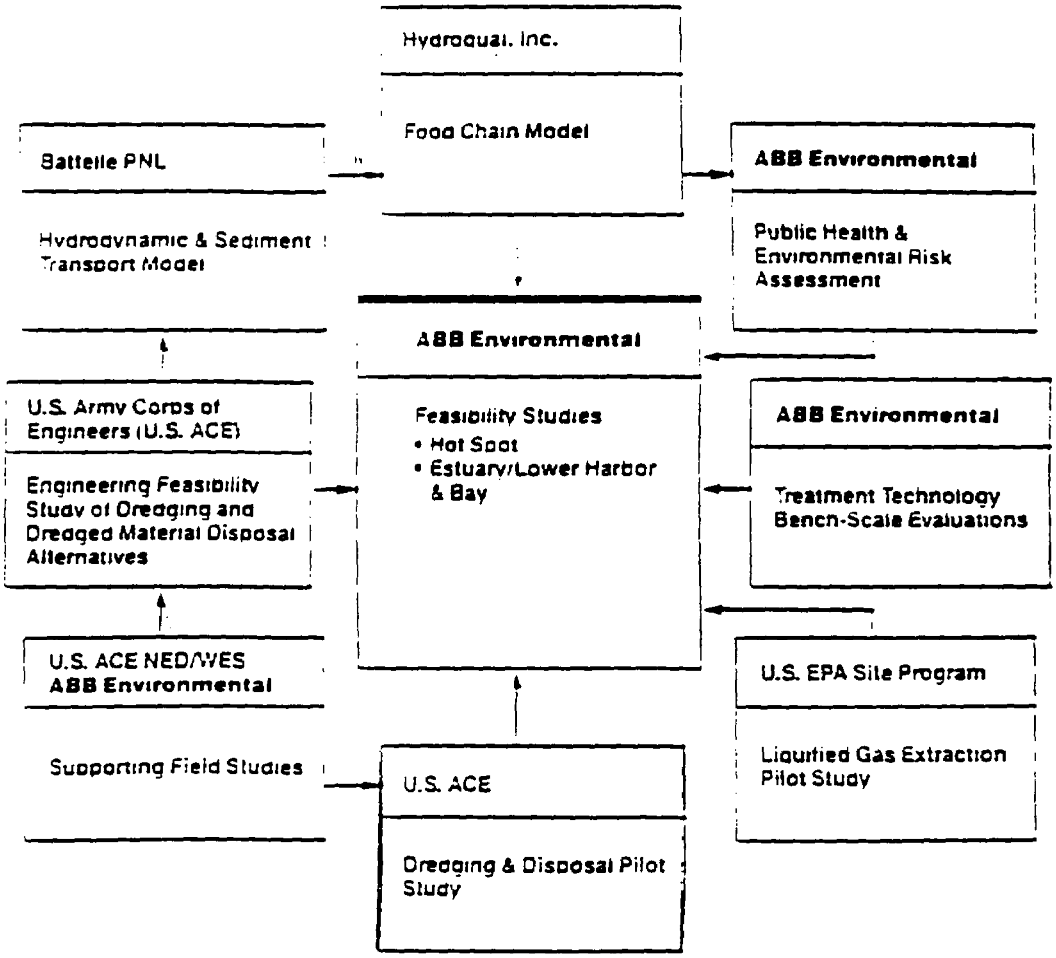


Figure A-2. Major Feasibility Study components and information flow for New Bedford Harbor site.

Source: ABB Environmental Journal, 1990.

TABLE A-1. IDENTIFICATION AND SCREENING OF HAZARDOUS WASTE TREATMENT TECHNOLOGIES FOR NEW BEDFORD HARBOR

Technology	Applicable to sediment matrix	Applicable to water matrix	Applicable for PCB treatment	Applicable for metals removal	Applicable to New Bedford Harbor			
					Sediment	Water	Support	Do not consider
Biological								
1 Advanced biological methods	Yes	No	Yes	No	X			
2 Aerobic biological methods	No	Yes	No	No				X
2 Anaerobic biological methods	Yes	No	No	No				X
3 Composting	Yes	No	No	No				X
5 Land spreading	Yes	No	No	No			X	
Physical								
6 Air stripping	No	Yes	No	No				X
7 Soil aeration	Yes	No	No	No				X
8 Carbon adsorption	No	Yes	Yes	No		X		
9 Flocculation/precipitation	No	Yes	Yes	Yes		X		
10 Evaporation	Yes	Yes	No	No			X	
11 Centrifugation	Yes	No	No	No			X	
12 Extraction	Yes	No	Yes	No	X			
13 Filtration	Yes	No	No	No			X	
14 Solidification	Yes	No	Yes	Yes	X			
15 Granular media filtration	No	Yes	No	Yes			X	
16 In situ adsorption	Yes	No	Yes	No	X			
17 Ion exchange	No	Yes	No	Yes		X		
18 Molten glass	No	No	Yes	No				X
19 Steam stripping	No	Yes	No	No				X
20 Supercritical extraction	Yes	No	Yes	No	X			
21 Vitrification	Yes	No	Yes	Yes	X			
22 Particle radiation	No	No	Yes	No				X
23 Microwave plasma	No	No	Yes	No				X
24 Crystallization	No	Yes	No	No				X
25 Dialysis/Electrodialysis	No	Yes	No	No				X
26 Distillation	No	Yes	No	No				X
27 Resin adsorption	No	Yes	No	Yes		X		
28 Reverse osmosis	No	Yes	No	Yes		X		
29 Ultrafiltration	No	No	No	No				X

TABLE A-1 (continued)

Technology	Applicable to sediment matrix	Applicable to water matrix	Applicable for PCB treatment	Applicable for metals removal	Applicable to New Bedford Harbor			
					Sediment	Water	Support	Do not consider
30 Acid leaching	Yes	No	No	Yes	X			
31 Catalysis	No	No	No	No				X
Chemical								
32 Alkali metal dechlorination	Yes	No	Yes	No	X			
33 Alkaline chlorination	No	No	No	No				X
34 Catalytic dehydrochlorination	No	No	Yes	No				X
35 Electrolytic oxidation	No	No	No	No				X
36 Hydrolysis	No	Yes	No	No				X
37 Chemical immobilization	Yes	No	No	Yes	X			
38 Neutralization	Yes	No	No	No				X
39 Oxidation/hydrogen peroxide	Yes	Yes	No	No				X
40 Ozonation	No	No	No	No				X
41 Polymerization	Yes	No	No	No				X
42 Ultraviolet photolysis	No	No	Yes	No				X
Thermal								
43 Electric reactors	Yes	No	Yes	No	X			
44 Fluidized bed reactors	Yes	No	Yes	No	X			
45 Fuel blending	No	No	Yes	No				X
46 Industrial boilers	No	No	Yes	No				X
47 Infrared incineration	Yes	No	Yes	No	X			
48 In-situ thermal destruction	No	No	Yes	No				X
49 Liquid injection incineration	No	No	Yes	No				X
50 Molten salt	No	No	Yes	No				X
51 Multiple hearth incineration	Yes	No	Yes	No	X			
52 Plasma arc incineration	No	Yes	Yes	No		X		
53 Pyrolysis processes	Yes	No	Yes	No				X
54 Rotary kiln incineration	Yes	No	Yes	No	X			
55 Wet air oxidation	No	Yes	No	No				X
56 Supercritical water oxidation	Yes	Yes	Yes	No	X			

Source: Allen and Ikalainen, 1988.

TABLE A-2. TREATMENT TECHNOLOGIES RETAINED FOR DETAILED EVALUATION

Technology	Effectiveness			
	Effective for treatment of these compounds	Feasibility for use in these matrices	Demonstrated reliability	Data needs
1 Advanced biological methods	PCBs	Sediment, aerobic conditions	Demonstrated on pilot scale for PCBs	Further information on effectiveness, feasibility, and costs.
2 Solvent extraction	PCBs	Sediment, limited success in high fines material	Demonstrated on pilot scale for PCBs	Bench-scale tests to prove feasibility, effectiveness, and cost information.
3 Supercritical extraction	PCBs	Aqueous streams or slurries	Demonstrated on pilot scale for hazardous wastes. Not suitable for high solids at supercritical conditions	Combine with solvent extraction.
4 Solidification	PCBs, metals	Sediments, ash	Demonstrated on full scale for a variety of soils and sediments	Bench-scale tests to determine proper applications, effectiveness, costs.
5 Vitrification	PCBs, metals	Low moisture sediments, limited volumes	Demonstration on pilot scale for soils and sediments	Bench-scale tests to determine feasibility, cost data.
6 Alkali metal dechlorination	PCBs	Low moisture sediments	Demonstrated on pilot scale for PCBs in soils	Bench-scale tests to determine effectiveness and feasibility cost data.
7 Fluidized bed reactors	PCBs	Sediments	Demonstrated on full sclae for PCBs in sediments	Further information on costs.

TABLE A-2 (continued)

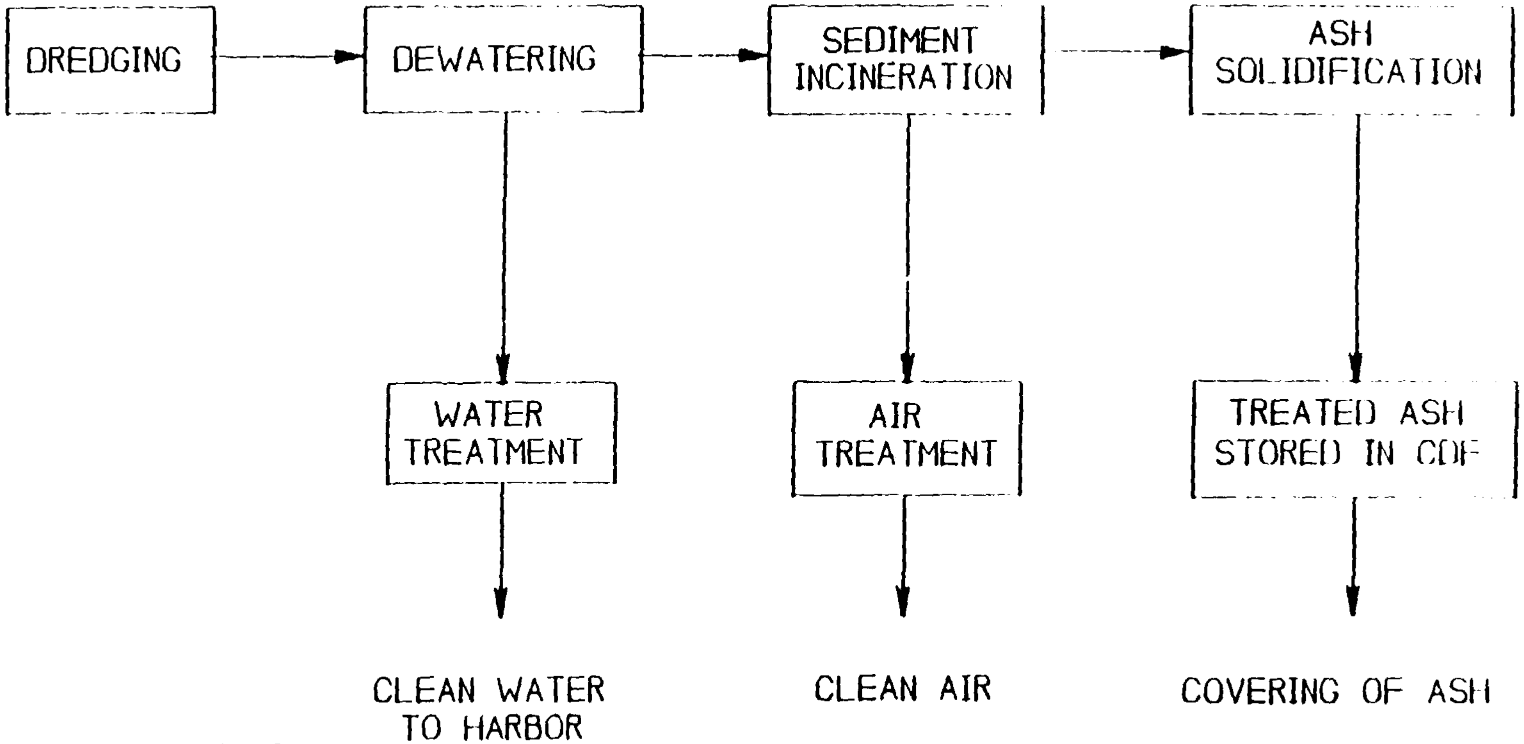
Technology	Effectiveness Effective for treatment of these compounds	Feasibility for use in these matrices	Demonstrated reliability	Data needs
8 Infrared incineration	PCBs	Sediments	Demonstrated on full scale for PCBs in sediments	Further information on costs.
9 Rotary kiln incineration	PCBs	Sediments	Demonstrated on full scale for PCBs in sediments	Further information on costs.
10 Supercritical water oxidation	PCBs	Slurry of sediment/water	Demonstrated for waste streams containing PCBs	Further information on effectiveness, feasibility, and costs.
11 Carbon absorption	PCBs	Aqueous streams, low suspended solids	Demonstrated on full scale with PCBs and other compounds	Bench-scale testing to evaluate efficiency. Data on costs.
12 Flocculation/precipitation/ coagulation	PCBs, metals	Aqueous streams, high suspended solids	Demonstrated on full scale for metals and particulate removal	Bench-scale testing to determine operating parameters. Data on costs.
13 Ion exchange	Metals	Aqueous streams, low suspended solids	Demonstrated on full scale for metals and particulate removal	Bench-scale testing to determine operating parameters. Data on costs.
14 Resin absorption	PCBs, metals	Aqueous streams, low suspended solids	Demonstrated for specialized use on specific compounds	Determine if effective for PCBs. Cost data.

Source: Allen and Ikalainen, 1988.

TABLE A-3. TECHNOLOGIES FOR ABB ENVIRONMENTAL BENCH TEST PROGRAM

Technology	Vendor	Description
Solvent extraction (B.E.S.T.™ process)	Resources Conservation Co. Bellevue, Washington	B.E.S.T.™ process uses inverse miscibility properties of aliphatic amines (e.g., triethylamine) to separate oils (PCBs) and organics from sludges and contaminated soils.
Alkali metal dechlorination (KPEG)	Galson Research Corporation East Syracuse, New York	KPEG process uses an alkaline reagent consisting of potassium hydroxide in polyethylene glycol (KPEG). KPEG reagent mixed with contaminated material and heated to 150° to dechlorinate PCBs.
Vitrification (modified in situ)	Battelle Pacific Northwest Laboratories, Richmand, Washington	Battelle process applies an electric current to electrodes inserted in contaminated material which is heated to >3600°F. Material converted to molten state; organics (PCBs) are pyrolyzed.
Advanced biological treatment	Radian Corporation, Milwaukee, Wisconsin	Microorganisms from New Bedford harbor are selectively cultivated in a nutrient-rich medium, acclimated to biphenyl, then exposed to PCB-sediments from New Bedford Harbor.
Supercritical fluid extraction (propane)	CF System Corporation Waltham, Massachusetts	Gases (typically carbon dioxide and propane) are heated and compressed to the critical point where they exhibit the diffusivity characteristics of a gas and the solvency of a liquid.

Source: Allen and Ikalainen, 1988.



Source: ABB Journal, 1990.

Figure A-3. U.S. EPA's selected remedy at New Bedford Harbor site.

KEPONE IN THE JAMES RIVER, HOPEWELL, VIRGINIA

Information contained at the James River case study was obtained primarily from the report prepared by Science Applications International Corporation (SAIC, 1985) and Robert J. Huggett's paper "Kepone and the James River" [National Research Council, 1989].

The James River originates in the Allegheny Mountains of Western Virginia and flows generally in an easterly direction through Richmond and Hopewell (south of Richmond) to Chesapeake Bay. The river is unnavigable above Richmond. Beyond the city of Richmond, the river is navigable. Between Richmond and Hopewell, a large number of industries are located on either banks of the river. A navigational channel 7-8 m deep is maintained to permit river traffic. The James River in this area flows at an average of 200 cu m/sec. This tidal section of the river is characterized by a sandy/silty bottom. Both fresh and salt water species inhabit the river, and fishery resources are diverse and productive. Beyond the Richmond-Hopewell area the only major populated area along the downstream river is at the river's mouth -- Newport News, Hampton, Portsmouth, and Norfolk.

Between 1966 and 1975, Allied Life and Science Company manufactured kepone, a pesticide for ant and roach control. The State of Virginia Department of Health closed the kepone manufacturing plant in July 1975 after finding that many workers were suffering from kepone poisoning. In response to requests by the governors of Virginia and Maryland, EPA initiated the Hopewell/James River Kepone Mitigation Feasibility Project. The study showed that kepone was released to the environment principally from four sources:

- Atmospheric releases from drying and bagging operations.
- Routine daily wastewater discharges.
- Releases to sanitary sewers from spills and intentional discharges.
- Bulk liquid and solid discharges to land around Hopewell.

The wastewater and sewer discharges were the primary sources of kepone. Analyses of oysters and fishes from the river showed elevated levels of kepone. It was estimated that between 1.2 to 1.7×10^5 kg of kepone had entered into the environment, of which 4.4 to 8.4×10^4 kg were found in the river sediments. Because of its highly refractory nature, no significant natural degradation of kepone had occurred.

The bottom sediments of the James River were contaminated with kepone to varying degrees. The main factors controlling the concentrations appeared to be made up of the sediments and the currents of the overlying water. Kepone associates with the organic portion of the bottom sediments. The distributions of the pesticide in the top two cm of bottom sediments in the channel of the river in 1977 and 1979 are shown in Figure A-4. In 1977 the highest concentrations were found in the vicinity of the maximum turbidity zone. By 1979, surface sediment concentrations diminished greatly. Analyses of sediment cores at varying depths showed that kepone was becoming diluted and buried by newly deposited material rather than being transported away or decomposing. This trend has continued since then, but in areas where the sedimentation rate is low, kepone is most concentrated near the surface. Where the sedimentation rates are high, concentrations of kepone increases with depth (Helz, and Huggett, 1987). This reduction is reflected in the residue concentrations in edible tissues of crabs and oysters (Figure A-5). The data are interesting in view of the fact crabs obtain most of their kepone from food whereas the oysters accumulate kepone both from solution and suspended particles.

Conventional and nonconventional techniques were considered in the evaluation of remedial action alternatives for the Hopewell/James River kepone contamination. Battelle Pacific Northwest Laboratories reviewed nonconventional remediation techniques while USACE (Norfolk district) evaluated other potential methods of dredging and potential disposal sites along the river. The nonconventional techniques reviewed by Battelle were as follows:

- **Dredged material fixation.** Four fixation agents were evaluated: silicate base, organic base, sulfur base, and asphalt base. All evaluations considered the agent's ability to isolate the contaminant and its ability to maintain physical integrity.

- **Elutriate, leachate, and/or the dredged material slurry treatment.** Seven treatment techniques were evaluated: photochemical degradation, amine photosensitization, chlorine dioxide treatment, ozonation, radiation, catalytic reduction, and carbon adsorption.

- **Two *in situ* treatments were selected:** sorbents and polymer films (for laboratory testing).

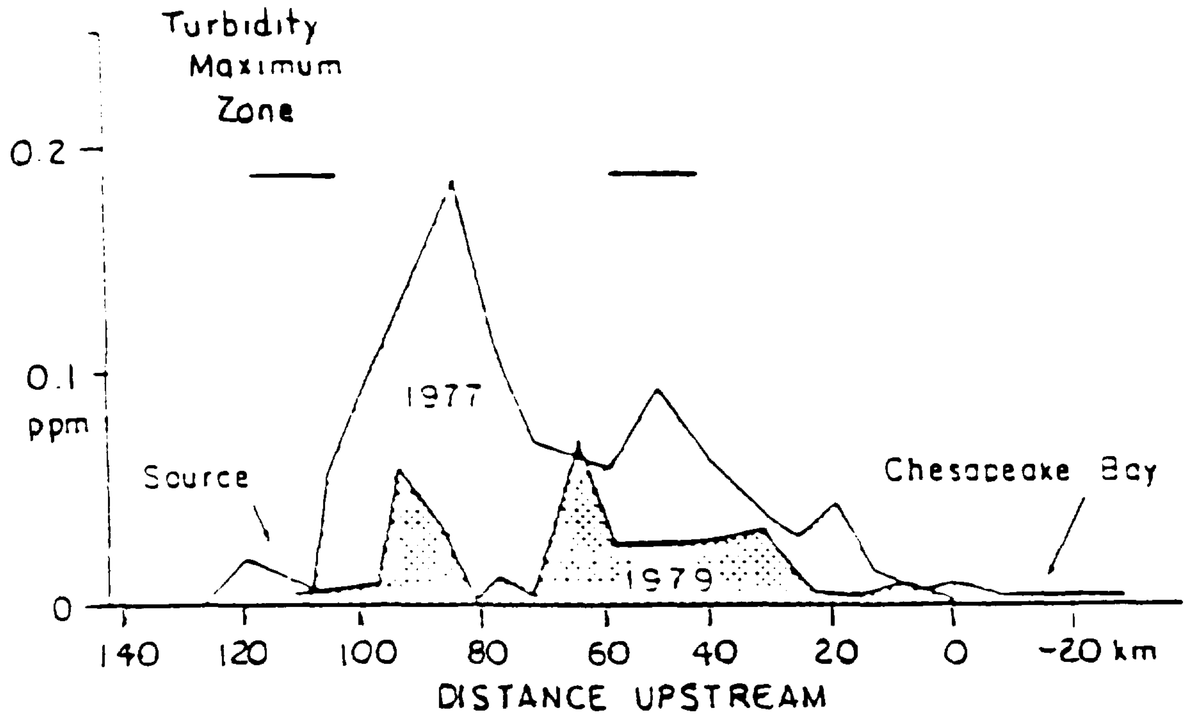


Figure A-4. Kepone in the top 2 cm of channel bottom sediment from the James River system.

Source: Huggett and Bender, 1980.

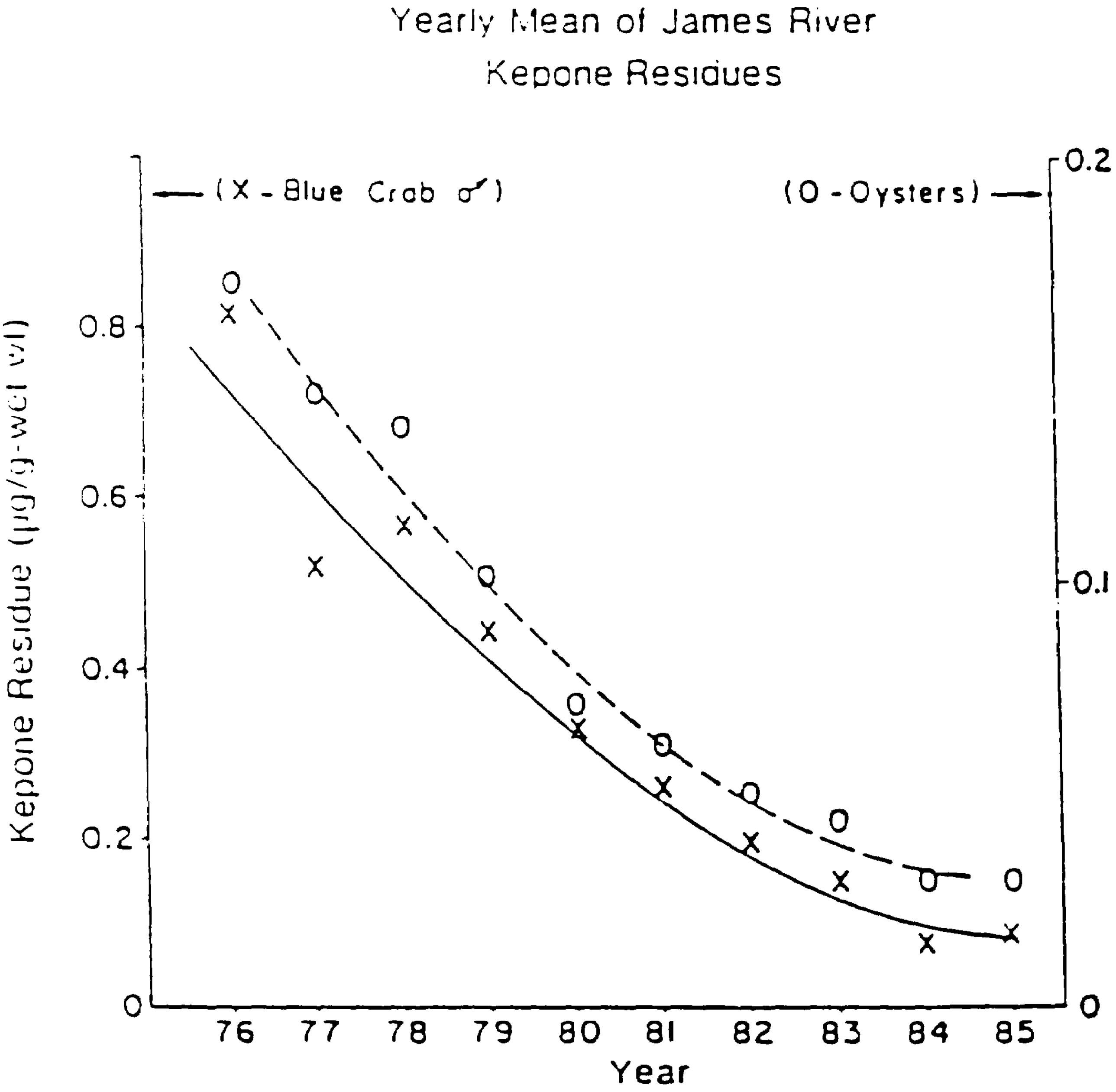


Figure A-5. Kepone concentrations in blue crabs and oysters.

Source: Majumdar, Hall, Austin, 1987.

- **Biological treatment appeared to offer no significant mitigation of kepone in the river.** Examination of this technique was confined to literature review and limited laboratory testing. Tables A-4 and A-5 summarize these studies.

It was concluded that none of these options was appropriate to remediate this site. USACE (Norfolk) performed three tasks for this project:

- Evaluation of all potential dredging techniques.
- Investigation of conventional means for checking kepone inflows from Hopewell area into the James River system.
- Preliminary estimates for removing kepone from the lower James River by dredging.

Alternate Dredging Technology

USACE evaluated several dredging technologies of both domestic and Japanese manufacturers. After further study it was decided to test the cutterhead dredged which has been used in the James River for decades, and the dustpan dredge currently being used in the Mississippi River. The objectives of this test were to minimize dredge-induced turbidity and achieve maximum containment of the contaminated sediment at or near in-place density. During this demonstration, the overboard disposal areas were monitored for the release of kepone in conjunction with state and federal agencies. Table A-6 summarizes the results of this study. USACE's water monitoring data showed that dissolved kepone levels for the cutterhead averaged more than three times the levels during dustpan operations (11.7 ppt and 3.2 ppt, respectively). According to USACE, the higher levels, according to ACE, are perhaps due to the fact that cutterhead operation removed more than five times the amount of material moved by the dustpan dredge. Although there were elevations in contaminant and turbidity levels, both remained within accepted limits and the elevations were short-term and confined to designated disposal areas. It was estimated that the dredging cost would be about $3/cu yd. The overboard disposal proved to be both economical and without serious environmental effects.

Alternatives for Checking Kepone Inflows

The evaluation of alternatives for controlling kepone flows from the Hopewell area involved the development of 18 engineering options shown in Table A-7. Because of the low levels of kepone in the Gravelly Run area, it was concluded that options 1 through 6 should not be considered further. Based on in-depth analyses involving costs and levels of contamination only alternatives 8, 14, and

TABLE A-4. MORE PROMISING NONCONVENTIONAL TREATMENT ALTERNATIVES INVESTIGATED

Approach	Alternative	Results	Costs	Comments
Spoil fixation	Silicate bases	High pH solubilizes kepone	Estimated \$10-15/yd^3	Promising to date; the Japanese firm, Takenaka, feels their process can be further refined for kepone and are still making modifications. Only operational large scale in-place fixation technology presently available.
	Organic bases	Yields 10-fold reduction in kepone levels	\$12.53/ft^3 fixed	Por Rok Epoxy sealant may be production limited; results slightly more consistent; requires greater than or equal to 50% solids.
		Resists leaching; poor response to elutriate test	Not determined	Dowell M 179 - Effective for percolation control.
	Sulfur bases	Yields 10-fold reduction in kepone leachate levels	\$1.30/ft^3 fixed	Molten sulfur-effective but serious environmental impacts could result. Sulfur is readily available, has good effectiveness, and requires greater than or equal to 50% solids.
Elutriate treatment	Biological degradation	Promising stains of fungi and mold	Not determined	Not suffiently developed.
	Amine photosensitization	Degradation occurs at exposed surfaces	\$0.805/lb for ethylenediamine plus\$500/acre application costs yield treatment at \$4,000/acre in treating top 1 inch of soil	Inappropriate on dredged soils, but potential for use on surface soils.

TABLE A-4 (continued)

Approach	Alternative	Results	Costs	Comments
Elutriate treatment (continued)	UV and ozone	*Good decompensation*	$433,000/MGD treated on small plant (capital cost) ($0.23/1,000 gal treated (O&M costs/yr) (For 50 MGD plant, capital costs are $7.9 *million* and O&M costs are $2.2 million/yr) $0.10-0.20/yd^3 preliminary)	Ultrox (Westgate) - Effective for solutions. Does not include clarification if needed.
	Gamma radiation	Dechlorinates, by-products unidentified	Not determined	Requires further testing.
	Electron beam radiation	Can infer from PCB work only	Not determined	Requires direct testing.
	Adsorption	Carbon and synthetic resins	$50.4 million - capital; $262,924 O&M/yd; based on a 50 MGD plant	Effective, does not destroy; concentrate kepone.
		Temporary filtration/carbon adsorption system	$3.06 x 10^6, 50 MGD system (capital cost)	Calgon system does not include costs for piping or pumping as required to deliver or dispose of waters, or the cost of the settling impoundment. Final disposal would include incapsulation and backfilling over the entire sand and carbon beds to prevent future leachate contamination.
	Coagulation	Removes particulate kepone	$10.1 million - capital, $551,650 O&M/yr; based on 50 MGD plant	Effective for bulk reduction; does not destroy kepone.

TABLE A-4 (continued)

Approach	Alternative	Results	Costs	Comments
In-situ processes	Retrievable solvents	Specific sorbents capable of removal	\$0.90/ft^3	Effective but requires incineration and regeneration production of media not currently commercially available.
	Coal	Initial data suggests no advantages	\$0.032/ft^3	Requires further study.
	Polymer films	Holding action only needed perforation may render ineffective	\$0.044/ft^3	Effectiveness questioned due to requirements. Applicable only to embayments.
	Activated carbon	Intermediate between coal and retrievable sorbents	\$0.52/ft^3	Effective -- will retard availability but not remove kepone. In all in situ processes, environmental impacts require serious consideration.

Source: Brossman, et al., 1978.

TABLE A-5. POTENTIAL BIOLOGIC APPROACHES TO THE MIGRATION OF KEPONE IN THE JAMES RIVER SYSTEM

	In situ		Secondary transport	
Organism	**Water**	**Sediment**	**Water**	**Sediment**
Higher plants (e.g., water hyacinth)	Leaf surfaces may accumulate kepone. However, this is not a practical alternative.	Roots not known to accumulate similar compounds. Not feasible (roots normally free floating).	Surface area/volume required is prohibitive.	Not feasible.
	Not known to metabolize kepone.	Not known to metabolize kepone.		
Fungi	Because of low kepone concentration in water, the use of possible aerobic fungi which degrade kepone is not feasible.	The sediments of Bailey Bay which are highly anaerobic and reducing will not permit the growth of fungi which are aerobic.	Aerobic fungi would require large shallow ponds for degradation. May be necessary to achieve 100% degradation.	Not feasible.
		Anaerobes are not likely to be of any value.	Accumulation of kepone by fungi used as biologic filters is possible.	
Bacteria	Because of low kepone concentration effective degradation or accumulation may not be possible while the organisms can effectively accumulate kepone many times, quantitatively the amounts removed would be small compared to current environmental levels.	Anaerobes show best potential for dechlorination of kepone in Bailey Bay sediments but no species have been identified.	Bacteria used as biologic filters is possible. Aerobes necessary to achieve 100% degradation.	Anaerobic digesters show potential for optimization of degradation.

TABLE A-5 (continued)

Organism	In situ		Secondary transport	
	Water	Sediment	Water	Sediment
Algae	Low kepone concentration reduces effectiveness of bioaccumulation while the organism can effectively accumulate kepone many times. Quantitatively the amounts removed would be small compared to current environmental levels.	Not feasible (though algae can accumulate carbohydrates anaerobically).	Have shown excellent bioaccumulation of similar compounds.	Not feasible.
All of the above	Because of the many interactions possible, it is not possible to predict how all four would relate in order to achieve maximal amelioration. The following generalizations can be made: (1) Anaerobes and sorbent must interact so that optimum degradation will be achieved. (2) Normal organism antagonisms may decrease the possibilities of amelioration.			

Source: Brossman, et al., 1978

TABLE A-6. COMPARISON OF DREDGING MODES

Parameter	Average value for parameter	
	Dustpan	Cutterhead
Resuspension at head (mg/l above background)	32.0	12.0
Vacuum (inches Hg)	16.8	17.1
Pressure (lbs/sq in)	69.7	100.0
Velocity (ft/sec)	18.3	21.0
Density (lbs/cu ft)	68.4	71.1
Output (cu yds/dredging hour)	1,163.0	1,855.0
Overall production (cu yds/operating hour)	300.0	700.0

Source: Klein, 1982.

17 were selected for final consideration.

James River Alternatives

Table A-8 shows the treatment costs developed by Battelle and USACE, for various remedial options for the James River.

The kepone levels in organisms in the James River in 1988 were found to be below the EPA and FDA action levels [National Research Council, 1989] and all fishing restrictions were lifted. It was concluded that any remedial action to remove kepone would be expensive and environmentally unwise. This decision, however, restricts normal dredging operations.

PCBs IN THE HUDSON RIVER

Information about the Hudson River site was obtained from *Removal and Mitigation of Contaminated Sediments* (SAIC, 1985), a paper by Mark Brown (Brown, 1988); John E. Sanders paper *PCB Pollution in the Upper Hudson River* (National Research Council, 1989); and a conversation with John Mulligan, Malcolm Pirmie, Albany, NY and Richard F. Bopp of New York Sate Dept. of Environmental Conservation, Albany, NY.

TABLE A-7. PROPOSED MITIGATION ALTERNATIVES FOR KEPONE CONTAMINATION IN BAILEY CREEK, BAILEY BAY, AND GRAVELLY RUN SITES

Alternative Number	Proposed Action
1	Dam and possible treatment plant at mouth of Gravelly Run; treat flows up to and including the 100 year flood level
2	Dam mouth of Gravelly Run exclude spillway and divert flow to Bailey Creek for treatment
3	Seal contaminated flood plain areas of Gravelly Run; elevate stream channel, rip rap creek bed, construct control structure at mouth
4	Relocate existing channel in Gravelly Run into a concrete channel or closed conduit; cover contaminated flood plain with 3 ft. minimum impervious cover
5	Dredge new channel adjacent to existing channel of Gravelly Run; seal side slopes of new one and cover contaminated flood plain. Place flow control structure at mouth
6	Dredge all contaminated material in Gravelly Run and place spoil in disposal site 14 in Bailey Bay
7	Dam and possible treatment plant at mouth of Bailey Creek; treat flows up to and including the 100 year flood level
8	Seal contaminated flood plain of Bailey Creek with 3 ft. minimum layer of native cohesive material; flow structure downstream to prevent seepage
9	Relocate existing channel in Bailey Creek into concrete conduit; cover and seal contaminated flood plain-3 ft. minimum of impervious cover
10	Dredge new channel in Bailey Creek adjacent to existing channel; seal side slopes of new one and cover contaminated flood plain. Place flow control structure at mouth
11	Dredge all contaminated material in Bailey Creek and place spoil in disposal site 14 in Bailey Bay
12	Reduce flows and treatment needs via impounding and diversion of upstream flows up to 100 year flow level in Bailey Creek, above old sewage treatment plant; diversion via overland pressure conduit to Chappel Creek or gravity conduit to the James River. This alternative would be combined with another to solve the Kepone problem in polluted stream portion below old treatment plant
13	Dredge all contaminated material from all of Bailey Bay. The top 15 inches would be dredged. Bailey Creek would be impounded and the spoil placed behind the dam
14	Construct a 14,250 ft. levee across Bailey Bay from 1 mile east of City Point to Jordan Point and treat entire discharge from Gravelly Run, Bailey Creek, and Bailey Bay
15	Construct dam near mouth of Bailey Creek; dredge all of Bailey Bay; place spoil behind Bailey Creek dam; construct dam at mouth of Gravelly Run and divert discharge to Bailey Creek; treatment facility at mouth of Bailey Creek to treat all effluent from the disposal area
16	Construct levee from 1 mile east of City Point across Bailey Bay to Jordan Point; use confined area for maintenance dredging of James River; treat effluent from disposal area
17	Construct levee from Jordan Point to east side of Bailey Creek; use confined area for disposal; dredge remainder of Bailey Bay, Bailey Creek, and Gravelly Run; proposed spoil site is number 14, judged to be the best
18	Cover all contaminated areas of Bailey Bay, Bailey Creek, and Gravelly Run with impervious blanket; allow drainage patterns to develop

TABLE A-8. TREATMENT COST ESTIMATES FOR ALTERNATIVES ON THE JAMES RIVER

Method	Costs	
	Without Dredging	With Dredging
Corps of Engineers (COE)*		
Dredging with Oozer Dredge	N/A	\$ 1.0×10^9
Molten Sulfur Stabilization	\$ 6.2×10^9	\$ 7.2×10^8
TJK Fixation with Removal	\$ $1.8\text{-}2.6 \times 10^9$	\$ $2.8\text{-}3.6 \times 10^9$
Elutriate Treatment - UV-ozone	\$ 12.4×10^6	\$ 1.01×10^9
Elutriate Treatment - temporary scheme filtration/carbon absorption	\$ 40.3×10^6	\$ 1.04×10^9
UV-ozone for Sediments	\$ $26.6\text{-}53.1 \times 10^6$	\$ $1.03\text{-}1.05 \times 10^9$
Battelle*		
In situ Application of Retrievable Sorbents	\$ 6.2×10^9	N/A
In situ Application of Coal	\$ 2.2×10^8	N/A
In situ Application of Activated Carbon	\$ 3.6×10^9	N/A

N/A - Not applicable.

* The areas used by the COE for determined dredging alternative costs were slightly different than those used by Battelle in determining non-conventional alternative costs. This difference does affect the cost ranking.

Source: Brossman, et. al., 1978

USACE is responsible for maintaining the waterborne traffic in the Hudson River. The Hudson River is divided into two sections: the upper Hudson which covers the 40-mile reach between Glenn Falls and the Federal Dam at Troy, and the lower Hudson -- 150-mile stretch between Albany and the mouth of the river in the upper New York Harbor.

The General Electric Company (GE) owned and operated two capacitor manufacturing plants in Glenn Falls for 25 years (ending in 1977). During this period it is estimated that the plant discharged about 500,000 pounds of PCBs into the Hudson River. Gross contamination of Hudson River fish was noted in the early 1970s. Health advisories for fish consumption from the lower river, and a complete ban on fishing from the upper river have been in effect since the mid-1970s. Extensive sampling by various authorities indicates that nearly two-thirds of the PCB-contaminated sediments in the upper Hudson River are over a 40-mile section between Fort Edward and the Federal Dam at Troy. Most of this sediment had accumulated behind the Fort Edward Dam. In 1973 the dam was removed allowing large quantities of the contaminated sediments to be transported down-river. Some of the sediments that had collected along the edges of the river behind the dam became exposed as the river lowered. These exposed contaminated sediments were classified as remnant deposits. Table A-9 shows the distribution of PCB-contaminated sediment in the Hudson River. As the data indicates, 26 to 33 percent of the total PCB mass is in the lower Hudson sediments.

Sampling of the upper Hudson River sediments was carried out by the New York State Department of Environmental Conservation (NYSDEC) and other consultants. Using the sampling results, "hot spots" of PCB-contaminated sediment were identified. PCB concentrations of 50 ppm or more were the primary criterion to define hot spots. Areas containing less than 50 ppm of PCBs were termed "cold spots". Forty "hot spots" were identified within a 40-mile section of the river between Roger Island and Mechanicsville. These "hot spots" contained 58 percent of the total contaminated sediments covering only 8 percent of the area (13.1×10^6 ft^2). The average PCB concentration within the "hot spots" was 127 ppm.

The mapping operations were done in 1978. In 1983 as part of the Superfund I Remedial Action Master Plan, the areas were reexamined. This new study showed that the total amount of PCBs in the Hudson River sediment was 504,000 pounds. The majority of the PCBs (95 percent) were found in the top 0.5 m of the sediment and 99.91 percent in the top 1 meter. The study also showed that the "hot spots" had not moved and did not contribute to the PCB's transport to the lower Hudson River.

Although PCBs are the major contaminants in the Hudson River sediments, they also contain elevated levels of toxic heavy metals, for example, lead, mercury, copper, cadmium, and nickel. Table A-10 shows the heavy metal content of some selected sediments. These heavy metals most likely originated from the Marathon Battery Plant, the Hercules Chemical (now CIBA-Geigy) plant, or other sources. Large lead discharges from the Hercules plant occurred at the same time as PCB discharges from the GE plants.

Cleanup of the contaminated area began in several phases. As a result of the 1976 Settlement Agreement, GE stopped discharging PCBs into the River on July 1, 1977. They also constructed wastewater treatment facilities at the capacitor manufacturing plants and replaced PCBs in the capacitor with alkyl phthalates.

The Department of Transportation responsible for routine channel maintenance undertook two clean-up operations at Fort Edward to mitigate remnant river bank deposits exposed (Figure A-6) by floods.

TABLE A-9. DISTRIBUTION OF PCBs IN THE HUDSON RIVER

Location	PCB mass estimates (pounds)
Remnant deposits	47,000 - 140,000
Upper Hudson River sediments	
Hot spots	170,000
Cold areas	120,000 - 180,000
Subtotal	290,000 - 350,000
Lower Hudson River sediments	169,000
TOTAL	506,000 - 659,000

Source: NUS Corporation, 1983.

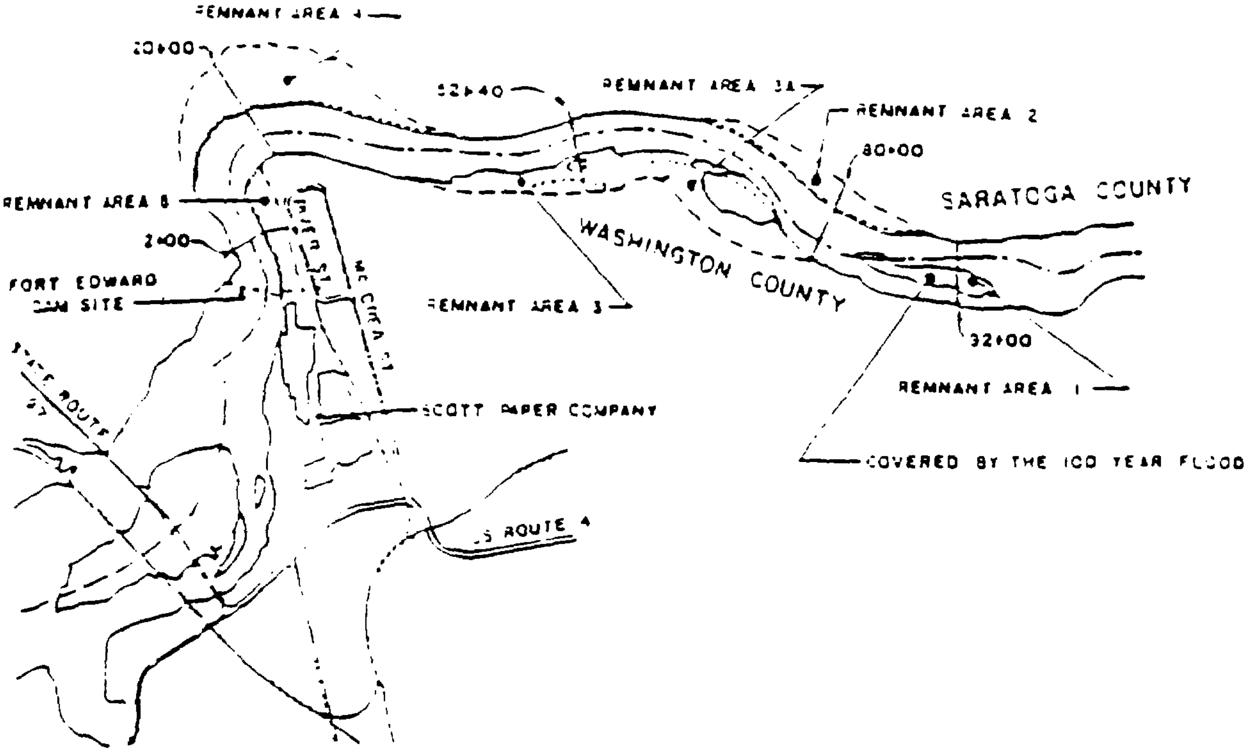
TABLE A-10. HEAVY METAL CONTENT OF SELECTED UPRIVER SEDIMENTS ($\mu g/g$)

Sample	Lead	Cadmium	Copper	Mercury	Arsenic	Zinc
Fort Edward Dam	234-3630	14-138	27-159	0.28-1.28	3.2-22	74-2950
Remnant deposits						
Area 3A	<3 to 5600	6 to 110				
Area 4	20-480	<4-12				
Area 5	40-1100	<4-93				

Source: Malcolm Pirnie, Inc.

NYSDEC constructed rip-rap above 1,100 feet of riverbank (at a cost of $75,000). In addition, the slope leading to the river along 2,800 ft of bank was graded and planted at a cost of $72,000. The highly contaminated sediments from area 3A were excavated and encapsulated.

During the period 1977-1978, 200,000 cu yd of contaminated sediments was dredged from the Hudson River near the PCB discharged plant and placed in a clay-lined landfill. The original remedial plan called for dredging of 1.5 million cu yd from the Upper Hudson River, removal of contaminated



Source: NUS

Figure A-6. Locations of remnant sediment deposits.

river bank deposits, and transfer of previously dredged sediment to a secure landfill. The cost (pre-RCRA) of this plan was estimated to be $40 million. However, because of the RCRA legislation, this cost estimate is no longer valid and the original plan has been pared down significantly.

A broad range of alternatives was considered in the feasibility study for the cleanup or isolation of contaminated sediments and remnant deposits. Table A-11 summarizes these alternatives. The estimated costs for these operations are shown in Table A-12. Based on the detailed evaluation of alternatives, the following recommendations were made:

- Containment of those remnant deposits with an average PCB content of 50 ppm or higher, and restricted access to the others. A remedial investigation would be performed to accurately delineate the areas to be covered. Those areas to be covered would have a 1-1/2 ft-thick layer of subsoil covered by a 6-in layer of topsoil. The cover would then be graded and seeded to minimize erosion. Where needed, bank stabilization would be placed along the riverbank to prevent scour. The restricted areas would be fenced and posted to prevent unauthorized entry. The estimated cost for the remedial action was $1,050,000, and for the remedial investigation was $200,000.

- Based on the data available on PCBs in the Hudson River, a 1984 ROD "no remedial action" alternative was selected. The limited threat to the public health did not justify the large expenditure of money required to remove the contaminated sediments. The 1984 ROD has recently been reopened and a new one is expected to be issued in 1992.

- The following remediation techniques were proposed for the cleaning up of the dredged sediments: biodegradation, incineration, dechlorination, low energy solvent extraction, and stabilization/solidification (using an organic polymer).

TABLE A-11. REMEDIAL ACTIONS CONSIDERED FOR THE INITIAL SCREENING

Remedial Action	Passed Initial Screening	Rationale for Eliminating
SEDIMENTS		
1. No action, but continue routine dredging required for navigation and treat contaminated water	Yes	--
2. No action, but continue routine dredging with no water treatment	Yes	--
3. No action, no routine dredging	No	Sediment-blocked channels would result in cessation of commercial shipping
4. River sediment dredging		
a. Bank-to-bank dredging	No	a. Cost prohibitive;
b. Full-scale dredging of 40 hot spots	Yes	b. Difficult to implement; c. Destructive to ecology
c. Reduced dredging of portions of hot spots	Yes	
5. Control river flow to reduce PCB migration during high flow periods	No	Cost prohibitive; offers on clear advantage over some less costly alternatives
6. In-place detoxification		Technologies not proven for in-place treatment
a. UV ozonation	No	
b. Chemical treatment	No	
c. Bioharvesting	No	
d. Activated carbon adsorption	No	
7. In-river containment of hot spots		High monitoring and maintenance costs; effectiveness of capping has not been demonstrated for rivers
a. Earthen dikes or berms	No	
b. Spur dikes	No	
c. Bulkheads	No	
d. Sheet pilings	No	
e. Impermeable liner	No	
8. In situ detoxification in combination with control of river flow	No	Construction of dams to control flow is cost-prohibitive
9. Dredging (full-scale or partial) together with control of river flow	No	Cost-prohibitive
10. Dredging (full-scale or partial) together with in-place containment	No	In-place containment with dredging offers no advantage over dredging alone
11. Control of river flow and in-place containment	No	Cost-prohibitive
12. Combination of partial dredging, in-place detoxification, in-place containment and control of river flow	No	Cost-prohibitive

TABLE A-11 (continued)

Remedial Action	Passed Initial Screening	Rationale for Eliminating
REMNANT DEPOSITS		
1. No action	Yes	--
2. Restricted access	Yes	--
3. In-place containment		
a. Placement of impermeable cover	Yes	--
b. Construction of protective blanket composed of graded material	Yes	
c. Construction of curtain wall to prevent groundwater infiltration	Yes	
4. Removal of contaminated materials		
a. Complete removal	Yes	--
b. Partial removal of Areas 3 and 5	Yes	
c. Complete removal of Areas 3 and 5	Yes	
5. Partial removal of deposits together with in-place containment	Yes	--
6. Partial removal of deposits together with restricted access	Yes	--
7. Partial removal of deposits together with detoxification	Yes	--
8. In-place containment together with restricted access	Yes	--
9. In-place containment together with in-place detoxification	Yes	--
10. Restricted access is combination with in-place detoxification	Yes	--
11. Combination of removal, restricted access, and detoxification	No	Not possible to determine the appropriateness of each method given the existing data base
12. Combination of removal, restricted access, and partial in-place containment	No	Not possible to determine the appropriateness of each method given the existing data base
13. Combination of removal, partial in-place containment, in-place detoxification, and restricted access	No	Not possible to determine the appropriateness of each method given the existing data base

TABLE A-11 (continued)

Remedial Action	Passed Initial Screening	Rationale for Eliminating
TREATMENT/DISPOSAL OF DREDGED SEDIMENTS		
1. Acurex process - dechlorination using a sodium reagent in a nitrogent atmosphere	No	Process difficult to use; not permitted by EPA for treatment of PCBs in sediments
2. Biological degradation	No	Not proven effective for PCBs
3. Goodyear process - uses sodium naphthalide in an inert atmosphere to destroy PCBs	No	Process is non-mobile; solvent extraction of sediments is required
4. Hydrothermal process - decomposition of PCBs at 570°F, 2560 psi, in presence of methanol and sodium hydroxide	No	Developmental
5. KOHPEG process - destruction of PCBs using polyethylene glycols and potassium hydroxide at 170-250°F	Yes	--
6. NaPEG process - uses molten sodium metal in polyethylene glycol to effect decomposition	No	Process performance is sensitive to presence of impurities
7. PCBX process - uses sodium salts of organic compounds in an amine solution to effect destruction	No	Not EPA-approved for treatment of PCB-contaminated sediments; requires solvent extraction
8. Plasma arc - PCB destruction by molecular fraction	No	Developmental
9. Pyromagnetics incineration	No	Developmental
10. Rotary kiln incinerator	Yes	--
11. Thagard high-temperature fluid wall incinerator	No	Non-mobile; cost-prohibitive
12. Wet air oxidation	Yes	--
13. Secure landfill disposal	Yes	--

TABLE A-12. COST COMPARISONS FOR REMEDIAL ALTERNATIVES

Remedial Alternative	Capital Costs	O&M Costs*	Total Costs*
1. No remedial action, water supply not treated	$ 0	$ 3,434,000	$ 3,434,000
2. No remedial action, water supply treated	$ 114,000	$ 3,617,000	$ 3,731,000
3. Dredging of 40 hot spots	$ 54,987,000	$ 5,321,000	$ 60,308,000
4. Reduced scale dredging	$ 34,048,000	$ 5,321,000	$ 39,369,000
5. Total removal of all remnant deposits	$ 12,894,000	$ 1,887,000	$ 14,781,000
6. Partial removal of remnant deposits	$ 6,917,000	$ 3,011,000	$ 9,928,000
7. Restricted access to remnant deposits	$ 372,000	$ 1,124,000	$ 1,496,000
8. In-place containment of remnant deposits	$ 2,282,000	$ 1,124,000	$ 3,406,000
9. In situ detoxification of remnant deposits	$ 66,696,000	$ 0	$ 66,696,000
10. No action on #1, 2, & 4/restrict access to #3 & 5	$ 154,000	$ 1,124,000	$ 1,278,000
11. Partial removal/ contaminant of remnant deposits	$ 9,010,000	$ 3,011,000	$ 12,021,000
12. Partial removal/restricted access of remnant deposits	$ 7,144,000	$ 3,011,000	$ 10,155,000
13. Partial containment/ restricted access to remnant deposits	$ 1,053,000	$ 1,124,000	$ 2,177,000
14. Partial containment/in-situ detoxification of remnant deposits	$ 38,878,000	$ 1,124,000	$ 40,002,000
15. Partial removal/in-situ detoxification of remnant deposits	$ 42,622,000	$ 1,887,000	$ 44,509,000
16. Partial detoxification/ restricted access of remnant deposits	$ 36,853,000	$ 1,124,000	$ 37,977,000
17. Detox. of sediments with KOHPEG	$ 289,877,000	$ 0	$ 289,877,000
18. Secure landfill disposal of sediments	$ 15,203,000	$ 1,887,000	$ 17,090,000
19. Incineration of sediments	$ 249,787,000	$ 0	$ 249,787,000
20. Wet air oxidation of sediments	$ 109,340,000	$ 0	$ 109,340,000

*Present worth over O&M life of alternative.

Source: NUS Corporation, 1983.

APPENDIX B

TREATABILITY STUDIES

APPENDIX B

TREATABILITY STUDIES

A large number of physical, chemical, and biological processes have been developed to treat contaminated solids, air, and water at sites that contain hazardous wastes. Some of these technologies were developed for specific sites and/or specific wastes. Others are adaptations of techniques that are used to treat process wastes and wastewater streams.

When a preliminary evaluation shows that one or more of these technologies might be effective at a specific hazardous waste site, a treatability study is usually required. Treatability studies -- which can be bench-scale, pilot-scale, or both -- determine whether a technology can meet the technical, environmental, and cost expectations developed in the preliminary evaluation. The EPA guidance document -- *Guide for Conducting Treatability Studies Under CERCLA, Interim Final,* EPA/540-2-89/058 -- discusses in detail the various aspects of a treatability study. Generally, the remedial action contractor (RAC) responsible for the site RI/FS, under the guidance of the RPM, also identifies the need for treatability studies and for specifying the goals of the treatability study.

In some cases, the RAC will also specify the procedures to be followed in conducting the treatability studies. In other cases the technology to be evaluated requires specialized equipment and techniques for a treatability study. In such cases the procedures are established by the equipment manufacturer or technology developers. Table B-1 summarizes a typical specification for a treatability study.

Various treatability studies -- laboratory-, bench-, and pilot-scale -- have been conducted with contaminated sediments. Since sediments can be considered water slurries of soils, and after dewatering, as wet soils, the remediation technologies applicable to soils are also potentially applicable to sediments. Therefore, several treatability studies conducted with soils have also been included among these studies. A list of treatability studies conducted are shown in Table B-2.

No Action

James River, Virginia--

Kepone was produced between 1966 and 1974 by Allied Chemical Corporation at Hopewell, VA. Kepone-containing effluents entered the James River and contaminated the river sediment.

TABLE B-1. TYPICAL SPECIFICATION FOR A TREATABILITY STUDY

1. Background
    - Site description
    - Waste stream description
    - Remedial technology description
    - Previous treatability studies at the site
2. Test Objectives
3. Approach
    - Task 1 - Work Plan preparation
    - Task 2 - SAP, HSP, and CRP preparation
    - Task 3 - Treatability study execution
    - Task 4 - Data analysis and interpretation
    - Task 5 - Report preparation
    - Task 6 - Residuals management
4. Reporting Requirements
    - Deliverables
    - Monthly reports
5. Schedule
6. Level of Effort

Source: USEPA, 1989k

Because of the high partition coefficient, the majority of kepone was found in the sediment. Kepone manufacturing was discontinued in 1975 and the kepone concentration in the surface sediment began to decrease significantly. This was attributed to the dilution and burial of the kepone by fresh sediment. By 1983 kepone concentrations in fish were low enough to lift restrictions on all commercial fishing.

Studies conducted to assess the feasibility of mitigating the kepone contamination included the following two options: dredging at an estimated cost of $3000 million (excluding disposal costs) and stabilizing the sediments with molten sulfur. Neither of these options were feasible, either economically or environmentally. Therefore, nothing was done. This no action decision was supported by the fact that natural sedimentation buried the kepone-contaminated surface sediment making kepone unavailable to biota. However, this decision also places a potential restriction on future dredging of the sediment to keep the James River navigable, since dredging might expose the kepone-contaminated sediment.

TABLE B-2. LIST OF TREATABILITY STUDIES

Technology	Site name	Medium	Contaminants
No action	James River, VA	Sediments	Kepone
In Situ Treatment			
Natural biodegradation	Great Lakes	Sediments	PCBs
Dredging and Disposal			
Ocean disposable	New York Bight	Sediments	PAHs, PCBs
Capping	Stanford, CT	Sediments	Not stated
	Norwalk, CT	Sediments	Not stated
	New York Mud Site	Sediments	Not stated
	Massachusetts Bay Foul Area Disposal Site	Sediments	Not stated
Dredging and Treatment	Tecumseh Motors Superfund Site, WI	Sediments	PCBs
Biological	LA, WI, and PA Army ammunitions plants	Sediments/soils	TNT, RDX, HMX, nitrocellulose
	General Motors, Massena, NY	Sludge	PCBs
Physical/Chemical			
Dechlorination	Naval Construction Battalion Center, Gulfsport, MS; Bengart and Memel Buffalo, NY; Montana Pole, Butte, MT	Soils	PCBs, dioxins, other chemicals
	Wide Beach Superfund Site, NY	Soils	PCBs
Solvent extraction	Various army depots and plants	Sediments	TNT, DNT, RDX, and others
	New Bedford Harbor	Sediments	PCBs
	Arrowhead Refinery Site, Hermantown, MN	Sludges	PAHs, VOCs, lead, zinc, and PCBs. Ineffective against metals
	Grand Calumet River, IN	Sediment	PCBs, PAHs, oil and grease
Soil washing	Superfund Site, MN	Soils	PCPs, PAHs, petroleum hydrocarbons, copper, chromium, and arsenic
	Saginaw River, MI	Sediments	PCBs
	Wood Preserving, CA	Soils	PAHs, copper, chromium, arsenic, and zinc
	Wood Preserving, FL	Soils	PCPs
	Chemical Plant, CA	Soils	Benzidine, azobenzene, and dichlorobenzidine
	Wire Drawing, NJ	Soils	TPHs, VOCs, copper, nickel, and silver

TABLE B-2. (Continued)

Technology	Site name	Medium	Contaminants
Soil washing (continued)	Town Gas, Quebec	Soils	Total PAHs
	Pesticide Formulation, CO	Soils	Pesticides
	Chemical Plant, CA	Soils	PCBs, Aroclor 1260
Solidification/Stabilization	Hialeah, FL	Soils	PCBs
	Douglassville, PA	Soils	Oil, grease, VOCs, PCBs, metals, and semivolatile organics
	Marathon Battery Site	Soils	Not stated
	Foundry Cove	Sediments	Cadmium, cobalt, and nickel
	Indiana Harbor Canal, IN	Sediment	Oil, grease, VOCs, PCBs, and metals
	Buffalo River, NY	Sediment	Oil, grease, VOCs, PCBs, and metals
Thermal Treatment			
Incineration	Louisiana Army Ammunition Plant	Sediment	TNT, RDS, tetryl, and nitrocellulose
	Swanson River Oil Field, AK	Soils/sediment	PCBs
	McColl Superfund Site, Fullerton, CA	Soils	Organics and metals
Shirco Infrared System	Peak Oil Superfund Site, Brandon, FL	Oil-like material	PCBs, other organics, and metals
Low Temperature Thermal Desorption	Kettleman Hills Facility, CA	Not stated	Not stated
	Buffalo River, Buffalo, NY	Sediments	PAHs, oil and grease
	Ashtabula River, Ohio	Sediments	PCBs and other chlorinated hydrocarbons

In Situ Treatment

The stabilization of contaminated sediments can be achieved by the injection of grouting materials into sediments. A commonly used Japanese method for grouting is the injection of clay-cement or quicklime mixtures into the bottom sediment via a deep soil mixing method (Hand et al., 1978).

The essential feature of this relatively new technology, shown in Figure B-1, is the injection mechanism -- a number of injection pipes mounted on a barge. The ends of these pipes incorporate internal mixing blades that enter into the sediments. The process begins by lowering the injecting/mixing apparatus to the required depth. The pipes then simultaneously inject a cement or lime-based slurry into the sediments. At the end of the process, the mixing blades are reversed and the shafts are removed and relocated.

A number of other types of grout injection and mixing apparatus are available. Multi-column, continuous mixing apparatus which lessens the need for raising, relocating, and lowering of the mixing apparatus is also available. However, the feasibility and reliability of these methods for contaminated sediments has not yet been demonstrated.

The use of this *in situ* method on a barge restricts offshore activity to calm waters and periods of good weather. Also, the injection operation may result in resuspension of sediments.

Natural Biodegradation

Anderson (1980) has shown that bacteria from Saginaw Bay and river sediments are capable of degrading PCB-contaminated sediments from the Great Lakes. The degradation rate is enhanced under aerobic conditions. The degradation rates of di- and trichlorobiphenyls are extremely rapid in incubated sediments. The tetra- and pentachlorobiphenyls are degraded at a slower rate than the di- and trichloro compounds. Anaerobic conditions were not conducive to degradation.

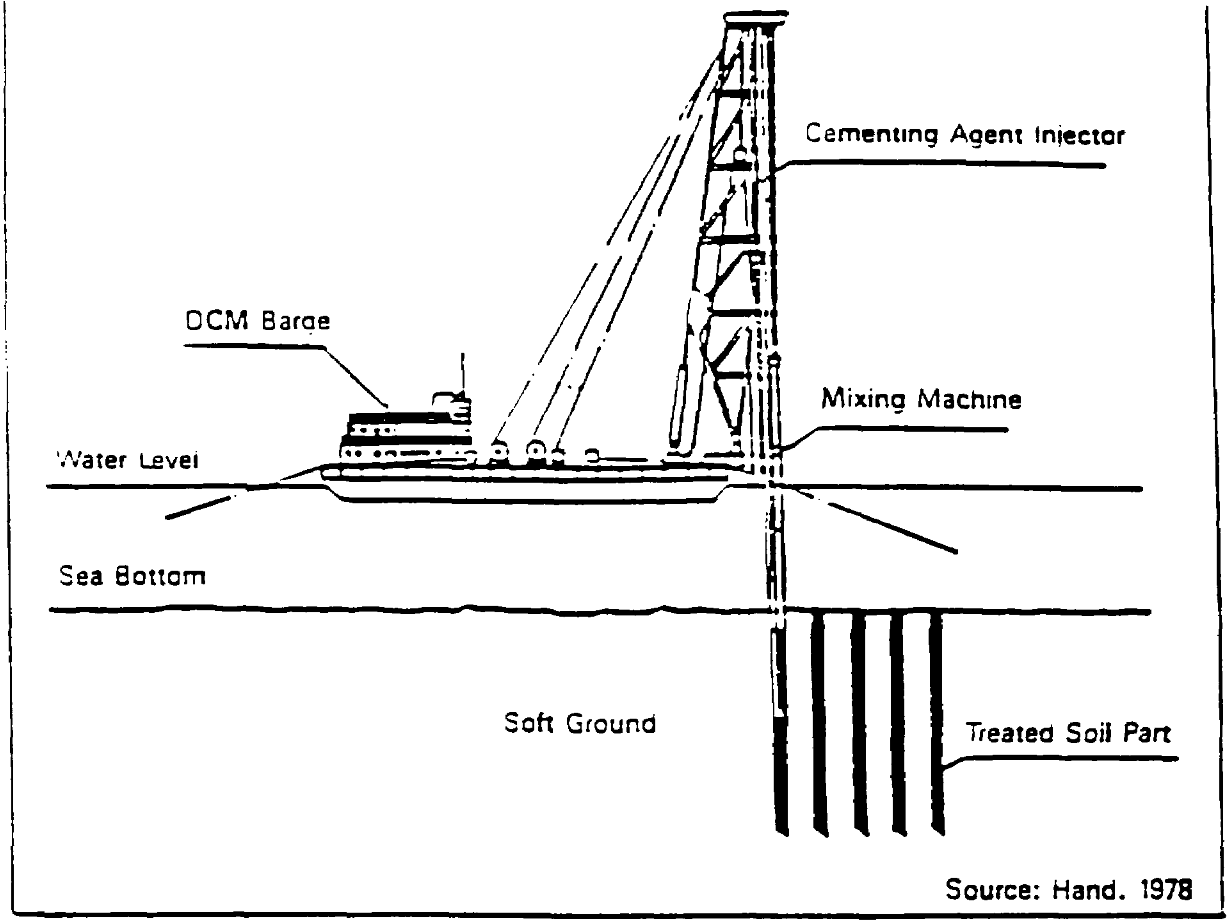


Figure B-1. Fixation by deep chemical mixing.

Dredging and Disposal

Ocean Disposal--

Concentrations of polynuclear hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) were measured in waters of New York Bight prior to, during, and after a dredged material disposal operation. P.D. Boehm compared the PAH profiles in water column with those in the dredged material to evaluat the short-term fractionation and weathering.

PAHs associated with the dredged material were rapidly altered in the water column by dissolution and microbial processes. The PAH and PCB measurements were sensitive indicators of the movement and fate of the particulate plumes from the dredged material. Fifteen minutes after the dredged material was dumped, the residual plume was found in near-bottom water and remained detectable for at least 2.5 hours. The study concluded that ocean disposal is a viable option (Boehm et al., 1983).

Capping--

The first field study of controlled capping of contaminated dredged material using a reasonable amount of capping material was conducted at the Central Long Island Sound Disposal Site in 1979. In this project two disposal mounds were formed underwater, each with approximately 30,000 m^3 of contaminated sediments from Stamford, Connecticut. These deposits were then capped, one with approximately 76,000 m^3 of silt, and the other with 33,000 m^3 of sand dredged from New Haven Harbor. The conclusions of the study were as follows:

- Disposal of contaminated sediments must be tightly controlled to reduce the spread of the sediment before they are capped. This can be accomplished through use of taut-wire disposal buoys and/or precision navigation control.

- Capping material must be spread over a large area in order to ensure adequate capping at the end's outer limits of the contaminated sediments. This is particularly important for silt, which does not spread as evenly as sand.

- Silt develops a thicker cap than sand and, hence, requires more material. Silt caps do not spread readily. However, a greater thickness is needed because the depth of bioturbation is deeper in silt than in sand.

- Silt caps recolonize with fauna similar to the surrounding silt environment, but sand caps with completely different species. Recolonization of both mounds occurred as expected. The impact to the surrounding environment was negligible.

- Caps are resistant to erosion. Once stabilized, both the silt and sand caps remain essentially unchanged.

Other successfully completed capping operations are:

- In **Norwalk, Connecticut**, a site in shallow water was dredged and contaminated sediment was placed in the dredged depression. The sediment was then covered with the dredged material. This technique was proposed for disposal of PCB-contaminated sediments at the New Bedford Superfund site. This technique is restricted to shallow-water environments.

- Open-water capping was tested at the **New York Mud Dump** site. Approximately 522,000 m^3 of contaminated sediment was covered by 1.2 million m^3 of clean sand in a mound which has persisted on the open ocean shelf for seven years. This experimental study concluded that a cap thickness of 1.5 to 2 m stabilizes the disposed material for at least seven years. Bottom profiles across the disposal site showed that the cap was continuous in nature.

- Laboratory studies by USACE (USACE, 1990) showed that a 35-cm cap effectively isolated contaminated sediment when spread over a confined aquatic area (CAD). However, an additional 20 cm of cap thickness was recommended to prevent burrowing organisms from having access to the contaminants. The additional material ensures effective coverage over the entire CAD area, protecting it against scouring by hydrodynamic forces, and providing long-term stability for the capped material.

These studies show that capping is a viable technique for safe disposal of contaminated sediments in the marine environment and that the factors affecting capping can be predicted with reasonable accuracy (National Research Council, 1989).

Disposal of contaminated sediments in the marine (ocean/bay) environment through capping with cleaner materials (sand, silt, limestone, etc.) is a viable option. Most capping operations are restricted to calm and shallow waters (20-30 m; 65-100 ft) but the knowledge and experience gained from these projects are helpful in predicting the consequences of extending such operations to deeper water. In order to ensure the integrity of the capped sediment, an extensive monitoring program, the Disposal Area Monitoring System (DAMOS), was developed by USACE, New England Division.

The DAMOS monitoring approach begins with site designation and extends through the disposal operation to post-disposal monitoring. The essential elements of the DAMOS program are shown in Table B-3 below.

The DAMOS program has developed a comprehensive data base that confirms the viability of several important parameters necessary for capping operations:

- Operational feasibility: navigational control and disposal operating procedures are adequate to create mounds of contaminated sediment and to spread sufficient cap material to effectively cover these mounds.

- Minimal dispersion during dispersal: extensive plume tracking studies have demonstrated that most dredged material remains at the bottom during the placement operation.

- Long-term stability of disposal mounds: repeated measurements over a ten-year period showed that, following initial placement, the capped disposal mounds remain unchanged over extended periods of time.

- Sand or silt cap material: all studies to date show that either sand or silt are adequate for capping contaminated sediment. Silt caps require more material than sand. Also, the spreading techniques for sand/silt are different. The economic feasibility of capping depends, to a large extent, on the availability of clean silt and/or sand.

- Isolation of contaminated material: both chemical and biological monitoring show that, given sufficient cap thickness and stability, neither bioactivity nor chemical leaching will expose the environment to the contaminated sediment.

TABLE B-3. ELEMENTS OF THE DAMOS PROGRAM

	Physical	Biological	Chemical
Site designation (characterization)	Bathymetry/SSCAN Remots Currents/waves Sediment grain size	Remots - habitat Benthic - type present Brat - fish habitat Fish - type present	Bulk sediment Analysis
Pre-disposal (baseline)	Bathymetry/SSCAN Harbor characterization (Density, GS, geotech) Disposal control	Benthic body burden Compounds selected based on waste characterization If >one year - Remots	Waste Characterization Bulk sediment analysis Bioassays, etc.
During disposal	Bathymetry/Remots Plume studies Mussels/Daisy		
Post-disposal	Bathymetry/SSCAN Remots Mussels/daisy	Remots (within 2 weeks)	
Monitoring	Bathymetry/Remots (next season, then annually, Aug/Sep) Mussels	Remots (next season, then annually, Aug/Sep) If recolonized: Benthic, brat, Body burden	If not recolonized: Bulk sediment analysis

The following instrumentation is required to confirm DAMOS monitoring:

- Microwave or acoustically assisted positioning of dredged material.

- Precision bathymetry (sonar) to facilitate monitoring of the volume/ distribution of sediments at the disposal site. These data are used to assess the effectiveness of capping and the long-term stability of the cap.

- Sediment profile photography in which a remote sensing camera determines the distribution and characteristics of near-surface sediments. This procedure determines the small-scale effects of physical erosion and bioturbation. It provides an effective method for measuring biological parameters in order to evaluate the impacts of disposal and capping operations.

- Advanced acoustic measurements. Modern acoustic instruments such as sidescan sonar, high resolution sub-bottom profilers, and high-frequency plume tracking systems provide information on the distribution and physical properties of sediments during and after disposal.

- Specialized instrumentation such as Disposal Area In Situ System (DAISY) provide information for addressing specific problems associated with dredged material disposal and capping. DAISY measures near-bottom current and wave energy associated with sediment resuspension and turbidity. It thus addresses the long-term stability of capped disposal mounds.

- A nuclear density probe coupled with a sediment penetration device is now used along with precision bathymetry, REMOTS, and sub-bottom profiling to determine the mass balance of sediment deposited in the capped mound.

These monitoring techniques and disposal procedures were applied in two major, recently completed field studies (the New York Experimental Mud Dump Site (EMD) and the Massachusetts Bay Foul Area Disposal Site (FADS). The objective of the EMD study was to assess the long-term (five years) stability of a sand capped contaminated sediment in the open-shelf environment. The FADS project involved the short-term (several months) effects of disposal of contaminated sediments in 90 m of water.

At the EMD, the results indicate that following disposal, a sand cap of approximately 1.5 to 2.0 m covered most of the contaminated material and that this cap was essentially unchanged during the subsequent five-year period. Sub-bottom profiles across the disposal site demonstrated the integrity of the cap. REMOTS photography supported the sub-bottom data. The photography also revealed that recolonization of the disposal mound by the aquatic biota took place, but biopenetration was restricted to only a few centimeters of the sand cap. Thus, the isolation of the contaminated material was assured. On the flanks of the mound, however, where the thickness of the cap is not so great, some dispersion of the sediment did occur.

Disposal of contaminated material at FADS was carried out by scows and hopper dredges at a water depth of 90 m. Disposal of cohesive sediments at this site did form proper mounds. REMOTS camera data showed that disposal of dredged material -- even under tight control -- resulted in a broad, low deposit spread evenly over a large area. The formation of thin and broad deposits proved that greater amounts of capping material are needed. For example, to effectively cap 100,000 m^3 of contaminated material, between 250,000 and 500,000 m^3 of capping material may be needed. Hence, careful consideration should be given before undertaking any projects using this technique.

Dredging and Treatment

Biological--

Sediment and soil from lagoons at Army ammunition plants in Louisiana, Wisconsin, and Pennsylvania containing TNT, nitrocellulose, and other organic nitro compounds were treated in two types of composts -- hay-horse feed and sewage sludge-wood shavings. Three ratios of sediment/soil to composts were utilized.

Six 488-gallon tanks 5-feet in diameter and 4-feet in height were used as composters. These were placed in greenhouses. Two drums of contaminated sediment from a dredging mound were used. The composts were incubated at 60°C with continuous aeration for 6-10 weeks. ^{14}C-labeled tracers were used to monitor the progress of degradation. The study showed that TNT degraded rapidly in all sewage sludge composts. However, breakdown in the hay-horse feed compost was adversely affected by the higher rates of sediment addition. Cleavage of the benzene ring during TNT breakdown did not appear to be significant.

RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine) was almost completely degraded in all composts during 10 weeks of incubation. Increased rates of sediment addition significantly reduced the rate of RDX breakdown in both composts. HMX (1,3,5,7-tetranitro-octahydro-octane) was not degraded in the hay-horse feed compost but was reduced by 30-50% during 10 weeks of incubation in the sewage sludge compost. In the sewage sludge compost 92-97% of the nitrocellulose degraded within 4 weeks. Leaching of explosives and heavy metals from the composts was minimal. Details of the study, including economic information, are available from Atlantic Research Corp. in *Composting Explosives/Organics Contaminated Soils*, a technical report prepared for USATHAMA in May, 1988.

Detox Industries, Inc. bench-tested PCB-contaminated sludge samples from the General Motors (GM) Massena, New York plant using their proprietary biological process. Partial results of the study are shown in Table B-4. The USEPA approved the GM request to conduct a full-scale study of this process at the GM site in Massena, NY.

TABLE B-4. PCB (1248) Biodegradation

	Untreated soil	Treated soil	Percent reduction
GM Lagoon #1	338 ppm	107 ppm	68.3
GM Digester	110 ppm	63 ppm	42.7
GM Activated Sludge	63 ppm	6.5 ppm	89.6

Source: USEPA, 1989i

Physical/Chemical Treatment

Dechlorination--

Galson Technical Services conducted bench- and pilot-scale treatability studies at three different sites: Naval Construction Battalion Center (NCBC) in Gulfport, MS; Bengart and Memel in Buffalo, NY; and the Montana Pole in Butte, MT. Soils contaminated with PCBs and/or dioxins were treated with a mixture of potassium hydroxide (KOH), dimethyl sulfoxide, polyethylene glycol, and other chemicals to dechlorinate the PCBs and dioxins. The ratios of reagents to soil, reaction times and temperatures were varied.

The results of the tests at Montana Pole showed that dioxin levels reduced from 100,000 ppb to less than 1 ppb after 1 hour of reaction time at 150°C. The results of the NCBC study showed that the soil from Gulfport, MS, could be decontaminated by mixing the soil with the APEG reagent and heating at 120°C for 7 hours. The results of the Bengart and Memel study show that PCBs in the soil can be reduced to less than 50 ppm by adding reagent to the soil and heating the soil/reagent mixture at 120°C for 12-24 hours. Table B-5 shows some of the results of the studies conducted at NCBC and Buffalo. For further details contact the vendor: Timothy Gerates, Galson Research Corp., 6601 Kirkville Road, E. Syracuse, NY 13057, 315-463-5160.

A more extensive study using this technique was carried out by Galson Research Corporation (GRC) of Syracuse (HMCRI, 1988). PCB-contaminated soils from the Wide Beach Superfund Site in New York State were treated by the KPEG process on bench- and pilot-scale. In the bench-scale study the soils were heated at 140 to 160°C for 4 to 8 hrs. The PCB concentrations were reduced from 490 to 620 ppm to less than 10 ppm. The bench-scale study estimated an approximate cost of $100-300/ton for Wide Beach soil treatment, excluding excavation. The pilot-scale study also produced encouraging results. Further process evaluation is in progress.

Solvent Extraction--

Lagoon sediments contaminated by explosives (TNT, DNT, RDX, and others) from several Army depots and plants were successfully decontaminated by contacting with acetone. This study was conducted by Environmental Science and Engineering, Inc. for DOD/USATHAMA. The contact is Wayne Sisk, Aberdeen Proving Ground, MD 21010-5401, (301) 571-2054. The explosive content of the untreated sediments varied from 0.1 to 99 percent and moisture content from 23.8 to 42.8 percent. Acetone was used as an extraction agent. Laboratory tests measured solubility, leaching efficiencies,

TABLE B-5. BENCH SCALE DATA ON NCBC (GULFPORT)

No.	Source	Compound	Process	Reagent	Loading	Temp. °C	Time	Concentration	
								Before	After
1	Gulfport	TCDD	Slurry	9:9:9-P.D.K.	100%	250	4 hours	2000 ppb	<1 ppb
2	Gulfport	TCDD	Slurry	1:1:1-P.D.K.	100%	160	2 hours	2000 ppb	<1 ppb
3	Gulfport	TCDD	Slurry	9:9:2-M.D.K.	100%	150	2 hours	2000 ppb	<1 ppb
4	Gulfport	TCDD	Slurry	9:9:2-M.D.K.	100%	100	2 hours	2000 ppb	<1 ppb
5	Gulfport	TCDD	Slurry	1:1:1-M.D.K.	100%	70	2 hours	2000 ppb	<1 ppb
6	Gulfport	TCDD	Slurry	9:9:2-M.D.K.	100%	70	2 hours	2000 ppb	<1.5 ppb
7	Gulfport	TCDD	Slurry	9:9:2-M.D.K.	100%	70	0.5 hours	2000 ppb	<15 ppb
8	Gulfport	TCDD	Slurry	1:1:1-M.D.K.	100%	50	2 hours	2000 ppb	<23 ppb
9	Gulfport	TCDD	Slurry	9:9:2-M.D.K.	100%	25	2 hours	2000 ppb	<36 ppb
10	Gulfport	TCDD	In Situ	1:1:1-P.D.K.	20%	25	7 days	2000 ppb	1000 ppb
11	Gulfport	TCDD	In Situ	1:1:1-P.D.K.	20%	70	1 day	2000 ppb	8.5 ppb
12	Gulfport	TCDD	In Situ	9:9:2-P.D.K.	20%	70	7 days	2000 ppb	<1 ppb
13	Gulfport	TCDD	In Situ	2:2:2:1-M.D.K.W.	20%	70	1 day	2000 ppb	3.3 ppb
14	Gulfport	TCDD	In Situ	2:2:2:1-M.D.K.W.	20%	70	2 days	2000 ppb	2.0 ppb
15	Gulfport	TCDD	In Situ	2:2:2:1-M.D.K.W.	20%	70	4 days	2000 ppb	2.5 ppb
16	Gulfport	TCDD	In Situ	2:2:2:1-M.D.K.W.	20%	70	7 days	2000 ppb	<1 ppb
17	Gulfport	TCDD	In Situ	1:1:1:3-M.D.K.W.	20%	70	7 days	2000 ppb	3.2 ppb
18	Gulfport	TCDD	In Situ	1:1:1:3-M.S.K.W.	50%	70	7 days	2000 ppb	2.7 ppb
19	Gulfport	TCDD	In Situ	1:1:1:15-M.D.K.W.	20%	70	7 days	2000 ppb	43 ppb
20	Gulfport	TCDD	In Situ	1:1:1:15-M.D.K.W.	50%	70	7 days	2000 ppb	14 ppb
Bench Scale Data on Bengart & Memel (Buffalo)									
21	Buffalo	PCB	Slurry	9:9:2:1-M.D.K.W.	100%	100	2 hours	77 ppm	4.2 ppb
22	Buffalo	PCB	Slurry	9:9:2:1-M.S.K.W.	100%	100	2 hours	77 ppm	6.7 ppb
23	Buffalo	PCB	Slurry	1:1:2:2:1-P.T.S.K.W.	100%	150	2 hours	112 ppm	6.7 ppm
24	Buffalo	PCB	In Situ	2:2:2:1-M.D.K.W.	20%	70	7 days	77 ppm	3.7 ppb
25	Buffalo	PCB	In Situ	2:2:2:1-M.S.K.W.	20%	70	7 days	77 ppm	4.0 ppb
26	Buffalo	PCB	In Situ	1:1:2:2:1-P.T.D.K.W.	100%	150	3 days	112 ppm	<0.1 ppb
27	Buffalo	PCB	In Situ	1:1:2:2:1-P.T.D.K.W.	100%	150	1 day	83 ppm	<0.1 ppb

Reagent Components Key

D - DMSO - dimethyl sulfoxide
K - KOH - potassium hydroxide
M - MEE - methyl carbitol - methoxy-ethoxy-ethanol
P - PEG - polyethylene glycol, avg. molecular weight of 400
S - SFLN - sulfolane - tetrahydrothiophene 1.1-dioxide
T - TMH - triethylene glycol methyl ether and highers
W - Water

Toxic Compounds Key

TCDD - 1,2,3,4-Tetrachlordibenzo-p-dioxin
PCB - polychlorinated biphenyls

Loading (%) = 100 x (reagent mass/soil mass)

Source: USEPA, 1989i

and settling. Solubility tests evaluated water/acetone ratios to determine optimum operational range for the contaminants present. Leaching tests determined the effectiveness of countercurrent extraction to calculate the contact time needed to establish equilibrium between the solvent and sediment. The leaching tests were performed in a 1-liter graduated cylinder. The tests showed that wet, explosive-containing sediments can be effectively decontaminated by an acetone/water mixture. In general, three to four contact stages of 30 minutes each were needed to bring the explosive level below 10 mg/kg. However, a fifth contact stage with a 50 percent efficiency is required to achieve the Louisiana-mandated sediment quality. Table B-6 shows the results of some explosives removal tests.

TABLE B-6. DOD/USATHAMA TREATABILITY RESULTS

Sediment	Initial explosives concentrations (mg/kg)	Final explosives concentrations (mg/kg)	4-Stage removal efficiency (%)
Ft. Wingate AD	1,200	6.0	99.5
Navajo AD	19,000	7.0	99.96
Louisiana	420,000	17.0	99.996

PCB-contaminated New Bedford Harbor sediment was treated on a pilot-scale, in a SITE demonstration of the CF Systems Supercritical Fluid Extraction Technology (USEPA, 1989h).

This technology is only applicable to organic contaminants. It extracts contaminants from solids/slurries with solvents in which the organic contaminants become dissolved. Typically 99 percent of the organics can be removed from the solids in liquid propane and/or butane. This technology was demonstrated concurrently with dredging studies managed by the USACE.

The following test results include, for each test, the number of passes made through CF systems Pit Cleanup Unit, the concentration of PCBs before test and PCB levels after test.

Test number	Passes	PCB Concentration Before	After
2	9	360 ppm	8 ppm
3	3	288 ppm	82 ppm
4	6	2575 ppm	200 ppm

Extraction efficiencies were high, despite some operating difficulties. The return of treated sediment, as feed, to the next pass caused cross-contamination in the system. Full-scale commercial systems are designed to eliminate the problems associated with the pilot-plant design.

The following conclusions were drawn from this series of tests and other data:

- Extraction efficiencies of 90-98 percent were achieved on sediments containing PCBs between 350 and 2,575 ppm. PCB concentrations fell as low as 8 ppm in the treated sediment.
- In the laboratory, extraction efficiencies of 99.9 percent were obtained for volatile and semivolatile organics in aqueous and semi-solid wastes.
- Operating problems included solids retention in the hardware and foaming in the receiving tanks. The vendor developed corrective measures for the full-scale commercial unit.
- Projected costs for PCB cleanups are approximately at $150 to $450/ton, including material handling as well as pre- and post-treatment costs. These costs are highly sensitive to the utilization factor and the job size, which may lower costs for large cleanups.

Resource Conservation Company's (RCC) B.E.S.T.™ process is a solvent extraction process which utilizes either a secondary or tertiary amine, usually triethylamine (TEA) to extract organic contaminants from soils, sludges, or sediments. E.C. Jordan Co. studied its applicability to New Bedford Harbor sediment. Preliminary results indicate that this technology is suitable for the removal of PCBs from contaminated sediments.

A bench-scale study of the B.E.S.T.™ process was conducted at the Arrowhead Refinery Superfund Site in Hermantown, Minnesota. The lagoon sludge and the soil contained PAHs, VOCs, lead, zinc, and small quantities of PCBs. RCC conducted a treatability study using these contaminated materials under a subcontract from CH2M Hill.

The results of the study show that RCC's process successfully separates the contaminated wastes into three fractions: aqueous, oil-containing organics and solids. The process, however, is not applicable to metals. As a result, lead was found at high concentrations in both the oil and the solid fractions. Water recovery was poor because of problems in the decantation steps. Distillation was therefore necessary, which added to the cost of the process. RCC estimated the process costs, for this site, to be $289 (sludges) and $300 (soil), respectively (comparable to incineration).

Soil Washing--

Soil washing, a volume reduction process, can concentrate both inorganic and organic contaminants in a small portion of the original feed. Water and water with other additives are used to achieve this goal (FWEI, 1989).

Biotrol's Soil Treatment System, EPA's Soil Washing Mobile System, and MTA Remedial Resources' Froth Flotation Unit have all been tested on contaminated soils.

The Biotrol process was tested on a pilot scale at a Superfund site in Minnesota that is contaminated with PCP, PAH, petroleum hydrocarbons, copper, chromium, and arsenic. A bench-scale treatability study (Stinson et al., 1988) successfully reduced the concentration of all the contaminants (Tables B-7 and B-8). TCLP tests for the treated and untreated soils showed substantial removal of PCPs. The total treatment cost (mobilization, treatment, and disposal) of the process at the Minnesota site is estimated to be $180/ton.

Results of treatability testing with various soil samples are shown in Table B-9 (USEPA, 1990m).

Solidification/Stabilization--

In this technique contaminated soils/sediments are mixed with pozzolanic material and some special additives. On curing, the soil/sediment hardens and encapsulates the contaminants. The encapsulated contaminants do not leach out and hence do not pose any threat to the environment.

The technical feasibility of reducing contaminant mobility in Indiana Harbor Canal sediment by solidification/stabilization was investigated in a series of laboratory-scale applications of selected solidification/stabilization processes. The processes evaluated were portland cement, portland cement with flyash, portland cement with flyash and/or sodium silicate, portland cement with WEST-P (proprietary polymer), Firmix with WEST-P, and lime with flyash. Evaluation of the physical properties of the solidified products showed that sediment from Indiana Harbor Canal can be physically stabilized by a variety of processes. The chemical leach data showed that solidification/stabilization of Indiana Harbor sediment reduced the mobility of some contaminants, depending on the type of setting agent(s) and

TABLE B-7. COMPARISON OF UNTREATED/TREATED SOIL IN A PILOT-SCALE TEST AT MINNESOTA WOOD TREATING SITE

Soil contaminant level	Parameter	mg/kg Feed soil	mg/kg Washed soil	Percent reduction
Low (Test 1 of 1)	Pentachlorophenol	130	12.0	91
	Total PAH	240	8.6	96
	TPH	3,300	210.0	94
	Arsenic	14	5.0	64
	Chromium	17	9.0	47
	Copper	15	6.2	59
High (Test 1 of 2)	Pentachlorophenol	540	56.0	90
	Total PAH	290	23.0	92
	TPH	8,800	470.0	95
	Arsenic	28	7.2	74
	Chromium	49	8.5	83
	Copper	39	5.2	87

PAH - Polynuclear aromatic hydrocarbons
TPH - Total petroleum hydrocarbons

Source: USEPA, 1990m

TABLE B-8. COMPARISON OF PCP-CONTAMINATED UNTREATED/TREATED SOIL AT SITE DEMONSTRATION

Soil contaminant level	Pentachlorophenol Washed soil, mg/kg	Pentachlorophenol Washed soil TCLP leachate, mg/L
Low (test 1 of 1)	10	0.23
	19	0.32
High (test 1 of 2)	59	0.74
	70	0.92

Source: USEPA, 1990m

TABLE B-9. RESULTS OF BENCH-SCALE TREATABILITY TESTING

Site description	Parameter	mg/kg Feed soil	mg/kg Washed soil	Percent reduction
Wood Preserving (California)	Total PAH	4,800	230	95
	Arsenic	89	27	70
	Chromium	63	23	63
	Copper	23	13	43
	Zinc	345	108	69
Wood Preserving (Florida)	Pentachlorophenol	380	4.0	99
	Pentachlorophenol	610	25	96
Chemical Plant (Michigan)	Dichlorobenzidine	770	13	98
	Benzidine	1,000	6	99
	Azobenzene	2,400	7	>99
Wire Drawing (New Jersey)	TPH	4,700	350	93
	VOC	2	0.01	>99
	Copper	330	100	70
	Nickel	110	60	45
	Silver	25	4	84
Town Gas (Quebec)	Total PAH	230	11	95
Pesticide Formulation (Colorado)	Chlordane	55	4.7	91
	Aldrin	47	7.5	84
	4,4-DDT	25	5.0	80
	Dieldrin	46	7.0	85
Chemical Plant (California)	PCB (Aroclor 1260)	290	<0.1	<99

Polynuclear aromatic hydrocarbons
Total petroleum hydrocarbons
Volatile organic compounds
Polychlorinated biphenyls

additive dosages used. Some additives increased the leachability of some metals (Environmental Laboratory, 1987).

An evaluation of solidification/stabilization technology was conducted on the bench-scale level on Buffalo River sediment to determine whether physical and chemical properties of the sediment would be improved. Chromium, copper, lead, nickel, and zinc were evaluated. Three binder materials were evaluated: cement, kiln dust, and lime-fly ash. Physical tests (USC, freeze/thaw, and wet/dry durability) and contaminant release tests (serial leach test and TCLP) were conducted. Results were similar to those for the Indiana Harbor tests, in that stabilized solids could be formed and the mobility of lead, nickel, and zinc were reduced, both in the serial leach tests and the TCLP. The leachability of copper and chromium was increased by the solidification/stabilization process (Fleming, et al., 1991).

An *in situ* solidification/stabilization process developed by International Waste Technologies (IWT) and implemented by Geo-Con, Inc. is capable of operating below water tables. This process was tested at a Superfund site in Hialeah, Florida (Stinson et al., 1988). The PCBs in the contaminated soil were immobilized. TCLP leachate analysis showed no leaching of PCBs. The bulk density of the soil increased by 21 percent after treatment and the volume increased by 8.5 percent. The wet/dry weathering test on treated soil produced satisfactory results. The process costs are favorable: $194/ton for 1-auger machine used in the demonstration and $110/ton for commercial 4-auger equipment. Since the IWT proprietary binding reagent use varies according to the nature of wastes, treatability studies should be performed for new site-specific waste.

The HAZCON solidification process was tested at the Douglassville, PA Superfund Site. The soil was contaminated with high levels of oil and grease, volatile and semivolatile organics, PCBs, and heavy metals.

The comparison of physical properties of untreated and treated soil samples 7 days, 28 days, 9 months, and 22 months after treatment were generally favorable. The physical test results were very good, with unconfined compressive strength between 220 and 1570 psi. Very low permeabilities were recorded, and the porosity of the treated wastes was rated moderate. Durability test results showed no change in physical strength after the wet/dry and freeze/thaw cycles. The waste volume increased about 20%. By using lesser amount of stabilizer it is possible to reduce volume increases but results in lower strengths of the treated soil. (There is an inverse relationship between physical strength and the waste organic concentration.)

The results of the HAZCON post-demonstration leaching tests were mixed. The TCLP results were very low; essentially all values of metals, volatile organics, and semivolatile organics were below 1 ppm. Lead leachate concentrations dropped by a factor of 200, to below 100 ppb. Volatile and semivolatile organic concentrations, however, did not change with treatment. Oil and grease concentrations were greater in the treated waste than in the untreated waste (from less than 2 ppm up to 4 ppm).

The HAZCON study concluded the following:

- The process can solidify contaminated material with high concentrations (up to 25 percent) of organics. However, organic contaminants, including volatiles and base/neutral extractables, were not immobilized to any significant extent.
- Heavy metals are immobilized. In many instances, leachate reductions were greater than a hundred fold.
- The treated waste exhibited high unconfined compressive strengths, low permeabilities, and good weathering properties.
- Treated soils underwent volumetric increases.
- The process is economical, with costs expected to range between approximately $90 and $120/ton.

Bench-scale solidification work was also performed by Chemfix Technologies and by Associated Chemical and Environment Services (ACES). They assessed the feasibility of using a pozzolanic solidification process as a component in the remediation plan for the Marathon Battery Site.

Although the Chemfix™ process is patented, different mixtures of common setting agents can be used to optimize both the physical and chemical characteristics of the waste. In the case of cadmium-contaminated sediments from Foundry Cove, Chemfix tested: 1) sodium silicate and portland cement; 2) sodium silicate and cement kiln dust; and 3) sodium silicate, portland cement, and a setting agent. The products were subjected to EP toxicity testing for metals and 48-hour unconfined compressive strength (UCS) tests. UCS results for mixtures 1, 2, and 3 were 34.7 psi (239.2 kPa), 20.8 psi (143.4 kPa), and 17.4 psi (120 kPa), respectively. Only the sodium silicate and portland cement mixture passed the EP Toxicity testing -- with a cadmium concentration of 0.709 mg/L or 0.709 ppm (the EP Toxicity maximum is 1 mg/L or 1 ppm). Since cobalt and nickel are not standard EP Toxicity parameters; they were not measured. ACES conducted bench-scale studies with three mixtures composed of differing weight percentages of waste, pozzolan, and lime. UCS 48-hour test results ranged from 7 to 91 psi (48.3-131 kPa). Cobalt and nickel were included in the EP Toxicity testing. Two of the three mixtures were found to have cadmium, cobalt, and nickel levels less than 1.0 mg/L or 1 ppm.

Solidification (specifically the Chemfix™ process) has been chosen in conjunction with hydraulic dredging and off-site disposal as the remedial action for East Foundry Cove Marsh (34 acres or 14 hectares) and East Foundry Cove (14 acres or 5.7 hectares). Both areas lie within of the Marathon Battery Site in the lower Hudson River, New York. The remedial treatment will include the following: hydraulic dredging, dewatering thorough agitation and mixing, continuous pumping through Chemfix™ treatment units, extruding the treated waste to a solidification area, and transfer of the solidified sediment to a disposal site.

Cost estimates for the solidification of the Foundry Cove site range between \$50 and \$75/yd^3.

Thermal Treatment

Incineration--

A bench-scale study was conducted by the Atlantic Research Corp., Alexandria, VA using explosive-contaminated sediments from the Louisiana Army Ammunition Plant [Atlantic Research Corporation]. Approximately 4 g of sediment in a crucible was placed in a muffle furnace at 500-700°C with varying residence time. Table B-10 shows the results of decontamination at various heating temperatures. The explosive (TNT, RDS, tetryl, and nitrocellulose) levels of the sediment

TABLE B-10. INCINERATION OF SEDIMENT EXPLOSIVES LEVELS

Temperature (°C)	Time (min.)	Concentration by dry sediment TNT (μg/g)	RDX (μg/g)	Tetryl (μg/g)	COD (μg/g)
No heat		424,000	159,000	15,800	206,000
200	5	10,000	<1	114	124,500
	30	1,500	<1	<0.3	116,500
	60	1,350	<1	<0.3	149,200
300	5	<2	<1	<0.3	55,200
	30	<2	<1	<0.3	52,300
	60	<2	<1	<0.3	30,000
500	5	<2	<1	<0.3	5,900
	30	<2	<1	<0.3	2,190
	60	<2	<1	<0.3	1,280
700	5	<2	<1	<0.3	8,720
	30	<2	<1	<0.3	1,310
	60	<2	<1	<0.3	2,320
900	5	<2	<1	<0.3	12,200
	30	<2	<1	<0.3	2,410
	60	<2	<1	<0.3	1,670

TNT - Trinitrotoluene
RDX - Hexhydro-1,3,5-trinitro-1,3,5-triazine
Tetryl - Trinitrophenylmethylnitramine
COD - Chemical oxygen demand

Source: USEPA, 1989i

were reduced from 109,000 to 1000 μg/g. Depending upon the sediment's moisture content, the costs can vary between $100,000 to 2,000,000.

PCBs-contaminated soil/sediment from the Swanson River Oil Field on the south coast of Alaska was successfully incinerated by Alliance Technologies Corporation of Bedford, MA and Ogden Environmental Services of San Diego, CA. In this field demonstration (USEPA, 1990m), Ogden's Circulating Bed Combustor (CBC), an advanced fluidized bed system, was used. The commercial-size system can treat up to 100 tons/day of contaminated soil. This technique is well-suited for materials with relatively low heating values.

A similar treatability study was carried out at Ogden's facility with contaminated soils from the McColl Superfund Site in Fullerton, California. The results of these studies are shown in the attached Tables B-11, B-12, B-13, and B-14. The McColl Site soil contained metals in addition to organics. TCLP tests on the ash showed arsenic, selenium, barium, cadmium, chromium, lead, mercury, and silver levels well below the federal requirements (40 CFR Part 268). The total CBC site remediation cost estimate for these sites varies between $100 and $300/ton. The main variable affecting cost are soil moisture content and quantity of the waste to be processed.

Shirco Infrared System--

The effectiveness of this technology was evaluated for the destruction of lagoon material containing PCBs and other organics. This material from the Peak Oil Superfund Site at Brandon, Florida -- also contained metals. The oil-like material with a pH of 2 to 4 was neutralized with lime and mixed with soil. A coffer dam had been erected around the lagoon, and the soil used in the process came from the lagoon and the coffer dam enclosure. The mixture was screened to remove all materials with diameters above 1 in. This material was treated in a full-scale Shirco system. The original material contained from 5 to 100 ppm of PCBs. Although lead in the ash failed to pass EP Toxicity Test, it did pass the TCLP. All organic compounds in the ash were below the regulatory levels (TCLP Test). DREs for all tests exceeded 99.99 percent. The projected average Shirco cost is $425/ton of contaminated feed material. More details are available in the EPA publication: *Shirco Infrared Incineration System,* EPA/540/A5-89/010.

The attached tables (B-15 through B-18) provide some information on the tests carried out at the Peak Oil Site (HMCRI, 1988).

TABLE B-11. SWANSON RIVER TESTS: OPERATING CONDITIONS TESTS 1 THROUGH 3

Test conditions	Test 1	Test 2	Test 3
Combustor temperature, °F	1,620.00	1,606.00	1,620.00
Residence time, sec	1.68	1.68	1.67
Soil throughput, lb/hr	8,217.00	8,602.00	8,603.00
Soil PCB concentration, ppm	632.00	615.00	801.00
Flue gas oxygen, dry %	7.10	7.40	6.90
CO emissions, ppm	12.00	11.00	17.50
HC emissions, ppm	2.00	2.00	2.00
SO_2 emissions, ppm	16.00	15.00	13.00
NO_x emissions, ppm	89.00	88.00	88.00
Carbon dioxide, %	8.80	8.70	8.60
HCl emissions, lb/hr	1.49	1.08	1.37
Particulate gr/dscf at 7% O_2	0.0072	0.0065	0.0093
Combustion efficiency, %	99.980	99.990	99.985
DRE, %	>99.99993	>99.99992	>99.99997

Source: HMCRI, 1989

TABLE B-12. SWANSON RIVER TESTS: OPERATING CONDITIONS TESTS 4 THROUGH 6

Test conditions	Test 4	Test 5	Test 6
Combustor temperature, °F	1,701.00	1,693.00	1,686.00
Residence time, sec	1.52	1.47	1.53
Soil throughput, lb/hr	8,194.00	9,490.00	9,555.00
Feed PCB concentration, ppm	289.00	608.00	625.00
Flue gas oxygen, dry %	6.20	6.10	8.10
CO emissions, ppm	8.70	10.00	12.50
HC emissions, ppm	2.00	2.00	2.00
SO_2 emissions, ppm	27.00	21.00	20.00
NO_x emissions, ppm	82.00	90.00	95.00
Carbon dioxide, %	8.80	8.90	8.80
HCl emissions, lb/hr	1.42	1.57	1.21
Particulate gr/dscf at 7% O_2	0.0120	0.0190	0.0182
Combustion efficiency, %	99.990	99.990	99.990
DRE, %	>99.99996	>99.99994	>99.99993

Source: HMCRI, 1989

TABLE B-13. McCOLL SITE TESTS: OPERATING CONDITIONS

Test conditions	Test 1	Test 2	Test 3
Combustor temperature, °F	1,721.00	1,726.00	1,709.00
Residence time, sec	1.54	1.52	1.55
Soil throughput, lb/hr	325.00	170.00	197.00
Carbon tetrachloride, lb/hr	0.00	0.00	0.22
Flue gas oxygen, dry %	11.00	9.90	11.80
CO emissions, ppm	30.00	30.00	26.00
HC emissions, ppm	5.00	1.00	2.00
SO_2 emissions, ppm	>95%	>95%	>95%
NO_x emissions, ppm	49.00	58.00	48.00
Carbon dioxide, dry %	9.90	11.90	9.20
HCl emissions, lb/hr	<0.0090	<0.0085	<0.0098
Particulate gr/dscf at 7% O_2	0.0041	0.0044	0.0035
Combustion efficiency, %	99.97	99.97	99.97
DRE, %			99.9937

Source: HMCRI, 1989

TABLE B-14. McCOLL SITE TEST: METALS PARTITIONING

	Metal	Total mg/hr	Fly ash fraction	Bed ash fraction	Flue gas fraction
Test 1	Copper	688	0.769	0.195	0.037
	Nickel	1350	0.714	0.278	0.007
	Cobalt	226	0.765	0.218	0.018
	Chromium	3206	0.843	0.154	0.003
	Barium	6110	0.832	0.167	0.001
	Manganese	15687	0.761	0.238	0.000
Test 2	Copper	1221	0.938	0.036	0.026
	Nickel	1171	0.904	0.049	0.047
	Cobalt	204	0.903	<0.053	0.041
	Chromium	2932	0.948	0.061	0.016
	Barium	6435	0.937	0.061	0.003
	Manganese	20741	0.958	0.041	0.001
Test 3	Copper	874	0.949	0.028	0.023
	Nickel	532	0.872	0.107	0.022
	Cobalt	150	0.941	0.047	0.012
	Chromium	1630	0.951	0.043	0.006
	Barium	4157	0.972	<0.026	0.002
	Manganese	11682	0.968	0.032	0.001

Source: HMCRI, 1989

TABLE B-15. WASTE FEED SOIL ANALYSIS

Waste feed	Measurement
	Nanograms per gram
PCB (total)	3480 to 5850
Heptachlorobiphenyl	940 to 220
Hexachlorobiphenyl	1100 to 1700
Pentachlorobiphenyl	200 to 490
Tetrachlorbiphenyl	400 to 830
Trichlorobiphenyl	570 to 820
Dichlorobiphenyl	120 to 190
Ethyl benzene	40 to 140
Methylene chloride	80 to 120
Toluene	130 to 300
Xylene	260 to 770
	Micrograms per gram
Antimony	2.1 to 3.6
Arsenic	2.0 to 2.9
Cadmium	3.9 to 4.6
Chromium	20 to 24
Copper	44 to 55
Strontium	50 to 62
Lead	4400 to 5000
Vanadium	7 to 11
Zinc	950 to 1100
	Percent
Moisture	14.2 to 16.6
Carbon	7.0 to 7.8
Sulfur	1.8 to 2.5
Chlorine	less than 0.1
Ash	70 to 75
Btu value (HHV)	1640 to 2065 Btu/lb

HHV - high heating value

TABLE B-16. METALS ANALYSIS

Parameter	Solid waste feed (μg/g)	Ash (μg/g)	Stack gas* (μg/dscf)
Aluminum	1625.00	2500.00	<210.00
Antimony	2.15	3.30	91.00
Arsenic	2.55	2.60	38.00
Barium	505.00	757.00	675.00
Beryllium	0.168	0.30	0.11
Boron	NA	NA	625.00
Cadmium	4.15	4.10	1920.00
Calcium	37500.00	50000.00	1680.00
Chromium	22.00	27.00	270.00
Cobalt	0.75	2.00	<11.00
Copper	49.00	64.00	420.00
Iron	2050.00	2600.00	440.00
Lead	4800.00	6400.00	58000.00
Lithium	ND	ND	21.00
Magnesium	850.00	1050.00	180.00
Mercury	ND	ND	<0.10
Molybdenum	ND	ND	50.00
Nickel	8.00	10.00	42.00
Phosphorus	790.00	770.00	0.00
Selenium	ND	ND	3.20
Silicon	NA	NA	780.00
Silver	2.00	4.00	10.00
Sodium	5550.00	5600.00	18600.00
Strontium	57.00	76.00	10.00
Sulfur	20500.00	24000.00	160000.00
Thallium	ND	ND	630.00
Titanium	41.00	115.00	<50.00
Vanadium	9.00	13.00	<25.00
Zinc	1030.00	1060.00	9400.00

*The stack gas contained 0.1015 grains/dscf of particulate (one grain - 64.8 mg)

ND - Not determined
NA - Not analyzed

TABLE B-17. LEACH TEST RESULTS

Parameter	EP Toxicity Average mg/L	EP Toxicity Regulatory level, mg/L	TCLP Analysis Average level, mg/L	TCLP Analysis Regulatory level
Arsenic	0.020	5.0	0.007	5.0
Barium	1.350	100.0	0.250	100.0
Cadmium	0.099	1.0	0.008	1.0
Chromium	0.037	5.0	0.037	5.0
Lead	31.000	5.0	0.011	5.0
Mercury	0.0015	0.2	ND	1.0
Selenium	ND	1.0	0.031	1.0
Silver	0.031	5.0	0.059	5.0
	Only compounds detected by TCLP are listed below			
Acrylonitrile			0.013	5.0
Methylene chloride			0.020	8.8
Toluene			0.0020	14.4
1,1,1-Trichloroethane			0.0006	30.0
Trichloroethane			0.0006	0.07

ND - Not detected

TABLE B-18. EMISSION DATA

Date of run	DRE for PCBs (%)	Particulate concentration corrected to 7% O_2, (grains/dscf)	SO_2 (g/hr)
8/1/87	99.99967	0.1590	27.6
8/2/87	99.9988	0.0939	1070.0
8/3/87	99.99972		
8/4/87	99.99905	0.0768	22.0
8/4/87		0.0761	20.6
Average	99.99931	0.1015	285.05

No chloride was detected in the flue gases.

Low Temperature Thermal Desorption--

The Chemical Waste Management's (CWM) low temperature (500-800°F) thermal desorption process -- X*TRAX^{TM} -- was used to volatilize PCBs and other organics from soils. The vapors are transported from the evaporators (indirectly heated with propane) by nitrogen gas into the condensing unit. The condensed organics are then treated further. For example, the chlorinated organics in the condensed liquid can be treated with the KPEG process.

The X*TRAX^{TM} system was tested, on a pilot scale, at the Kettleman Hills Facility in central California (USEPA, 1990g). Several other treatability studies were conducted in the laboratory with contaminated soils and sludges. (Tables B-19 through B-23.) According to CWM, the average cost of treatment is between $150-$250/ton of feed.

During the TSCA tests, the process vent was continuously monitored for total hydrocarbon emissions. The average release rate for hydrocarbons was very low and PCBs were nondetectable.

Twelve cubic yards of contaminated sediments from the Buffalo River were processed in a low temperature thermal desorption unit provided by Remedial Technologies, Inc. at a CDF managed by U.S. Army Corps of Engineers. This unit volatilized the organics and recondenses them in an oil mixture. The remaining solid material was either combined with portland cement to determine the effectiveness of restricting the leaching of heavy metals or disposed of at an appropriate facility.

TABLE B-19. LABORATORY X*TRAX™ TEST USING SYNTHETIC SOIL MATRIX (SSM-1)

Compound	Feed conc. (ppm)	Product conc. (ppm)	Removal (%)
Volatiles			
Acetone	3,200	16.0	99.5
Total xylene	2,900	9.50	99.7
Ethylbenzene	1,900	5.20	99.7
Styrene	240	<0.005	>99.99
Tetrachlorethylene	180	0.094	99.95
Chlorobenzene	130	0.180	99.86
1,2-Dichloroethane	46	0.062	99.87
Semivolatiles			
Anthracene	3,100	12.0	99.6
Bis(2-ethylhexyl)phthalate	3,020	<0.33	>99.99
Pentachlorophenol	397	2.8	99.3

Source: USEPA, 1990m

TABLE B-20. LABORATORY X*TRAX™ NON-PCB SOIL, SLUDGE, AND MIXTURE

(Concentration - mg/kg)

Run number	Parameter	Concentration Feed	Concentration Product	Removal (%)
DB0627	Total solids (%)	94.1	100	N/A
Clay soil	Azobenzene	3,190	4.9	99.8
	3,3'-Dichlorobenzidine	1,820	<0.66	>99.96
	Benzidine	842	ND	--
	2-Chloroanaline	828	ND	--
	Nitrobenzene	45.6	<0.33	>98.6
DB0629	Total solids (%)	73.1	100	N/A
Soil/sludge	3,3'-Dichlorobenzidine	958	<0.66	>99.0
	Azobenzene	61.0	ND	--
	Benzidine	17.8	ND	--
DB0706	Total solids (%)	52.4	100	N/A
Sludge	Azobenzene	47,900	327	99.3
	Toluene	4,470	<0.42	>99.99
	3,3'-Dichlorobenzidine	3,590	18.4	99.5
	2-Chloroaniline	2,100	47.5	99.7
	Benzene	1,870	<0.21	>99.99
	Benzidine	1,010	3.7	99.6
	Aniline	267	43.3	83.8
DB0710	Total solids (%)	47.0	100	N/A
Sludge	3,3'-Dichlorobenzidine	1,070	<0.66	>99.94
	Azobenzene	35.7	ND	--

Source: USEPA, 1990m

TABLE B-21. PILOT X*TRAX™ USING PCB-CONTAMINATED SOILS

Run number	Matrix	Feed (ppm)	Product (ppm)	Removal (%)
0919	Clay	5,000	24.0	99.5
0810	Silt clay	2,800	19.0	99.3
1003	Clay	1,600	4.8	99.7
0727	Sandy	1,480	8.7	99.1
0929	Clay	630	17.0	97.3

Source: USEPA, 1990m

TABLE B-22. COMPARISON OF LAB AND PILOT X*TRAX™ TESTS USING PCB-CONTAMINATED SOILS

Matrix	System scale	Run ID number	Amount (lb)	Feed (ppm)	Product (ppm)
Sand	Lab	RS0829	19	5,100	9.7
	Pilot	RS0727	4,958	1,480	8.7
Silt/clay	Lab	GR0524	31	962	21
	Pilot	GR0810	4,584	2,800	19

Source: USEPA, 1990m

TABLE B-23. PILOT X*TRAX™ TSCA TESTING - VENT EMISSIONS

Run number	Total hydrocarbons (ppm-V) Before carbon	After carbon	Removal (%)	VOC (lb/day)	PCB* (mg/m^3)
0914	1,320	57	95.6	0.02	<0.00056
0919	1,031	72	93.0	0.03	<0.00055
0921	530	34	93.3	0.01	<0.00051
0926	2,950	170	94.2	0.07	<0.00058
0929	2,100	180	91.4	0.08	<0.00052

* - OSHA permits 0.50 mg/m^3 PCB (1254) for 8-hr exposure.

Source: USEPA, 1990m

Vapor Extraction System (VES)--

The VES uses a low-temperature, fluidized bed. It can remove volatile and semivolatile organics, including PCBs, PAHs, and PCP, volatile inorganics, and some pesticides from soil, sludge, and sediment. In general, the process treats wastes containing less than 5 percent total organic contaminants and 30 to 90 percent solids. Nonvolatile inorganic contaminants (such as metals) in the waste feed do not inhibit the process, but are not removed by this process.

- **American Toxic Disposal, Inc.** has developed a VES which feeds contaminated materials into a co-current, fluidized bed, where they are mixed with hot gas (about 320°F) from a gas-fired heater. Direct contact between the waste material and the hot gas volatizes water and contaminants from the waste into the gas stream, which flows out of the dryer to a gas treatment system where dust and organic vapors are removed from the gas stream. A cyclone separator and baghouse then remove most of the particulates in the stream. Vapors from the cyclone separator are cooled in a venturi scrubber, counter-current washer, and chiller section before they are treated in a vapor-phase carbon adsorption system. The liquid residues are clarified and passed through two activated carbon beds, arranged in series. Clarified sludge is centrifuged, and the liquid residue is also passed through carbon beds.

By-products from the VES treatment include as follows: 96 to 98 percent of a solid waste feed exits as clean, dry dust; a small quantity of pasty sludge containing organics; a small quantity of spent adsorbent carbon; wastewater that may need further treatment; and small quantities of baghouse and cyclone dust.

EPA is currently locating a demonstration site for this process. Harbor or river sediments containing at least 50 percent solids and contaminated with PCBs and other volatile or semivolatile organics is the scheduled feed (USEPA, 1989h).

Pyrolysis--

Pyrolysis is a thermal process which destroys organic materials in the absence of oxygen at a high temperature so that toxic organic constituents are reduced to elemental gases and water vapor. The absence of oxygen allows separation of the waste into a gaseous organic fraction and an inorganic fraction (salts, metals, particulates) as char. The process conditions range from pure heating (thermolysis) to conditions in which only slightly less than the theoretically necessary quantity (stoichiometric) of air is supplied. Gases are the principle product generated by the pyrolytic reaction, although ash can also result (USEPA, 1988b). Because of lack of oxygen, PCBs are not incinerated, but they do break down into gaseous hydrogen, chlorine, hydrochloric acid, and a free-flowing, solid waste containing carbon (Sullivan, 1989).

- The pyrolytic incineration process marketed by **Midland Ross Corporation** is a two-step process. In the first step, waste material is decomposed at 1000 to 1400°F in the absence of air, or oxygen into an organic gaseous fraction and an inorganic solid fraction. In the second step, the organic fraction is fed into a high-temperature, direct-fired incinerator operated at 2200°F, where hazardous components are destroyed and clean, decontaminated gases are sent to an energy recovery device (USEPA, 1988b). Feed material must be predried and screened to 35 mesh or smaller. This process achieves DREs exceeding 99.99999 percent.

  This technology is commercially available, and has been used at RCRA facilities. However, its application to CERCLA wastes has not been commercially demonstrated. Costs are estimated at about \$900/m^3, including dredging, transport, treatment, and redeposition (Sullivan, 1989).

Wet Air Oxidation (WAO)--

WAO is a thermal treatment technology that breaks down suspended and dissolved oxidizable inorganic and organic materials by oxidation in a high temperature, high pressure, aqueous environment. WAO is used primarily to treat biological wastewater treatment sludges. It has potential for application to concentrated liquid or sludge waste streams containing organic and oxidizable inorganic wastes that are not readily biodegradable. WAO is particularly well-suited to the treatment of organic waste streams that are too diluted (less than 5 percent organics) to treat economically by incineration. Highly-chlorinated species, such as PCBs, are too stable for complete destruction without the addition of catalysts or the use of very high pressure and temperature (USEPA, 1987a). Bench-scale testing of WAO on Indiana Harbor sediments indicated a 52 percent removal efficiencies for PCBs (USEPA, 1989g).

- The **EcoLogic** process uses hydrogen at elevated temperatures to reduce, rather than to oxidize, chlorinated organics. Since there is no free oxygen in the reducing atmosphere, no dioxin or furan formation is possible. Since combustion air is not required, there is no nitrogen to use up reactor volume and heat, resulting in much smaller reactor than in an incinerator handling the same throughput. Bench-scale tests have shown that a well-mixed combination of hydrogen and chlorinated organic waste, subjected to 850°C or higher for a period of 1 second, will result in 99.9999% or better destruction. A field test of this process is scheduled at a harbor project for the Canadian Department of Defence. Capital and operating costs are predicted to be 3 to 10 times lower than incineration technologies with comparable capacities (Hallett, 1990).

- The **Taciuk process** uses heat to separate organics from sediment. This process has been chosen to treat the sediments in Waukegan (IL) Harbor, which are heavily contaminated with PCBs. The process is expected to remove more than 97% of the PCBs from the treated sediment. The remediation is in progress now at this site. Originally developed to extract oil from oil sands and oil shales, the process feeds sediments into a preheated zone where water and light hydrocarbons are extracted in an anaerobic environment. A second, hotter zone extracts PCBs and other heavy hydrocarbons. The PCBs are not degraded by the process, but they are separated from the sediments; they can then be deposited in a hazardous waste landfill or treated further by incineration or any other means (Sullivan, 1989).

APPENDIX C

SUMMARY OF SEDIMENT CONTAMINATION RECORDS OF DECISION (1982-1989)

TABLE C-1. SUMMARY OF FY82-FY89 RECORDS OF DECISION (RODs)
DOCUMENTING SEDIMENT CONTAMINATION

Site name	Region	Contaminants	RODs selected remedy	Quantity of sediments (cu yd)
1. Baird & McGuire, MA	I	PAHs, pesticides, arsenic	Incineration	1,500
2. Cannon Engineering Corp., MA	I	PAHs, pesticides, lead	Incineration	
3. Charles George Reclamation Landfill, MA	I	Benzene, TCE, PCE, PAHs, arsenic	Solidification	500
4. Hocomonco Pond, MA	I	Organics, inorganics, metals	On-site landfilling	
5. Norwood PCBs, MA	I	PCE, TCE, PAHs, PCBs, phenols, metals	Solvent extraction	3,000
6. Nyanza Chemical, MA	I	Organics, inorganics, metals	Consolidation and on-site disposal	
7. O'Connor, ME	I	Benzene, PCBs, PAHs, lead	Solvent extraction	23,500 (soil and sediment)
8. Ottati & Goss, NH	I	TCE, PCBs, inorganics	Incineration	19,000 (soil and sediment)
9. Re-Solve, MA	I	VOCs, PCBs	KPEG dechlorination and on-site placement	3,000
10. Rose Disposal Pit, MA	I	Benzene, PCE, TCE, toluene, xylenes, PCBs	Incineration	
11. Saco Tannery Waste Pits, ME	I	Arsenic, chromium, lead	Solidification	
12. South Municipal Water Supply Well, NH	I	PCE, TCE, toluene, PCBs, PAHs, metals	Off-site disposal	1,170

(continued)

TABLE B-1. Continued

Site name	Region	Contaminants	RODs selected remedy	Quantity of sediments (cu yd)
13. Sullivans Lodge, MA	I	Benzene, TCE, PCBs, PAHs, lead	Solidification	1,900
14. W.R. Grace, MA	I	Benzene, toluene, arsenic	Incineration of highly contaminated soil and solidification of less contaminated soil	
15. American Thermostats, NY	II	VOCs	Low temperature thermal desorption	300
16. Bog Creek Park, NJ	II	Benzene, toluene xylene, phenols, lead	Incineration	90
17. Brewster Well Field, NY	II	PCE, TCE	Incineration	
18. Bridgeport, NJ	II	VOCs, PCBs	Incineration	
19. Burnt Fly Bog, NJ	II	PCBs, lead	Off-site disposal	5,600
20. Chemical Control, NJ	II	PAHs, PCBs, VOCs	No action	
21. General Motors/Central Foundry Division, NY	II	PCBs	Slurry phase bioremediation	62,000
22. Hudson River, NY	II	PCBs	In situ containment	
23. King of Prussia, NJ	II	Cadmium, chromium, silver	Soil washing	20,000 (soils and sediment)
24. Lang Property, NY	II	VOCs, metals	Off-site disposal	
25. Lipari Landfill, NJ	II	Benzene, toluene, xylenes, arsenic, chromium, lead	Thermal treatment	
26. Love Canal, NY	II	Dioxin	Thermal treatment	
27. Ludlow Sand and Gravel, NY	II	VOCs, PCBs, phenols	On-site disposal and RCRA cap	10,000 (soil and sediment)
28. Marathon Battery, NY	II	Cadmium, nickel	Solidification	55,000
29. Myers Property, NJ	II	SVOCs, dioxins	Dechlorination, soil washing	50,000 (soil and sediment)

(continued)

TABLE C-1. Continued

Site name	Region	Contaminants	RODs selected remedy	Quantity of sediments (cu yd)
30. South Brunswick Landfill, NJ	II		No action	
31. Spence Farm, NJ	II		No action	
32. Vineland Chemical, NJ	II	Metals, arsenic	Water wash extraction	62,600
33. York Oil, NY	II	VOCs, metals, PCBs	Solidification	8,000
34. Army Creek Landfill, DE	III	VOCs, inorganics, metals	No action	
35. Bergs Sand Pit, PA	III	PCE, 1,1-DCE, 1,1,1-TCA	Incineration	
36. Douglassville Disposal, PA	III	Benzene, toluene vinyl chloride, PAHs, PCBs, phenols, lead	Incineration with possible solidification of ash prior to disposal	600
37. Drake Chemical, PA	III	Benzene, toluene, TCE, xylenes, PAHs, phenols, arsenic, chromium, lead	Incineration	252,000 (soil, sediment, and sludge)
38. Harvey-Knott Drum, DE	III	VOCs, metals, PCBs, inorganics	Off-site disposal	
39. L.A. Clarke & Sons, VA	III	PNAs, benzene	Land farming	118,000 (soil and sediment)
40. Leetown Pesticide, WV	III	Pesticides	Anaerobic biodegradation	
41. Limestone Road, MD	III	TCE, PCE, metals	No action	
42. Millcreek Dump, PA	III	PCBs, PAHs, inorganics, metals	On-site consolidation and RCRA cap	
43. Ordnance Works Disposal, WV	III	Arsenic, PAHs, PCBs	Incineration	
44. Sand, Gravel, and Stone, MD	III	Organics, metals	No action	

(continued)

TABLE C-1. Continued

Site name	Region	Contaminants	RODs selected remedy	Quantity of sediments (cu yd)
45. Southern Maryland Wood Treating, MD	III	VOCs, PNAs	Incineration	
46. Taylor Borough, PA	III	VOCs, organics	Off-site disposal	
47. Tyson's Dump, PA	III	VOCs	Off-site disposal	50
48. West Line, PA	III	PAHs, phenols	Off-site incineration	
49. West Virginia Ordnance, WV	III	Nitroaromatics, lead	No action	
50. Whitmoyer Laboraties, PA	III	VOCs, SVOCs	Ex situ bioremediation	5,600 (soil and sediment)
51. Wildcat Landfill, DE	III		No action	
52. A.L. Taylor, KY	IV	VOCs, PCBs, PAHs, metals	On-site containment and RCRA cap	
53. Airco Carbide, KY	IV	PCBs	On-site disposal	
54. Brown Wood Preserving, FL	IV	PAHs	On-site biodegradation, off-site disposal	3,000
55. Cape Fear Wood Preserving, NC	IV	Benzene, PAHs, arsenic, chromium	Low temperature thermal desorption desorption followed by soil washing or solidification	
56. Celanese, NC	IV	Ketone, phthalates	On-site disposal	110
57. Coleman Evans, FL	IV	VOCs, PCP, chromium	Incineration	9,000 (soil and sediment)
58. Flowood, MS	IV	Lead	Solidification	6,000 (soil and sediment)
59. Geiger/C&M Oil, SC	IV	Lead	No action	
60. Independent Nail, SC	IV	Metals	Solidification	6,200 (soil and sediment)
61. Newsom Brothers/Old Reichold, MS	IV	PAHs, PCBs, PCP metals	Incineration	7,300
62. Sapp Battery, FL	IV	Metals	Solidification	

(continued)

TABLE C-1. Continued

Site name	Region	Contaminants	RODs selected remedy	Quantity of sediments (cu yd)
63. Smith's Farm, KY	IV	PAHs, PCBs, lead	Incineration, solidification	5,200
64. Wamchem, SC	IV	VOCs, organics	No action	
65. Whitehouse Waste Oil Pits, FL	IV	Benzene, phenols, PAHs, Cr	Removal and off-site disposal	
66. Zellwood, FL	IV	Organics, metal	Thermal destruction	20,000
67. Arrowhead Refinery, MN	V	VOCs, PAHs, lead	On-site incineration	350
68. Burrows Sanitation, MI	V	Metals, cyanides	Solidification	350
69. Envirochem, IN	V	VOCs, PCBs, inorganics	On-site disposal and RCRA cap	
70. E.H. Schilling Landfill, OH	V	Benzene, phenol, PAHs, pesticides, arsenic	Disposal in landfill	500
71. Fields Brook, OH	V	TCE, PCE, PCBs, metals	Thermal treatment and solidification	52,000
72. Industrial Excess Landfill, OH	V	Organics, metals	Capping	
73. Lake Sandy Jo, IN	V	VOCs, PAHs, metals	On-site consolidation	
74. LaSalle Electrical Utilities, IL	V	VOCs, PCBs	Incineration	
75. MIDCO I, IN	V	Benzene, toluene, TCE, PCBs, phenols, PAHs, chromium, lead	Solidification and RCRA cap	1,200
76. MIDCO II, IN	V	Benzene, toluene, TCE, xylenes, PCBs, arsenic, chromium, lead	Solidification and RCRA cap	500
77. Moss-American, WI	V	PAHs	Slurry phase bioremediation followed by soil washing	5,200

(continued)

TABLE C-1. Continued

Site name	Region	Contaminants	RODs selected remedy	Quantity of sediments (cu yd)
78. New Lyme Landfill, OH	V	VOCs, organics, inorganics	Consolidation and RCRA cap	
79. Ninth Avenue Dump, IN	V	Benzene, TCE, toluene, PAHs, PCBs, lead	On-site disposal and RCRA cap	
80. Old Mill, OH	V	VOCs, PCBs	Off-site disposal	
81. Outboard Marine/Waukegan Harbor, IL	V	PCBs	Low temperature thermal desorption followed by incineration	16,000 (soil and sediment)
82. Pristine, OH	V	PCE, TCE, metals, pesticides, dioxins	On-site consolidation with in situ vitrification	
83. Schmalz Dump, WI	V	VOCs, PCBs, chromium	Off-site disposal	
84. Seymour Recycling, Inc.	V	TCE, organics	Consolidation on-site	
85. Summit National, OH	V	Benzene, toluene, xylenes, TCE, phenol, PAHs, PCBs, arsenic, chromium	On-site incineration	1,500
86. United Scrap Lead, OH	V	Arsenic & lead	Acid washing	400
87. Velsicol Chemical Corporation, IL	V	Benzene, PAHs pesticides	On-site disposal	10,200
88. Wedzeb Enterprises, IN	V	PCBs	Incineration	
89. AT&SF (Clovis), NM	VI	Phenols, arsenic, chromium, lead	On-site biodegradation	
90. Bailey Waste Disposal, TX	VI	Benzene, PAHs, metals	Solidification	
91. Bayou Bonfouca, LA	VI	PAHs	Incineration	
92. Cleve Reber, LA	VI	Organics	Backfilling of on-site ponds	

(continued)

TABLE C-1. Continued

Site name	Region	Contaminants	RODs selected remedy	Quantity of sediments (cu yd)
93. Gurley Pit, AR	VI	PCBs, oily waste, metals	Stabilization	
94. Koppers Texarkana, TX	VI	Benzene, toluene, xylene, PAHs, PCP, arsenic	Soil washing	
95. Motco, TX	VI	Benzene, PAHs, arsenic, chromium, lead	Containment	140,000 (soil and sediment)
96. North Cavalcade Street, TX	VI	PAHs, benzene, toluene, xylene	Biodegredation	
97. Old Midland Products, AR	VI	PCP, PNAs	Incineration	850
98. Kem-Pest Laboratories, MO	VII	Xylene, pesticides, organochlorine, arsenic	Off-site disposal in a RCRA landfill	4,050 (soil and sediment)
99. Minker Stout/Romaine Creek, MO	VII	TCDD	On-site disposal (temporary)	
100. Burlington Northern (Somers Plant), MT	VIII	PAHs, phenols, zinc	Biological treatment	11,700 (soil and sediment)
101. Denver Radium/Card Property, CO	VIII	Radium	On-site storage followed by on-site disposal	
102. Iron Mountain Mine, CA	IX	Metals	No action	
103. MGM Brakes, CA	IX	PCBs, VOCs	Off-site disposal	
104. Commencement Bay near Shore/Tide Flats, WA	X	PCBs, PAHs, arsenic mercury, lead, zinc	In-situ capping, CAD, confined near-shore disposal, and upland disposal	1,818,000

(continued)

TABLE C-1. Continued

Site name	Region	Contaminants	RODs selected remedy	Quantity of sediments (cu yd)
105. Gould, OR	X	Lead	Stabilization	5,500
106. Queen City Farms, WA	X	TCE, PCBs, chromium, lead	Stabilization	
107. Western Processing, WA	X	VOCs, PCBs, PAHS, metals	Removal	

Source: USEPA, 1990b
Note: For an updated version of RODs involving sediment contamination, contact the Region III Hazardous Waste Technology Information Center.

APPENDIX D

CONTAMINANT GROUP CONSTITUENTS

TABLE D-1. EXAMPLES OF CONSTITUENTS WITHIN WASTE GROUPS

Halogenated Volatiles

Bromodichloromethane
Bromoform
Bromomethane
Carbon tetrachloride
Chlorodibromomethane
Chlorobenzene
Chloroethane
Chloroform
Chloromethane
Chloropropane
Dibromomethane
Cis,1-3-dichloropropene
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethene
1,2-Dichloroethene
1,2-Dichloropropane
Fluorotrichloromethane
Methylene chloride
1,1,2,2-tetrachlorethane
Tetrachloroethene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
1,2-Trans-dichloroethene
Trans-1,3-dichloropropene
1,1,2-trichloro-1,2,2-trifluoroethane
Trichloroethene
Vinyl chloride
Total chlorinated hydrocarbons
Hexachloroethane
Dichloromethane

Nonhalogenated Semivolatiles

Benzoic acid
Cresols
2,4-dimethylphenol
2,4-dinitrophenol
2-methylphenol
4-methylphenol
2-nitrophenol
4-nitrophenol
Phenol
Acenaphthene
Acenapthylene
Anthracene
Benzidine
Benzo(a)anthracene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(a)pyrene
Benzo(ghi)perylene
Benzyl alcohol
Bis(2-ethylhexyl)phthalate
Butyl benzyl phthalate
Chrysene
Dibenzo(a,h)anthracene
Dibenzofuran
Diethyl phthalate
Dimethyl phthalate
Di-n-butyl phthalate
4-6-dinitro-2-methylphenol
2,4-dinitrotoluene
2,6-dinitrotuelene

Volatile Metals

Arsenic
Bismuth
Lead
Mercury
Tin
Selenium
Zinc

Other Categories

Asbestos

Inorganic Corrosives

Hydrochloric acid
Nitric acid
Hydrofluoric acid
Sulfuric acid
Sodium hydroxide
Calcium hydroxide
Calcium carbonate
Potassium carbonate

PCBs

PCB (Arochlor)-1016
PCB (Arochlor)-1221
PCB (Arochlor)-1232
PCB (Arochlor)-1242
PCB (Arochlor)-1248
PCB (Arochlor)-1254
PCB (Arochlor)-1260
PCB NOS (not otherwise specified)

Organic Corrosives

Acetic acid
Acetyl chloride
Aniline
Aromatic sulfonic acids
Cresylic acid
Formic acid

TABLE D-1. (continued)

Halogenated Semivolatiles

2-chlorophenol
2,4-dichlorophenol
Hexachlorocyclopentadiene
p-chloro-m-cresol
Pentachlorophenol
Tetrachlorophenol
2,4,5-trichlorophenol
2,4,6-trichlorophenol
Bis(2-chloroethoxy)methane
Bis(2-chloroethyl)ether
Bis(2-chloroiospropyl)ether
4-bromophenyl phenyl ether
4-chloroaniline
2-chloronaphthalene
4-chlorophenyl phenylether
1,2-dichlorobenzene
1,3-dichlorobenzene
1,4-dichlorobenzene
3,3-dichlorobenzidine
Hexachlorobenzene
Hexachlorobutadiene
1,2,4-trichlorobenzene
Bis(2-chloroethoxy)phthalate
Bis(2-chloroethoxy)ether
1,2-bis(2-chloroethoxy)ethane

Nonhalogenated Semivolatiles (continued)

Di-n-octyl phthalate
1,2-diphenylhydrazine
Fluoranthene
Fluorene
Indeno(1,2,3-cd)pyrene
Isophorone
2-methylnapthalene
Napthalene
2-nitroaniline
3-nitroaniline
4-nitroaniline
Nitrobenzene
n-nitrosodimethylamine
n-nitrosodi-n-propylamine
n-nitrosodiphenylamine
Phenanthrene
Pyrene
Pyridine
2-methylnaphthalene
Bis phthalate
Phenyl napthalene

Nonmetallic Toxic Elements

Fluorine
Chlorine

Nonvolatile Metals

Aluminum
Antimony
Barium
Beryllium
Bismuth
Cadmium
Calcium
Chromium
Copper
Cobalt
Iron
Magnesium
Manganese
Nickel
Potassium
Selenium
Sodium
Vanadium
Zinc

TABLE D-1. (continued)

Nonhalogenated Volatiles

Acetone
Acrolein
Acrylonitrile
Benzene
2-butanone
Carbon disulfide
Cyclohexanone
Ethyl acetate
Ethyl ether
Ethyl benzene
2-hexanone
Isobutanol
Methanol
Methyl isobutyl ketone
4-methyl-2-pentanone
n-butyl alcohol
Styrene
Toluene
Trimethyl benzene
Vinyl acetate
Xylenes

Pesticides

Aldrin
BHC-alpha
BHC-beta
BHC-delta
BHC-gamma
Chlordane
4,4'-DDE
4,4'-DDE
4,4'-DDT
Dieldrin
Endosulfan I
Endosulfan II
Endolsulfan sulfate
Endrin
Endrin aldehyde
Ethion
Ethyl parathion
Heptachlor
Heptachlor epoxide
Malathion
Methylparathion
Parathion
Toxaphene

Radioactives

Radioactive isotopes of iodine, barium, uranium
Radium
Gamma radioactivity
Radon; alpha radioactivity

Organic Cyanides

Organonitriles

Inorganic Cyanides

Cyanide (sodium cyanide)
Complex cyanides (e.g., ferricyanide)

Oxidizers

Chlorates
Chromates

Reducers

Sulfides
Phosphides
Hydrazine

EPA
United States
Environmental Protection Agency
(WH-585)
Washington, DC 20460