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HANDBOOK: RESPONDING TO DISCHARGES OF SINKING HAZARDOUS SUBSTANCES

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NOTICE

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FOREWARD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory of the U.S. Environmental Protection Agency (USEPA) and the Environmental Technology Branch of the U.S. Coast Guard (USCG) assist in providing an authoritative and defensible engineering basis for assessing and solving these problems. Products support the respective policies, programs, and regulations of the Environmental Protection Agency and the Coast Guard, the permitting and other responsibilities of state and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

This document provides guidance on the response to spills of chemicals that sink in water bodies and contaminate bottom materials. It describes the decisionmaking process associated with defining spill parameters and impacts and selecting appropriate response measures. It also describes the cleanup and mitigative technologies that may be used, including containment, removal, treatment, disposal, and in situ techniques. This document provides governmental and industrial technical personnel with the means to respond to bottom material contamination situations, whether for quick response or for long-term remediation. For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory, USEPA, or the Environmental Technology Branch of the Office of Research and Development, USCG.

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ABSTRACT

This handbook provides guidance for making decisions in response to discharges of hazardous substances that sink in water bodies. It is intended to be used by personnel that direct spill response actions and emphasizes spilled contaminants that deposit on the bottom of water bodies. The majority of the information provided also applies to long-term, chronic contamination of bottom materials.

This handbook provides a framework for gathering information and for evaluating the spilled material, the environmental setting of the spill, and the potential impacts of interaction between the material and the environment. Considerations pertaining to the spilled material include its composition, chemical and physical characteristics, quantity, location, and distribution within the water column and along the bottom of the water body. The setting includes the depth, flow velocity, currents, tidal action, and uses of the water body; the aquatic environment; and the pathways to potentially affected humans. Impacts of the interaction between the spilled material and the environment include contamination of sediment and water (affecting water supplies, fisheries, and recreation), bioaccumulation and biomagnification of contaminants in organisms, and transport of contaminants to previously unaffected areas.

The handbook also focuses on techniques for minimizing the impacts of the spill on the environment. Responses are categorized into containment, removal, treatment, and disposal of contaminants and contaminated materials (generally water and sediments), as well as *in situ* response techniques. Information and criteria are provided for selecting among the techniques and combining various techniques into complete response alternatives. Additional information and criteria are provided for selecting the most appropriate response alternative for implementation and for assessing the adequacy and effectiveness of the completed response.

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CONTENTS

	Page
FORWARD	iii
ABSTRACT	iv
ACKNOWLEDGEMENTS	xiii
1. INTRODUCTION	1-1
1.1 PURPOSE	1-1
1.2 SCOPE	1-2
1.3 SUMMARY OF RESPONSE DECISIONMAKING PROCESS	1-2
1.3.1 Spill Characterization	1-5
1.3.2 Response Needs	1-5
1.3.3 Response Alternative Selection	1-5
1.3.4 Assessment of Response Effectiveness and Need for Further Response	1-6
2. CHARACTERIZATION OF THE DISCHARGE SITUATION AND IMPACTS	2-1
2.1 CHARACTERIZATION OF THE DISCHARGE	2-4
2.1.1 Characterization of Discharge Circumstances	2-4
2.1.2 Characterization of Discharged Material	2-6
2.2 CHARACTERIZATION OF THE WATER BODY AND THE ENVIRONMENTAL SETTING	2-10
2.2.1 Characterization of the Water Body	2-13
2.2.2 Characterization of the Environmental Setting	2-21
2.3 DETERMINATION OF THE EXTENT OF CONTAMINATION	2-25
2.3.1 Information Requirements	2-25
2.3.2 Methods for Obtaining Information	2-30
2.4 DETERMINATION OF EXPOSURE AND IMPACTS	2-33
2.4.1 Information Requirements and Analysis	2-34
2.4.2 Information Sources	2-36
2.5 LEVEL OF APPLICATION OF CHARACTERIZATION PROCESS	2-36
3. DETERMINATION OF RESPONSE NEEDS	3-1
3.1 ASSESSMENT OF NEED FOR RESPONSE	3-1

CONTENTS (continued)

Page

3.2 ESTABLISHMENT OF RESPONSE OBJECTIVES 3-3
3.2.1 Priorities 3-3
3.2.2 Response Criteria 3-4

3.3 ESTABLISHMENT OF OBJECTIVES FOR IMMEDIATE RESPONSE 3-5
3.3.1 Priorities 3-5
3.3.2 Response Criteria 3-6

4. SELECTION OF RESPONSE MEASURES 4-1

4.1 SCREENING OF RESPONSE CATEGORIES 4-3
4.1.1 Screening Process 4-5
4.1.2 Alternatives to the Removal Response Category . . . 4-13
4.1.3 Process Summary 4-14

4.2 SCREENING OF RESPONSE TECHNIQUES 4-14

4.3 DEVELOPMENT OF RESPONSE ALTERNATIVES 4-22
4.3.1 Combination of Response Categories 4-22
4.3.2 Combination of Techniques to Form Alternatives . . . 4-23

4.4 ALTERNATIVES EVALUATION AND SELECTION OF PREFERRED ALTERNATIVE 4-26
4.4.1 Performance 4-26
4.4.2 Reliability 4-27
4.4.3 Implementability 4-27
4.4.4 Environmental and Public Health Impacts 4-27
4.4.5 Safety 4-27
4.4.6 Cost 4-27
4.4.7 Ranking of Alternatives 4-28

4.5 LEVEL OF APPLICATION OF RESPONSE SELECTION PROCESS 4-28

5. DETERMINATION OF RESPONSE COMPLETION 5-1

5.1 ASSESSMENT OF RESPONSE EFFECTIVENESS 5-1
5.1.1 Data Collection 5-3
5.1.2 Assessment of Meeting Response Objectives 5-4

5.2 DETERMINATION OF NEED FOR FURTHER RESPONSE 5-4

APPENDICES

A. CONTAINMENT TECHNIQUES A-1

A.1 CONTAINMENT CURTAINS A-1

A.2 TRENCHES A-4

A.3 DIKES A-7

A.4 COFFERDAMS A-9

A.5 PNEUMATIC BARRIERS A-13

A.6 FLOATING BREAKWATERS A-15

A.7 TEMPORARY COVERING AND CAPPING A-18

A.8 SUMMARY A-18

B. CONTAMINATED MATERIAL REMOVAL TECHNIQUES B-1

B.1 MECHANICAL DREDGES B-2
B.1.1 Clamshell Dredges B-2
B.1.2 Draglines B-4
B.1.3 Conventional Earth Excavation Equipment B-5
B.1.4 Dipper Dredges B-6
B.1.5 Bucket Ladder Dredges B-7

B.2 HYDRAULIC DREDGES B-8
B.2.1 Portable Hydraulic Dredges B-9
B.2.2 Hand-Held Hydraulic Dredges B-10
B.2.3 Plain Suction Dredges B-11
B.2.4 Cutterhead Dredges B-13
B.2.5 Dustpan Dredges B-14
B.2.6 Hopper Dredges B-15

B.3 PNEUMATIC DREDGES B-17
B.3.1 Airlift Dredges B-17
B.3.2 Pneuma Dredges B-18
B.3.3 Oozer Dredges B-20

B.4 SUMMARY B-21

CONTENTS (continued)

C. TREATMENT TECHNIQUES FOR REMOVED CONTAMINATED MATERIALS C-1

C.1 SEDIMENT/WATER SEPARATION C-1
C.1.1 Impoundment Settling Basins C-3
C.1.2 Conventional Clarifiers C-5
C.1.3 High Rate Clarifiers C-6
C.1.4 Hydraulic Classifiers C-7
C.1.5 Granular Media Filters C-9
C.1.6 Hydrocyclones C-10
C.1.7 Summary C-11

C.2 SEDIMENTS DEWATERING C-14
C.2.1 Dewatering Lagoons C-14
C.2.2 Centrifugation C-16
C.2.3 Filtration C-17
C.2.4 Gravity Thickening C-20
C.2.5 Summary C-21

C.3 WATER TREATMENT C-21
C.3.1 Activated Carbon C-25
C.3.2 Biological Treatment C-26
C.3.3 Ion Exchange C-27
C.3.4 Neutralization C-31
C.3.5 Precipitation C-32
C.3.6 Flocculation C-33
C.3.7 Ultrafiltration C-34
C.3.8 Ozonation and Ultraviolet Radiation C-35
C.3.9 Discharge to Publicly Owned Treatment Works . . . C-37
C.3.10 Summary C-41

C.4 TREATMENT OF SOLIDS C-41
C.4.1 Solidification/Stabilization C-41
C.4.2 Chemical and Biological Treatment C-45
C.4.3 Summary C-50

D. CONTAMINATED MATERIAL DISPOSAL TECHNIQUES D-1

D.1 SEDIMENTS D-2
D.1.1 Landfilling D-2
D.1.2 Open Water Disposal D-5
D.1.3 Land Treatment/Disposal D-6

D.2 LIQUIDS D-8
D.2.1 Direct Discharge D-8
D.2.2 Deep Well Injection D-9

CONTENTS (continued)

		Page
D.3	SLUDGE AND SOLID TREATMENT RESIDUALS	D-10
D.3.1	Landfilling	D-10
D.3.2	Incineration	D-11
D.3.3	Land Treatment/Disposal	D-12
D.4	SUMMARY	D-13
E.	IN SITU CONTAMINANT TREATMENT AND ISOLATION TECHNIQUES	E-1
E.1	TREATMENT	E-1
E.1.1	Sorption	E-1
E.1.2	Chemical and Biological Treatment	E-4
E.2	ISOLATION	E-7
E.2.1	Covering and Capping	E-7
E.2.2	Fixation	E-11
E.3	SUMMARY	E-12
F.	DATA ON CHEMICALS THAT SINK	F-1
F.1	BACKGROUND OF THE SINKERS LIST	F-2
F.2	CONTENT OF THE SINKERS LIST	F-3
F.2.1	Chemical Name and CHRIS Code	F-3
F.2.2	Physical State	F-6
F.2.3	Specific Gravity	F-6
F.2.4	Water Solubility	F-6
F.2.5	Toxicity	F-6
F.2.6	Ignitability and Reactivity	F-7
F.2.7	Bioaccumulation and Aquatic Persistence	F-7
F.2.8	Recovery and Handling Hazards	F-7
F.2.9	Recommended Response	F-8
G.	GLOSSARY	G-1
H.	REFERENCES	H-1
I.	BLANK WORKSHEETS FOR DOCUMENTATION AND DECISIONMAKING	I-1

FIGURES

Number		Page
1-1	Sequence of Response Events	1-4
2-1	Sequence of Response Events	2-2
2-2	Process for Determining Spill Impacts	2-3
2-3	Example Discharge Summary Worksheet	2-5
2-4	Example Spilled Substance Data Worksheet	2-11
2-5	Example Water Body Data Collection Worksheet	2-17
2-6	Example Site Map for Recording Data and Observations - Water Body	2-21
2-7	Example Environmental Setting Worksheet	2-22
2-8	Example Site Map for Recording Data and Observations - Environmental Setting	2-26
2-9	Example Site Map for Recording Data and Observations - Current Extent of Contamination	2-29
2-10	Example Site Map for Recording Data and Observations - Future Extent of Contamination	2-31
2-11	Example Exposure and Impact Data Worksheet	2-35
3-1	Sequence of Response Events	3-2
4-1	Sequence of Response Events	4-2
4-2	Alternative Response Categories and Response Train Used in Overall Sinker Spill Response Selection Process	4-4
4-3	Example Worksheet for Screening Response Categories	4-8
4-4	Decision Process to Determine Applicability of Removal Response Category	4-12
4-5	Example Worksheet for Screening Response Techniques	4-19
4-6	Example Worksheet for Development of Response Alternatives	4-25

FIGURES (continued)

Number		Page
4-7	Example Alternatives Evaluation Worksheet	4-29
5-1	Sequence of Response Events	5-2
A-1	Applications of Containment Curtains to Control Resuspended Material	A-2
A-2	Application of a Spill Containment Trench to Control Sinking Substances	A-5
A-3	Application of a Spill Containment Dike to Control Sinking Substances	A-8
A-4	Streamflow Diversion for Sediment Excavation Using Two Cofferdams and Diversion Channel	A-11
A-5	Streamflow Diversion for Sediment Excavation Using Single Cofferdam	A-12
A-6	Cross-Section of a Pneumatic Barrier Application	A-14
A-7	Tethered Float Breakwater	A-16
C-1	Typical Sequence of Steps for Treatment of Removed Contaminated Bottom Materials	C-2

TABLES

Number		Page
2-1	Discharged Material Information Requirements and Sources	2-7
2-2	Water Body Information Requirements and Sources	2-14
2-3	Additional Information Sources for Water Body Data	2-20
2-4	Environmental Setting Information Sources	2-27
4-1	Decision Matrix for Screening Response Categories	4-6
4-2	Technology Screening Criteria For Action Response Categories	4-16
A-1	Summary of Contaminant Containment Techniques	A-19
B-1	Summary of Contaminated Material Removal Techniques	B-22
C-1	Summary of Sediment/Water Separation Techniques	C-12
C-2	Summary of Solids Dewatering Techniques	C-22
C-3	Summary of Biological Treatment Processes	C-28
C-4	Summary of Wastewater Treatment Techniques	C-38
C-5	Summary of Solids Treatment Techniques	C-51
D-1	Summary of Contaminated Material Disposal Techniques	D-14
E-1	Summary of *In Situ* Contaminant Treatment and Isolation Techniques	E-13
F-1	Key to Abbreviations and Symbols	F-4
F-2	Hazard Rating Criteria	F-4
F-3	Bioaccumulation Rating Criteria	F-5
F-4	Summary of Data on Chemicals that Sink	F-9

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SECTION 1

INTRODUCTION

1.1 PURPOSE

Materials that are spilled into a water environment can either float, dissolve or become suspended in the water column, or sink to the bottom (where dissolution can later occur), depending on the material's chemical and physical properties. Materials that sink to the bottom have the potential to contaminate bottom sediments and be carried downstream by currents, further spreading the contamination. Such spills can pose a serious threat to public health and welfare and to the environment, and significant economic consequences can result from the destruction of food resources, contamination of water supplies, and reduction in recreational resources.

Contamination of bottom materials (i.e., sediments, organic matter, and interstitial water) by substances that sink (sinkers) can pose long-term threats. Once contaminated, bottom materials can be an ongoing source of contaminant release to the environment. Contaminants can be transported long distances over time and often bioaccumulate and biomagnify in benthic and aquatic organisms. Rapid and effective response techniques can be applied to mitigate actual and potential damages from spilled sinkers. The implementation of such techniques should protect resources and minimize additional damage to public health, the environment, and property from any response measures taken.

This handbook provides information and guidance on the process and techniques for responding to spills of sinkers to inland and coastal waters. It is intended for use by the United States Environmental Protection Agency (USEPA) and Coast Guard (USCG) on-scene coordinators (OSCs) and state, local, and private spill control cleanup personnel. The handbook outlines the sequence of response events; the decisionmaking criteria for identifying appropriate responses; and the techniques that are currently available to contain, remove, treat, and dispose of contaminants and contaminated materials. The procedures described are specific to the cleanup of bottom materials that have been contaminated by spills of sinkers.

Because it is usually not practical to call on a wide range of technical disciplines in response to a spill or other discharge, this handbook does not discuss complex scientific and engineering principles. The terminology used is intended to be familiar to persons with a basic understanding of the physical and environmental sciences, spill response, hazardous materials, navigation, construction, and regulations and their interrelationships. In addition, a glossary of frequently used terms is provided in Appendix G. However, because environmental contamination and cleanup can be technically complex, users of this handbook should consult technical specialists whenever possible.

1.2 SCOPE

This handbook addresses contamination of bottom materials of water bodies through spills and other discharges of substances that sink in the water environment and response techniques for contaminant cleanup. As such, the handbook does not include response measures that may be taken to prevent sinkers from reaching bottom materials or to protect receptors from exposure, nor does it provide guidance for responding to discharges of substances that are not sinkers or are entrained in the water column. It also does not address the implementation of response measures.

The guidance provided in this document is designed to protect public health, the environment, and property. Furthermore, the procedures presented are intended to supplement the knowledge of experienced response personnel to quickly formulate appropriate mitigative measures. The approach focuses on what decisions need to be made, the framework for the decisionmaking, and the information needed; it does not address the "how to" aspects of decisionmaking, data collection and analysis, and response implementation. Because of the complexity of environmental contamination and cleanup, users of this manual should consult referenced sources of information and technical specialists for further information on techniques that are evaluated and/or selected through the decisionmaking process.

1.3 SUMMARY OF RESPONSE DECISIONMAKING PROCESS

In responding to spills of substances that sink, the following general types of activities must be conducted:

- Obtaining data relevant to the decisionmaking process
- Analyzing these data with regard to the spill situation to address specific decision parameters

- Developing decisions on response needs and capabilities

- Applying techniques to mitigate and/or clean up contaminated materials.

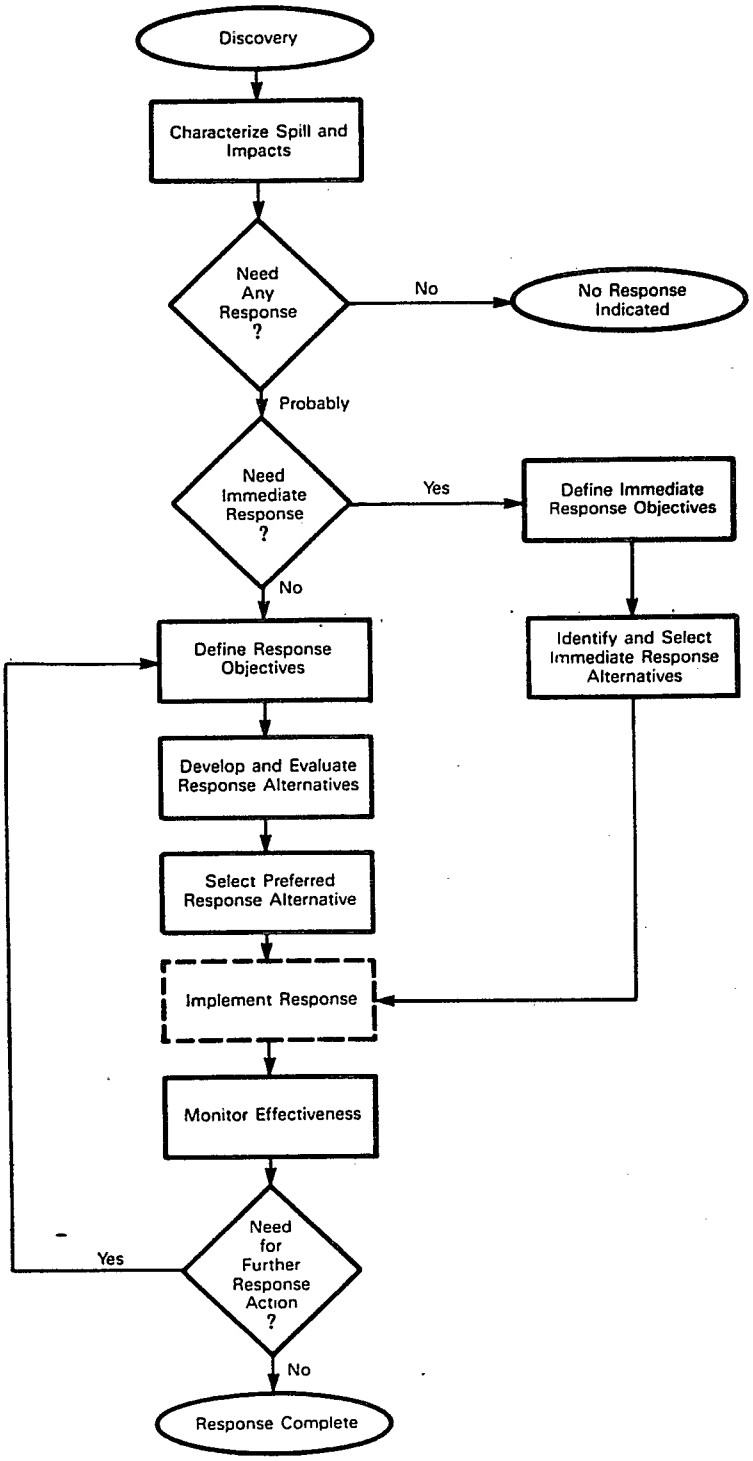
A process for conducting these activities is provided in this handbook. The process is designed to aid the user in identifying and documenting data needs, analysis requirements, and mitigating factors to consider in completing the selection. The process formalizes a decisionmaking process that is often performed mentally rather than on paper. The amount of time and the depth of analysis conducted at each step must be considered with regard to the spill situation encountered. For example, a rapidly spreading or moving spill of highly toxic chemicals would require a quick analysis to identify immediate response measures, while an area of stable, contaminated sediments would permit more time to consider and select an appropriate response. Where possible, guidance on critical factors and decision criteria, as well as relatively "rough" analysis methods, are identified.

The response decision process has been designed to meet response needs from quick-response spill situations to long-term cleanup efforts. This process sets forth decision steps to facilitate the systematic selection of techniques that are appropriate to the specific discharge situation being addressed. To assist the user of the handbook in evaluating and selecting between the available techniques, technical information on containment, removal, treatment, disposal, and in-place (or in situ) treatment/isolation techniques is provided in Appendices A through E.

Figure 1-1 shows the response activities identified as a generalized sequence of response steps from the discovery of a spill to the completion of the response. The response sequence begins with the discovery of contamination or the potential for contamination of bottom materials. Such contamination could result from a spill or from long-term discharges attributable to a variety of sources. The causative discharge may be ongoing or may have ceased some time past. Further, the affected area may be confined to the area of the original discharge, or contamination may have spread over a much larger area.

Response steps that follow discovery are: spill characterization, determination of response needs, selection of a response alternative, and assessment of the effectiveness of the response. Each step is briefly described below and is described in detail in Sections 2 through 5. Worksheets are also provided to assist the user in tracking and documenting the flow of information and bases for decisionmaking throughout the response process. Supporting information for completing the worksheets and examples of completed worksheets are provided in Sections 2 through 5. Blank worksheets are compiled from all of the sections in Appendix I. It is suggested that users of this handbook make detached copies of the blank worksheets for use in field response situations.

FIGURE 1-1. SEQUENCE OF RESPONSE EVENTS



1.3.1 Spill Characterization

The initial response effort following discovery is to characterize the spill situation and to obtain information pertinent to making decisions on the need for and type of response; this effort is described in Section 2. This effort involves identifying and characterizing the spilled substance, the affected water body, and potential receptor/resources exposed. These data are used to determine the area of contamination, predict the future movement of contaminants, quantify the contamination, identify receptors and levels of exposure to contaminants, and determine impacts of the exposure.

1.3.2 Response Needs

Following spill characterization, the need for response action is assessed based on the data obtained in the spill characterization; this assessment is described in Section 3. The assessment focuses on determining whether existing present or future impacts or damages, which may occur through contaminant movement and exposure, are significant and warrant a response. The result of this assessment may be the decision that no response is warranted. However, if response actions are warranted, the need for immediate response measures to control contaminant movement or to minimize exposure prior to full-scale response must be addressed along with long-term response measures. Response objectives, priorities, and criteria are then established to set the framework for selecting appropriate response techniques.

1.3.3 Response Alternative Selection

Given the need for a response to a spill, response alternatives are developed and evaluated and the preferred alternative is selected and implemented. This process begins with selecting applicable categories of response actions based on response objectives and site data. Techniques within each identified category are screened to eliminate those techniques that are not applicable or are not practical to the situation. Individual techniques are then combined into response alternatives, which are evaluated against response objectives and technical, environmental, and other relevant criteria, to select an alternative that will most effectively resolve the identified problems. Throughout this process, the objectives may be revised to reflect the limitations of available techniques. Further, situations may arise where no response is possible or where no response is the preferred alternative.

Section 4 presents this evaluation and selection process. Appendices A through E provide detailed information on temporary containment, removal, treatment, disposal, and in-place (or *in situ*) remediation techniques and are reference tools for this analysis.

Upon selection, the preferred alternative is implemented to resolve the site problems. It should be noted that this document does not address response action implementation and operation.

1.3.4 Assessment of Response Effectiveness and Need for Further Response

After the response action has been implemented and completed, the site should be monitored and evaluated to assess the effectiveness of the response actions, whether the response objectives were met, and whether the implemented response sufficiently minimizes future risk to public health and the environment. These assessments are described in Section 5. The extent of cleanup, presence of residual contamination, and present and future damages that may be incurred from remaining contamination are specifically addressed. As a result of this assessment, a decision is made that either further response action is necessary or that the response is complete. Where further response action is indicated, the decisionmaking process would recommence with establishing new response objectives.

SECTION 2

CHARACTERIZATION OF THE DISCHARGE SITUATION AND IMPACTS

The first activity that is conducted following the discovery of a discharge of a sinking substance is to collect and analyze data that define the physical situation of the spill and the impacts that have resulted. This characterization process defines the important factors that form the foundation for subsequent decisionmaking. Figure 2-1 identifies the overall sequence of response events and the relationship of the spill and impacts characterization to the overall process.

The ultimate goal of the characterization process is to define known or anticipated spill impacts in order to assess the need for, and the urgency of, spill response. To achieve this goal, data need to be collected in the following areas:

- Spill circumstances
- Chemical characteristics
- Receptor identification and locations
- Environmental monitoring (chemical movement)
- Water body characteristics
- Regulatory standards and other criteria for assessing exposure and contamination.

These data feed into analyses of the present and future extent of contamination, exposure, and impacts. Figure 2-2 illustrates the analytical process leading to the identification of spill impacts.

Subsequent sections describe each step of the characterization process. Section 2.1 addresses the characterization of the discharge, both the spill circumstances and the discharged materials. Section 2.2 provides guidance on characterizing the water body involved and its environmental setting (i.e., receptors). Section 2.3 focuses on determining the extent of present and future contamination. Section 2.4 describes the exposure and impacts analysis process. Section 2.5 addresses the application of the overall process at different levels of detail.

FIGURE 2-1. SEQUENCE OF RESPONSE EVENTS

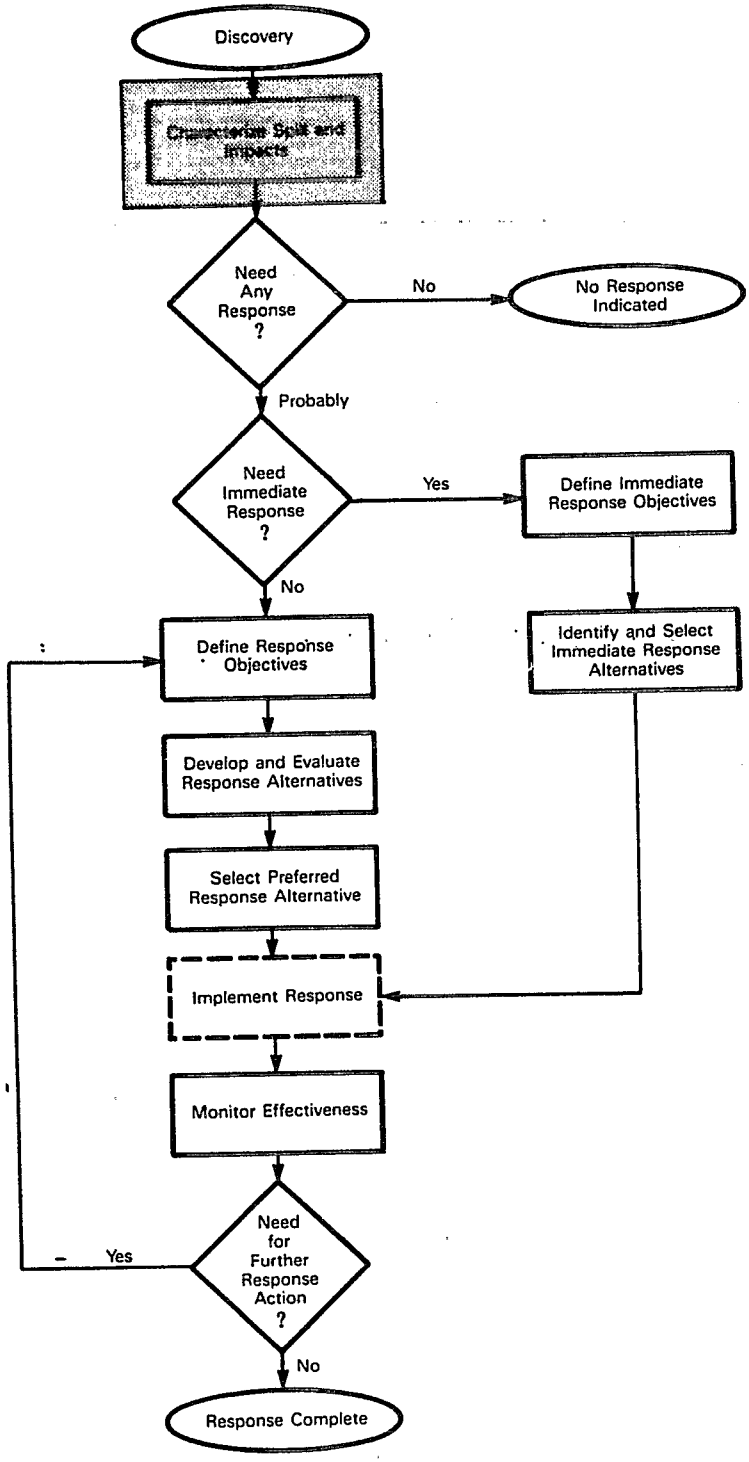
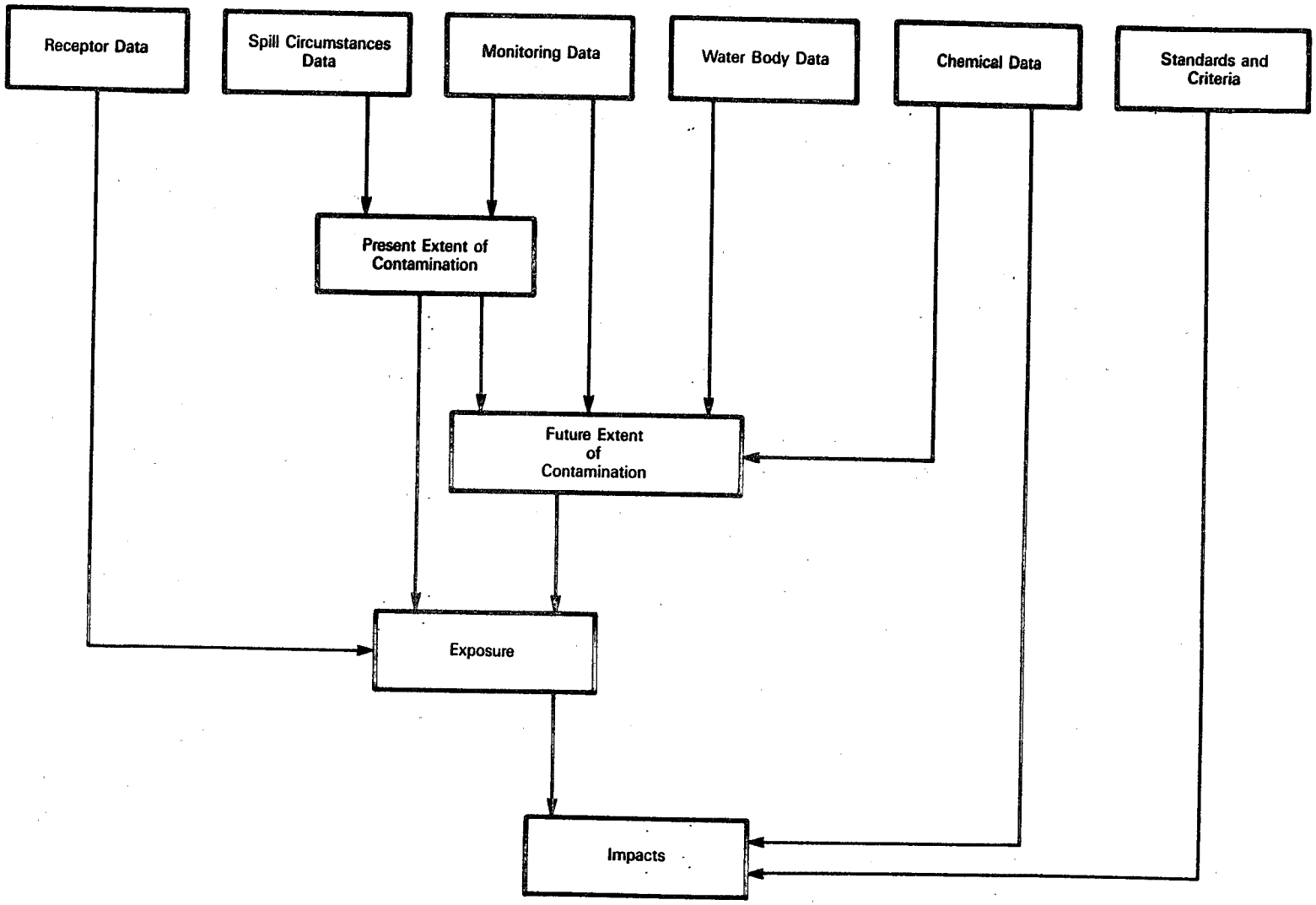


FIGURE 2-2. PROCESS FOR DETERMINING SPILL IMPACTS



2.1 CHARACTERIZATION OF THE DISCHARGE

The two major components in characterizing a spill of sinking substances are the spill circumstances and the nature of the spilled substances. Collection of information defining these components establishes the framework for analyzing the spill situation and selecting an appropriate and timely response. The factors relevant to characterizing the spill circumstances and the discharged material, as well as sources of this information, are described in the following sections.

2.1.1 Characterization of Discharge Circumstances

Information on the circumstances surrounding the discharge or spill of substances into a water body is useful for the response decisionmaking process. The information collected through observation when the situation is first encountered can be used to identify the specific substances involved and the extent of resulting contamination. Specific spill information that is needed and sources of this information are identified below.

2.1.1.1 Information Requirements

Figure 2-3 is an example completed worksheet used to record and summarize pertinent information regarding the circumstances, status, and characteristics of a discharge. A blank worksheet is provided in Appendix I. This information provides background and time-related data that can be used to determine the nature of the problem and the need for immediate action (such as stopping ongoing or intermittent contaminant sources or shutting off affected water intakes). This information may also be used in subsequent analyses to estimate the current extent of contamination or the future extent of contamination based on the rates of spill spread. All of these analyses contribute to the spill response decision process.

The worksheet shown in Figure 2-3 also provides space for recording additional pertinent information based on observation of the discharge situation. An example is an observation of a fish kill, apparently related to the discharge situation, which may indicate that the materials involved in the discharge are highly toxic to aquatic species. Human uses of the area could also be noted based on litter or other evidence near the site.

2.1.1.2 Information Sources

The information to be recorded on the Figure 2-3 worksheet is generally derived through observation of the spill circumstances and the surrounding

FIGURE 2-3. EXAMPLE DISCHARGE SUMMARY WORKSHEET

Site North River at Route 59 bridge
Time of Observation 11:50 a.m. Date 7-29-85
Type of Water Body Slow flowing, winding river

CIRCUMSTANCES OF DISCHARGE

Location North bank on downstream side of bridge

Source Tank trailer

Cause Trailer overturned and tank ruptured, spilling contents into the river

Status (Circle One): (Discrete) Intermittent Continuous

Time Elapsed Since Discharge Began Approx. 1 hour

Quantity of Material Released Approx. 7,000 gal. Rate of Release N/A

Duration of Release (if intermittent) N/A

Substances Released	Quantity
Carbon tetrachloride (CHRIS Code is CBT)	Approx. 7,000 gal.

Form of Release (Circle One):
Powder Crystal/Pellets Chunks Semi-Solid (Liquid)

EXTENT OF CONTAMINATION

Sediments	Water Body
Not known	Not known; see observation below

OBSERVATIONS Estimated 500-1,000 dead fish observed within 1/2 mile of spill location; strong solvent odor in vicinity of spill

N/A - Not applicable

area, as well as through interviews with witnesses or other knowledgeable parties. Additional information (such as discharge rates or contamination spread rates) may be estimated from measured observations.

Information on the chemicals spilled and the quantity spilled must be obtained from specific sources, which include:

- Captain or crew of vessel
- Shipping papers, transport or waste manifests, cargo labels, or other identifying papers/markings
- Shipping agent
- Company discharge records or environmental permits
- USEPA Regional Office or state permit data.

Sampling may be necessary to identify or confirm the chemicals involved in the absence of any identifying data or where available data provide conflicting answers.

2.1.2 Characterization of Discharged Material

Sinking materials are chemical substances that are denser than water and are relatively insoluble in water. When a sinking material is spilled and enters a surface water body, it tends to fall or flow to the bottom and, when the material is a liquid, it will permeate or move along the top of the sediments. Once the material has reached the bottom, its properties determine its fate in the environment and potential hazards posed to the population, the environment, and property. Appendix F provides and explains a list of 468 chemicals that have been identified as sinking chemicals.

2.1.2.1 Information Needs

Table 2-1 lists important physical, chemical, and biological properties that should be determined for each sinking substance involved in a spill to a water body. Such data should also be collected for any breakdown products of the spilled substance that may result from hydrolysis or other chemical reactions in the environment or from biological transformation (e.g., microbial metabolism). These data will be used in subsequent analyses to assess the spread of contamination and the likely impacts. These data may also be used in the technology selection and evaluation process (described in Section 4) to identify containment, removal, treatment, or disposal methods applicable to the chemicals of interest or to identify adverse

TABLE 2-1. DISCHARGED MATERIAL INFORMATION REQUIREMENTS AND SOURCES

Information Factor	Use of Information	Information Source
Specific Gravity	Ability to settle to bottoms and prediction of movement along bottom. Once settled, to estimate future extent of contamination and impacts.	Appendix F. References in Note 1.
Physical State	Prediction of potential to remain suspended in water column. Ability to solubilize. Prediction of movement along bottom or into water column, once settled. Selection of containment, removal, treatment, and disposal technique.	Appendix F. Observation of spill. Transport manifest or container label. Discussion with notifier of spill company agent or other knowledgeable person.
Particle Size	Ability to remain in water column rather than settle. Selection of containment, removal, or treatment technique.	Observation of spill. Transport manifest or container label. Discussion with notifier of spill company agent or other knowledgeable person.
Water Solubility	Prediction of dissolution from sediments into water column. Prediction of solubilization rather than settling to the bottom. Selection of containment or treatment technique.	Appendix F. References in Note 1.

(continued)

1 - See Reference Nos. 8, 9, 35, 38, 41, 42, 51, 53, 56, 64, 72, 73, 74, 75, 80, and 82 in Appendix H. Also consult USEPA, Duluth, MN, "AQUIRE" database on aquatic toxicology; Occupational Health Services, Inc., New York, NY, "HAZARDLINE" database on physical/chemical properties, toxicology, spill response, and waste disposal; and National Oceanic and Atmospheric Administration's Hazardous Materials Response Project, Seattle, WA, for information on degree of hazard.

TABLE 2-1. (continued)

Information Factor	Use of Information	Information Source
Water Reactivity	Potential for rapid dispersement throughout water body.	Appendix F. References in Note 1.
Chemical Reactivity	Potential for transformation into another substance of greater or lesser concern. Selection of chemical management measures during and upon removal. Selection of treatment and disposal techniques.	References in Note 1.
Ignitability	Selection of treatment techniques for removed materials. Selection of special handling and management techniques during and upon removal. Selection of treatment and disposal techniques.	Appendix F. References in Note 1.
Surface Tension	Prediction of compound-water interaction and compound settlement and dispersal.	Observation of spill. References in Note 1.
Octanol-Water Partition Coefficient	Prediction of compound-water interaction.	References in Note 1.

(continued)

1 - See Reference Nos. 8, 9, 35, 38, 41, 42, 51, 53, 56, 64, 72, 73, 74, 75, 80, and 82 in Appendix H. Also consult USEPA, Duluth, MN, "AQUIRE" database on aquatic toxicology; Occupational Health Services, Inc., New York, NY, "HAZARDLINE" database on physical/chemical properties, toxicology, spill response, and waste disposal; and National Oceanic and Atmospheric Administration's Hazardous Materials Response Project, Seattle, WA, for information on degree of hazard.

TABLE 2-1. (continued)

Information Factor	Use of Information	Information Source
Sediment-Water Partition Coefficient	Assessment of future extent of contamination based on compound distribution between sediments and water.	References in Note 1.
Bioaccumulation[2]	Estimation of future contamination, exposure, and impacts.	Appendix F. References in Note 1.
Aquatic Persistence	Prediction of future extent of contamination and estimation of future exposure and impacts	Appendix F. References in Note 1.
Transformation Rate Constants or Half-Lives o Hydrolysis o Oxidation o Biotransformation	Prediction of chemical transformation into substances of greater or lesser concern. Prediction of future extent of contamination and estimation of future exposure and impacts.	References in Note 1.
Toxicity o Aquatic Species o Mammals o Human (ingestion) o Food Chain	Evaluation of health impacts of expected exposure levels on receptors of concern. Selection of special handling or management procedures during and following removal.	Appendix F. References in Note 1.

1 - See Reference Nos. 8, 9, 35, 38, 41, 42, 51, 53, 56, 64, 72, 73, 74, 75, 80, and 82 in Appendix H. Also consult USEPA, Duluth, MN, "AQUIRE" database on aquatic toxicology; Occupational Health Services, Inc., New York, NY, "HAZARDLINE" database on physical/chemical properties, toxicology, spill response, and waste disposal; and National Oceanic and Atmospheric Administration's Hazardous Materials Response Project, Seattle, WA, for information on degree of hazard.

2 - Consists of 3 measures: octanol-water partition coefficient, bioconcentration factor, and sediment/soil adsorption (sediment-water partition coefficient).

environmental or human health effects from contaminated sediment disturbance and resuspension during their removal. Specific data usage is summarized in the second column of Table 2-1.

Figure 2-4 is an example completed worksheet for use in collecting the chemical data needed for further analysis. A blank worksheet is provided in Appendix I. For a given spill situation, each chemical involved would be listed and the necessary data would be obtained.

2.1.2.2 Information Sources

Table 2-1 identifies information sources for each information factor listed. Numerous texts and documents presently available may provide the physical, chemical, and biological information needs identified in Table 2-1. Most of this information has been compiled and analyzed, and is presented in Appendix F as part of the chemical sinkers list.

The amount of available data varies for each chemical. Some chemicals have been studied to a greater extent than others and therefore have more data available. Thus, data for each factor identified in Table 2-1 may not be available. In such situations, best judgment based on knowledge of chemical behavior or observations of the spill situation will be necessary to complete subsequent analyses and decisionmaking. For example, the physical state and particle size of a spilled substance may be determined from the material container, known characteristics of similar materials, shipping documents, or company representatives. Fish or animal kills would indicate the toxicity of the material. Further, extensive water column discoloration could indicate entrainment of the spilled substance in the water column through chemical solubility, chemical specific gravity near that of water, low surface tension of the chemical, or significant dissolution to the water from contaminated sediments.

The source of each piece of information that is noted on the worksheet in Figure 2-4 should be specifically identified.

2.2 CHARACTERIZATION OF THE WATER BODY AND THE ENVIRONMENTAL SETTING

Once the spill circumstances are identified, information should be collected concerning the characteristics of the water body into which sinking substances were spilled and the surrounding environmental setting that may be affected.

The following sections identify important information needs and potential sources of this information.

FIGURE 2-4. EXAMPLE SPILLED SUBSTANCE DATA WORKSHEET

Information Factor	Substance A CBT	Information Source	Substance B _____	Information Source
1. Specific Gravity	1.590	Handbook, Appendix F		
2. Physical State	Liquid	Observation		
3. Particle Size	N/A			
4. Water Solubility	800 ppm	Handbook, Appendix F		
5. Water Reactivity	No reaction	Handbook, Appendix F		
6. Chemical Reactivity	N/A, only one chemical present			
7. Ignitability	Not ignitable	Handbook, Appendix F		
8. Surface Tension	Not available			

(continued)

N/A – Not applicable

FIGURE 2-4. (continued)

Information Factor	Substance A CBT	Information Source	Substance B	Information Source
9. Octanol-water partition coefficient	417	Hansch & Leo, 1979		
10. Sediment-water partition coefficient	631	Calculated from octanol-water coef. per Lyman et al., 1982		
11. Bioaccumulation	Low	Handbook, Appendix F		
12. Aquatic persistence	High	Handbook, Appendix F		
13. Transformation rate constants • Hydrolysis • Oxidation • Biotransformation	Not available			
14. Toxicity • Aquatic species • Mammals • Human • Food chain	Aquatic Toxicity Rating: TL_m96: 100-10 ppm* Oral rat LD_{50} = 1,770 mg/kg* Oral LD_{LO} = 60 mg/kg*; 0.4 µg/l WQC for 10^{-6} cancer risk;** SDWA Health Advisories: 1 day — 0.2 ppm 10 day — 0.02 ppm			

*Registry of Toxic Effects of Chemical Substances, NIOSH, 1976.

**EPA Water Quality Criteria (45 FR 79318-79379, 11-28-80)

2.2.1 Characterization of the Water Body

Spills of sinking chemicals may occur in any type of surface water. Each water body has certain physical and chemical characteristics that affect the movement of spilled substances and the application of particular technologies to control or remove the contaminants. In the response decision process, water body data contribute to estimating the future extent of contamination, exposure levels, and impacts; hazards or water body data also contribute to screening technologies for their applicability and contribute to evaluating response alternatives for their relative success or merit.

2.2.1.1 Information Requirements

Table 2-2 lists important physical and chemical factors that should be determined for a water body with bottom materials contaminated by sinking chemicals. These data will be used in subsequent analyses and decision steps. Specific data usage is summarized in the second column of Table 2-2.

Figure 2-5 is an example completed worksheet for use in collecting the water body data needed for further analysis. A blank worksheet is provided in Appendix I. It includes space to record data and to identify sources of information.

A map of the area should also be obtained. A United States Geologic Survey (USGS) topographic map and a navigation chart for the water body (if available) can provide pertinent information on the water body and the surrounding areas. Site data can also be recorded on the maps to provide a comprehensive picture of the situation; as additional data are collected (discharge circumstance, water body, etc.), they can be recorded or "overlayed" on the map. An example map is provided as Figure 2-6. Time-related observations, such as the location of the leading edge of the spill at different times, may also be recorded on the map and used to estimate further movement; prediction of contaminant movement is discussed in Section 2.3.1.2.

2.2.1.2 Information Sources

Table 2-2 identifies information sources for each information factor listed. Most of the information can be obtained from navigation charts (from National Ocean Services under the National Oceanic and Atmospheric Administration, NOAA) or topographic maps (from USGS). Observations of the water body can also provide the necessary data.

Many Federal and state agencies have much of this type of information available. Table 2-3 lists additional sources of information, identifying agencies to contact and the type of data that may be available.

TABLE 2-2. WATER BODY INFORMATION REQUIREMENTS AND SOURCES

Information Factor	Use of Information	Information Sources
Depth to Contaminated Bottom Materials	Ability of dredges to reach and remove contaminated materials.	Navigation chart. Direct measurement. Remote sensing (sonar).
Depth of Water Body or Water Channel (minimum, maximum, mean)	Ability to operate/maneuver dredging equipment. Accessibility of dredging equipment to site. Prediction of discharged substances or sediments movement.	Navigation chart. Table 2-3. Remote sensing (sonar).
Width of Water Body or Water Channel (minimum, maximum, mean)	Ability to operate/maneuver dredging equipment. Accessibility of dredging euqipment to site. Prediction of discharged substances or sediments movement.	Navigation chart. USGS topographic map. Table 2-3.
Configuration of Channel or Water Body	Ability to operate/maneuver dredging equipment. Accessibility of dredging equipment to site. Prediction of discharged substances or sediments movement.	Table 2-3. Remote sensing (sonar, video sounders).

(continued)

TABLE 2-2. (continued)

Information Factor	Use of Information	Information Sources
Water Current Direction (surface, subsurface)	Prediction of discharged substances or sediments movement.	Navigation chart. Table 2-3. Direct measurement/observation.
Water Current Velocity (surface, subsurface)	Prediction of discharged substances or sediments movement.	Navigation chart. Table 2-3. Direct measurement.
Tidal Cycle (time of high and low tides, velocity of tide, amplitude of tide)	Ability of dredging equipment to operate. Prediction of discharged substances or sediments movement.	Table 2-3. Direct measurement/observation.
Wave Height	Ability to operate/maneuver dredging equipment.	Table 2-3.
Suspended Particulate Concentration	Potential for contaminants to adhere to particulates rather than settling to sediments. Impact on need for containment. Impact on containment method selection.	Table 2-3 Observation (general estimate).
Water Temperature Profile	Ability of discharged material to solubilize while settling to sediments. Ability of discharged material to settle out.	Table 2-3.

(continued)

TABLE 2-2. (continued)

Information Factor	Use of Information	Information Sources
Salinity Profile	Ability of discharged material to solubilize while settling to sediments. Impact on sediment treatment option.	Table 2-3.
Seasonal Considerations (drought, snow melt, storm flood)	Affect on physical characteristics of the water body, thereby affecting ability to operate/ maneuver dredging equipment and prediction of contaminant movement.	Table 2-3. Direct measurement observation.
Sediment Type and Grain Size	Impact on type of dredging equipment may be used. Impact on sediment treatment and disposal method selection. Impact on containment method selection.	Table 2-3. Sampling and analysis Remote sensing (in-situ nuclear density probe).
Sediment Organic Carbon Content	Impact on adhesion of contaminants to sediments. Impact on treatment method selection.	Table 2-3. Sampling and analysis.

FIGURE 2-5. EXAMPLE WATER BODY DATA COLLECTION WORKSHEET

Information Requirements	Site-Specific Data	Information Source
WATER BODY:		
Depth of Water Body		
Minimum	5 ft	Observation, soundings from Route 59 bridge
Maximum	30 ft	
Average	20 ft	
Width of Water Body		
Minimum	150 ft	Observation, USGS quad map
Maximum	225 ft	
Average	200 ft	
Water Current Direction		
Surface	East	Observation, direction of flow
Subsurface	East	
Water Current Velocity		
Surface	1 ft/sec.	Observed time of flow of floating object
Subsurface	Not Known	
Tidal Cycle		
Time of high tide	N/A	
Time of low tide		
Velocity of tide		
Amplitude of tide		
Wave Height	N/A	

(continued)

N/A - Not applicable

FIGURE 2-5. (continued)

Information Requirements	Site-Specific Data	Information Source
SEDIMENTS:		
Depth to Contaminated Sediments	20 ft±	Contamination assumed to be on surface
Sediment Type	Mix of mineral and organic matter	Grab sample from Route 59 bridge
Sediment Grain Size	Mostly sand and silt	Grab sample
Sediment Organic Carbon Content	Not known, except organic matter is present	Grab sample
WATER:		
Suspended Particulate Concentration	Moderately turbid	Grab sample
Water Temperature Profile	Approx. 50°F, little variation w/ depth	Field measurement from Route 59 bridge
Salinity Profile	N/A	
SEASONAL CONSIDERATIONS:		
Seasonal Conditions and Impacts Drought Snow melt Storm flood	River is at normal summer level; subject to rapid rise and drop following rain	Local experience and observation of Hanover County firefighters

N/A — Not applicable

SKETCH WATER BODY/CHANNEL CONFIGURATION (CROSS-SECTION)

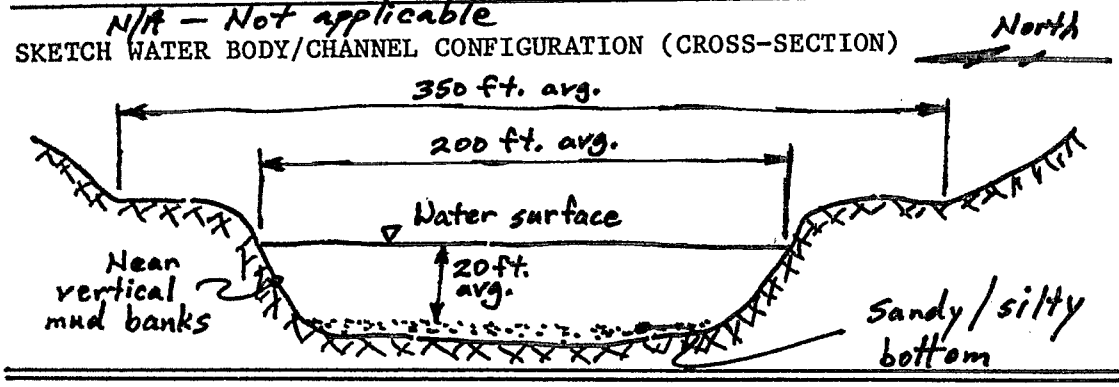


FIGURE 2-6. EXAMPLE SITE MAP FOR RECORDING DATA AND OBSERVATIONS — WATER BODY

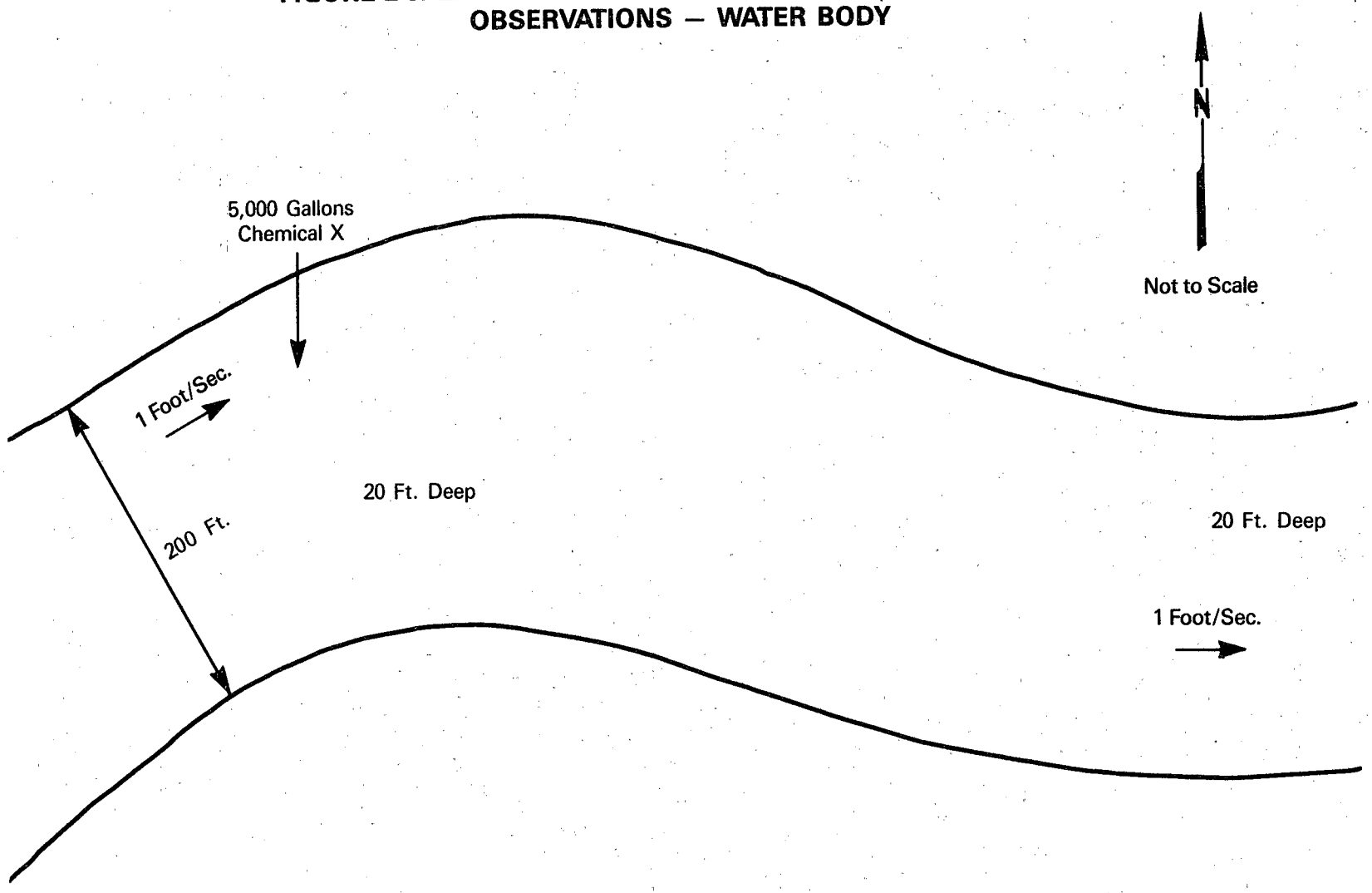


TABLE 2-3. ADDITIONAL INFORMATION SOURCES FOR WATER BODY DATA

Source	Information Available
U.S. Coast Guard District Offices	Historical spill data, local meteorological data, oceanographic data.
U.S. Geologic Survey	Topographic maps, data on the geologic and hydrologic features of a spill area, topographic data.
U.S. National Weather Service	Meteorological and nautical data.
U.S. Army Corps of Engineers	Historical water data for spill site, predicted flow patterns of an area.
U.S. National Oceanic and Atmospheric Administration	Nautical and meteorological data, visual reconaissance capabilities, modeling of contaminant trajectory.
U.S. Department of Interior and State Departments 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 within 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.

Adapted from Byroade, Twedell, and LeBoff, 1981.

In the absence of any specific data or estimates based on general information, sampling or direct measurements may need to be conducted to define the necessary data. These activities may range from taking soundings or measuring currents to sampling sediments for analysis. Where such activities are indicated, they should be planned and conducted in conjunction with other sampling or monitoring activities in the data collection and analysis effort to ensure efficient use of time and resources.

2.2.2 Characterization of Environmental Setting

The biological environment surrounding the spill of a sinking chemical consists of species, populations, and communities (i.e., receptors) at risk of exposure to the spilled substances. The receptors may be at risk through exposure to toxic substances or the destruction of their living environment (habitat). Economically important receptors, such as fish and shellfish, may also be affected by a spill of sinking chemicals. The economic and public welfare value of the water body for drinking water, industrial use, or recreational use may also be reduced as a result of the spill. Thus, the identification of receptors surrounding the spill area (flora, fauna, and human) and the uses of the water body information to assess exposure and impacts of the spill, as well as the need for immediate protective measures, need to be applied.

2.2.2.1 Information Requirements

For the purposes of spill response decisionmaking, the environmental setting of the area surrounding the spill of sinking substances includes the following:

- Distinctive, sensitive, or protected habitats
- Endangered species
- Sensitive or indicator species
- Sensitive water body use
- Potential receptors.

All of these components represent environmental areas or species subject to exposure that may require protection during cleanup or may be considered in evaluating the need for immediate response.

Figure 2-7 is an example completed worksheet for compiling environmental setting data. A blank worksheet is provided in Appendix I. This worksheet provides a detailed breakdown of information under each of the five components identified above.

FIGURE 2-7. EXAMPLE ENVIRONMENTAL SETTING WORKSHEET

Site Information	Information Sources
DISTINCTIVE HABITATS (Check and list if near spill area)	
✓ 1. Breeding Grounds, Nesting, or Roosting Sites Trout spawning 5 miles ± downstream	State DNR
✓ 2. Wildlife/Refuges East of Thompson State Park	State DNR
____ 3. Endangered Species Habitats	
____ 4. Marshes or Swamps (e.g., mangrove)	
____ 5. Subtidal Seagrass Systems	
____ 6. Harvesting Beds	
____ 7. Coral Reefs	
____ 8. Soft Bottom Benthos	
____ 9. Unused Natural Ecosystem (ecologically or aesthetically important)	
____ 10. Other	

(continued)

FIGURE 2-7. (continued)

Site Information	Information Sources

ENDANGERED SPECIES (List)

None

SENSITIVE SPECIES (Check if applicable and list)

✓ 1. Aquatic (Fish/Shellfish) Trout and small mouth bass — State DNR

___ 2. Birds

___ 3. Reptiles/Amphibians

___ 4. Mammals

___ 5. Plants

SENSITIVE WATER BODY USAGE (Check if applicable)

Type of Use	Distance Downstream From Spill
CONSUMPTIVE WATER USE	
✓ 1. Drinking Water Supply	Midville intake is approx. 2 miles downstream
___ 2. Industrial Water Supply	
___ 3. Irrigation	
___ 4. Fire Water Supply	
RECREATIONAL USE	
✓ 1. State/National Park	Thompson State Park – 1 mile
✓ 2. Swimming	Thompson State Park – 1 mile
✓ 3. Boating	Continuous along river
✓ 4. Fishing	Continuous along river
___ 5. Other	

(continued)

FIGURE 2-7. (continued)

Site Information	Information Sources
COMMERCIAL USE (Check if applicable and list)	
____ 1. Shellfish	
____ 2. Finfish	
✓ 3. Resort area or other waterfront property Residences and vacation homes	Hanover County Vol. Fire Dept.
✓ 4. Marinas Launching ramp at Thompson State Park	State DNR
✓ 5. Harbor/Docks Small docks at residences	Observation
____ 6. Transportation (shipping lanes)	
POTENTIAL RECEPTORS (Check if applicable and identify)	
✓ 1. Fish Primarily trout and small mouth bass	State DNR
____ 2. Shellfish	
____ 3. Aquatic Plants	
____ 4. Reptiles/Amphibians	
____ 5. Other aquatic or benthic receptors	
____ 6. Birds	
____ 7. Mammals	
✓ 8. Humans Fishermen, boaters, swimmers	Hanover County Vol. Fire Dept.

Adapted from Byroad, Twedell, and LeBoff, 1981.

This information should also be recorded on a site map, as described in Section 2.2.1. Figure 2-8 provides an example map; note that the environmental setting information has been recorded onto the same map as the water body characteristics (Figure 2-6). This data-overlaying process helps to build an overview of the spill, its movement, and crucial areas the spill may impact; thus, the data presented on the map reflect distance and time components of the spill.

2.2.2.2 Information Sources

Table 2-4 identifies Federal and state agencies and organizations that may be able to provide environmental setting information. For each agency or organization identified, the type of information or the services available are described.

Topographic maps from the USGS are useful information tools. These maps show state parks, marshes, wildlife refuges, and other distinctive habitat areas. They also identify nearby dwellings, towns, and cities. As described in Section 2.2.2.1, these maps may be used as a base map to record collected site data.

2.3 DETERMINATION OF THE EXTENT OF CONTAMINATION

An essential component in evaluating the impact of discharged sinking material is to assess the spread of contaminants from the sediments along the bottom and into the water column. The objective of this assessment is to determine the environmental concentrations of these substances or their transformation products and to plot migration pathways and concentration gradients over time. From this information, it is possible to determine levels of exposure to species, populations, and environmental systems identified earlier to evaluate risk of adverse effects.

2.3.1 Information Requirements

Determining the extent of contamination for a spill of sinking substances involves two components: (1) the current extent of contamination, and (2) the future extent of contamination. The first component provides a picture of the contamination situation as it exists at a certain time (generally, when the OSC first arrives on site). The second component considers the dynamic aspects of contamination to characterize the contamination situation as it changes over time, i.e., to build a series of pictures of the contamination situation at specific intervals within a defined period of time. Both components address (for sediments and water column) the dimensions of the contaminated areas and the concentration gradient within the contamination zone.

FIGURE 2-8. EXAMPLE SITE MAP FOR RECORDING DATA AND OBSERVATIONS — ENVIRONMENTAL SETTING

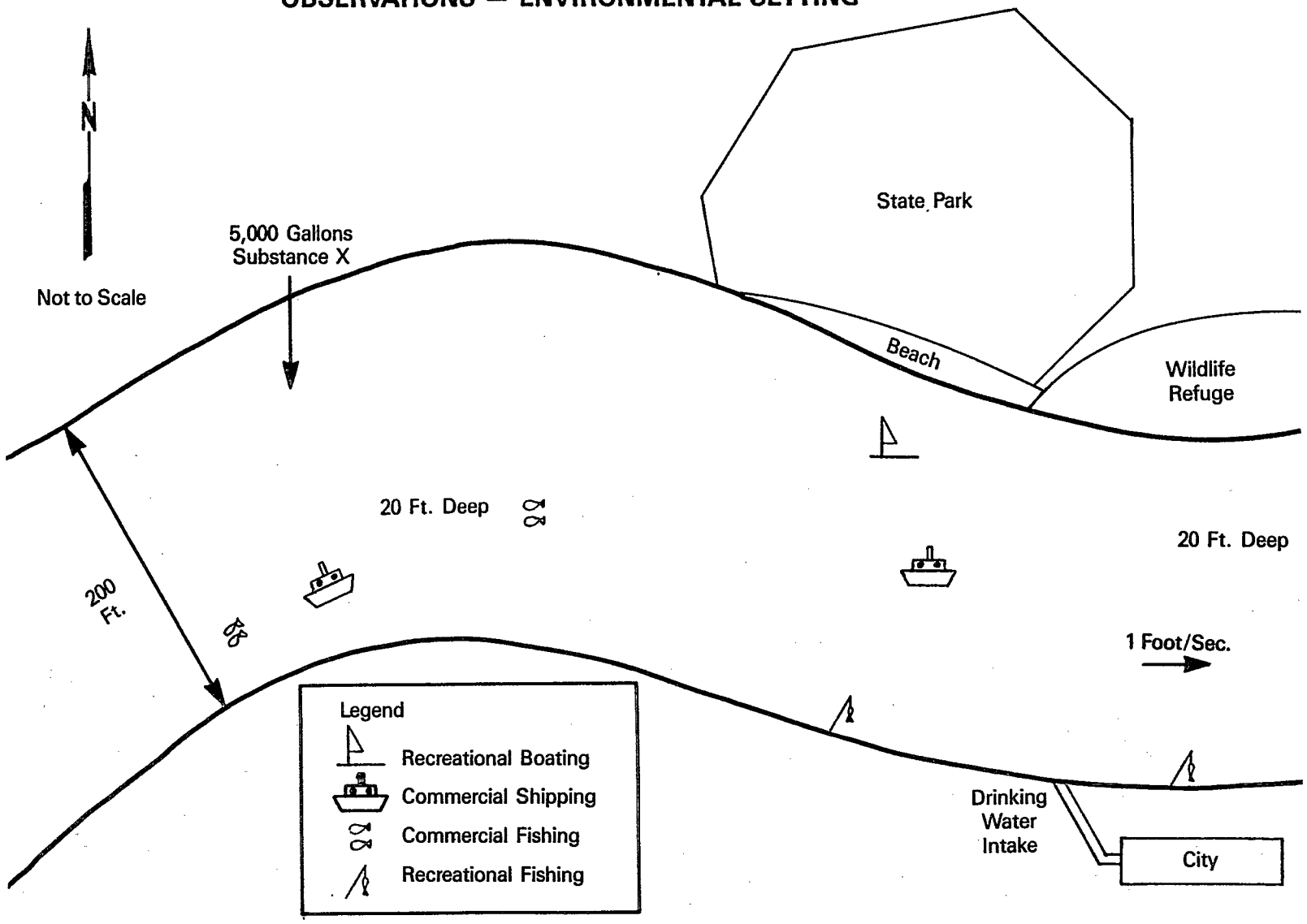


TABLE 2-4. ENVIRONMENTAL SETTING INFORMATION SOURCES

Source	Information Available
U.S. Fish and Wildlife Service	Data pertaining to possible sensitive and unique areas, data concerning threatened species in a spill area, directions to take concerning the protection or cleanup of important ecological systems (rookeries, hatcheries, etc.).
National Oceanic and Atmospheric Administration	Data pertaining to wildlife species, in general, and sensitive species in particular.
State Water Departments	Data concerning all water systems within a state, data concerning water uses in an area.
State Fish and Game Departments	Data detailing locations of major aquatic breeding and habitat areas within a state, data concerning wildlife water uses.
State Coastal Department	Data on coastal shoreline development areas, data on where the recreational, commercial, and wilderness shorelines are located.
State and Local Parks and Recreation Departments	Data on the recreational use of certain areas, data on the habitats of recreational wildlife (game fishes, birds, etc.).
State and Local Universities and Colleges	Data pertaining to wildlife species, in general, and sensitive species in particular.
State and Local Historical and Conservation Groups	Input as to the aesthetic and historical values of an area.
National Conservation and Wildlife Organizations	Input concerning the existence of threatened or endangered species in a spill area.
State and Local Government Officials	Information concerning water uses, outside considerations, spill area uniqueness.

Adapted from Byroade, Twedell, and LeBoff, 1981.

The following sections address the information requirements to determine the current and future extent of contamination for a spill of sinking chemicals.

2.3.1.1 Current Extent of Contamination

The fundamental process for determining the current extent of contamination is to define the boundaries of the contaminated bottom materials and the area of the water column that is contaminated. Where pools of liquid contaminants exist on top of bottom materials, the areal extent of the liquid should be defined and the surrounding areas of contaminated sediments should be identified.

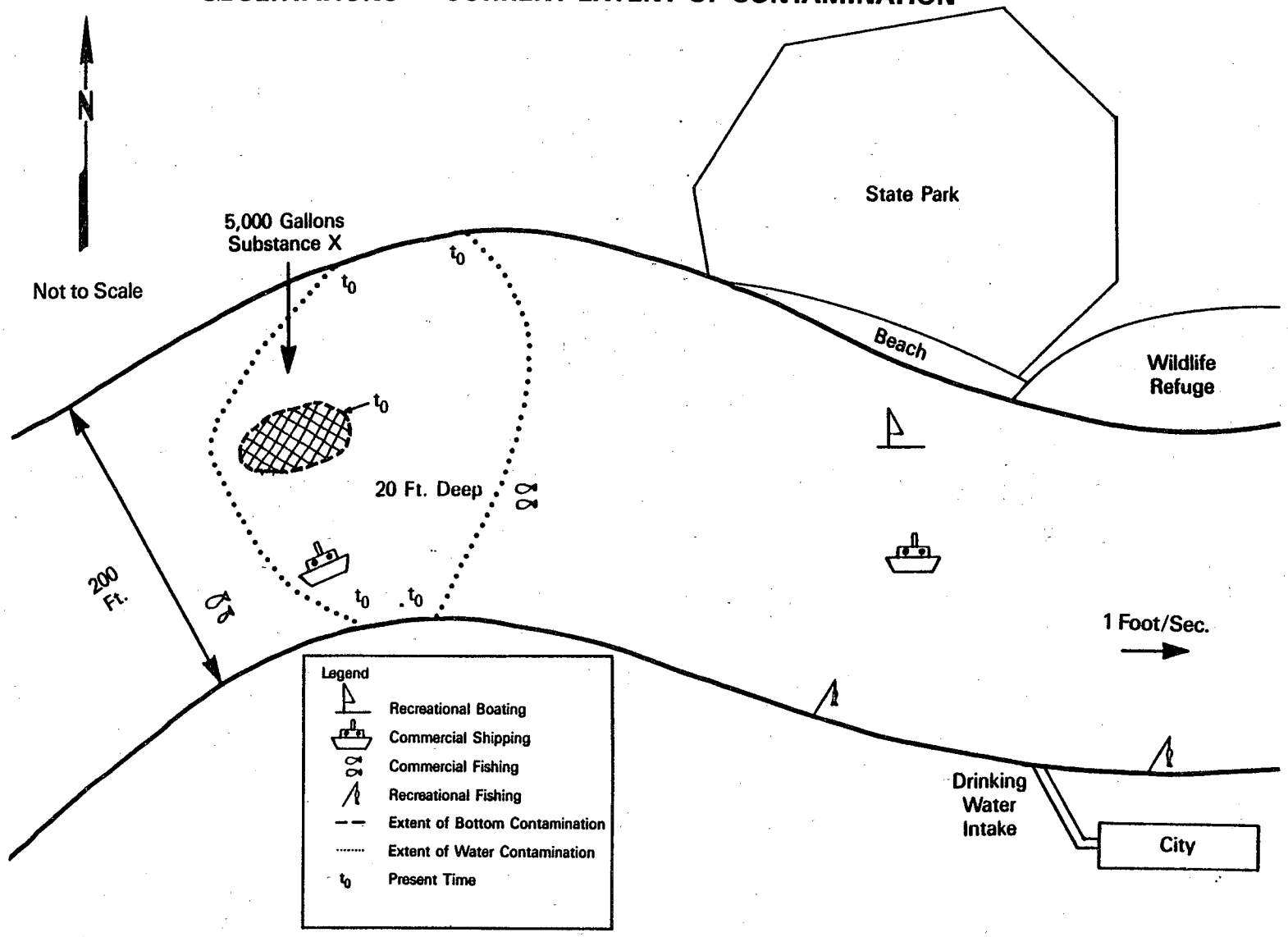
Defining the extent of contamination of bottom materials includes the number of contaminated areas, the length and the width (distance dimensions) of contamination associated with each area, and the depth of contamination (from top of sediments) for each area. For the water column, the extent of contamination includes the length and the width (distance dimensions) along the water body that contamination from the sediments exists and the depths within the water column that are contaminated (e.g., is the entire water column from the bottom to water surface contaminated, or is only a portion of the water column contaminated). The areal extent of water contamination should also be defined. All of this information may be obtained through monitoring studies (observations, remote sensing, or sampling) and spill circumstances data (Section 2.1.1).

This information should be mapped to provide a visual summary of the contaminated area (sediments and water column). The number of contaminated areas and zones of contamination can be recorded directly onto the data overlay maps described in previous sections.

Subsurface cross-sections of the sediments and the water column should also be drawn to further describe the vertical and areal extent of contamination. Figure 2-9 provides an example map that illustrates the current areas of contamination.

The concentration gradient for the contaminants should be defined within each contamination area for both water and sediments. This information may also be recorded on a map, as shown in Figure 2-9. Concentration data can only be obtained through sampling and analysis and through direct measurement (e.g., conductivity).

FIGURE 2-9. EXAMPLE SITE MAP FOR RECORDING DATA AND OBSERVATIONS — CURRENT EXTENT OF CONTAMINATION



2.3.1.2 Future Extent of Contamination

The information used to assess the current extent of contamination is also used to assess the future extent of contamination:

- Sediments

  - Number of contamination areas
  - Length and width of each area
  - Depth of contamination in sediments
  - Contaminant concentration gradient

- Water Body

  - Areal extent of contamination zone
  - Vertical depth of contamination across the contamination zone
  - Contaminant concentration gradient.

For future contamination, this information must be predicted or estimated for specific future time periods to build a picture as to how far the contamination area is spreading, at what rate it is spreading, and how the contaminant concentrations are changing over time. These changes are estimated or predicted based on the current situation, the chemical data (Section 2.1.2), and the water body data (Section 2.2.1), and may require monitoring studies as well.

This information can be mapped along with other information to provide a visual summary of how the contamination zone may change over specific time periods. Figure 2-10 provides an example map that illustrates this process.

2.3.2 Methods for Obtaining Information

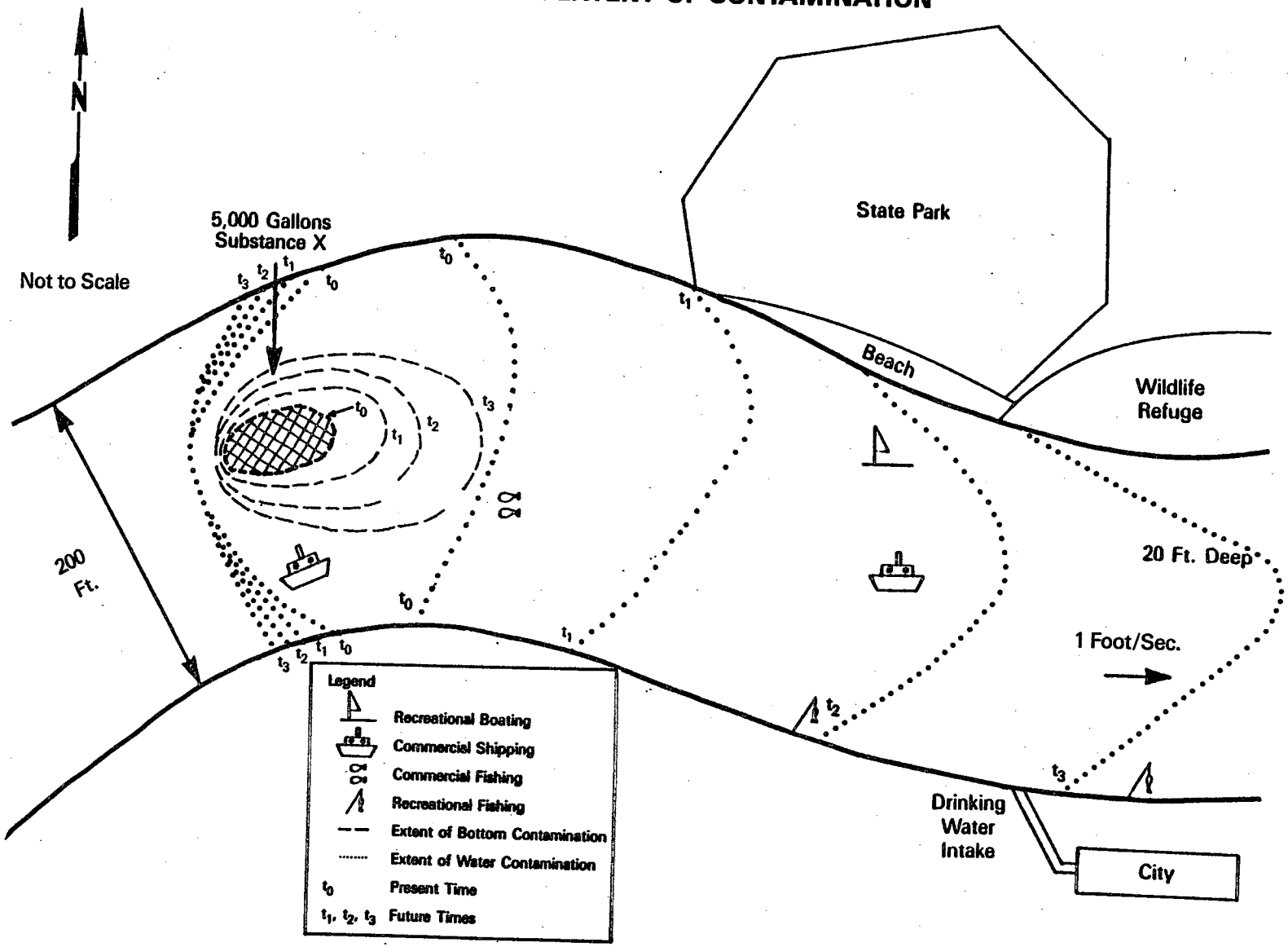
The information required to determine the extent of contamination may be obtained through monitoring studies, prediction methods, or a combination of the two. Application of these methods often requires a well-considered plan that must be specific to the water body characteristics, spill conditions, spill volume, and overall immediacy of resolution. The following sections briefly describe these information collection methods.

2.3.2.1 Monitoring Methods

Monitoring methods that may be used to collect information include:

- Direct (visual) observation and measurement

FIGURE 2-10. EXAMPLE SITE MAP FOR RECORDING DATA AND OBSERVATIONS — FUTURE EXTENT OF CONTAMINATION



- Remote sensing
- Sampling and analysis.

These methods are generally used to define current contamination.

Direct observation is limited by spill and by environmental conditions. In shallow or clear water, direct observation may be used to identify the area of contamination of bottom materials if the contaminant is a distinctive color; otherwise, divers may be needed to establish the extent of the area. When distinctively colored contaminants have entered the water column, discoloration of the water may be used as a guide to the extent of contamination. The Discharge Summary Worksheet, presented earlier as Figure 2-3, provides space to note observations of contamination dimensions.

Remote sensing techniques and equipment can provide information about subsurface conditions more quickly than sampling. Remote sensing may be used to monitor contaminants in bottom materials both to detect the presence of contaminants and to quantify their concentrations. These methods may be conducted on a one-time basis to define the current situation or on a continuing basis to quantify movement and concentration changes over time.

Techniques currently in use include electrical conductivity, x-ray fluorescence, and photography (underwater and aerial). These methods may be used to determine the areal extent of contamination on top of sediments, to monitor the movement of chemicals along the bottom, and to detect the contaminants in sediments or the water column.

Sampling is the fundamental tool for determining the extent of contamination. Sampling may be applied to bottom materials or to the water column on a one-time basis to determine current contamination dimensions or on a continuous basis to define changes in location and concentration over time, enabling prediction of these variables.

A variety of grab samplers, corers, and sample bottles are available. These may be used to obtain samples of sediments, contaminants pooled on top of sediments, and the water column at various depths. The samples may be analyzed for contaminant concentrations and for sediment characteristics using either portable/transportable on-site facilities or off-site laboratories.

2.3.2.2 Predictive Methods

Predictive methods that may be used in determining future contaminant location and concentration include general estimates or the application of models.

General estimates provide a quick means of determining the rate of contaminant movement and thereby estimating the spread of contamination in

bottom materials or through the water column in an "order-of-magnitude" level of analysis. These estimates can be made based on observations or sampling results within a certain time period and extrapolated for longer intervals. Such a method provides a "rough" estimate, which may be sufficient where immediate response action is indicated to control the spill or to protect human health or the environment. However, these estimates are limited in their application because they do not take into account the dynamic nature of the water body, the sediments, and the contaminant concentration and transformation.

Modeling studies are useful predictive tools to indicate the possible areal extent of contaminated sediments, contaminant movement, and water column contamination over time. Such studies may also indicate locations where contaminants or contaminated bottom materials tend to accumulate.

Mathematical models are available for predicting sediment transport, erosion, and deposition, as well as contaminant transport in rivers, estuaries, lakes, and oceans. Numerous methods are available, and some involve the use of numerical computer models. Vyas and Herbich (1977) and Neely and Blau (1976) are information sources on the use of models in analyzing sediment transport and deposition. Methods for analyzing transport in water bodies are further described in Fischer et al. (1979). Physical models can also be used to predict the behavior of water bodies under varying conditions. For example, existing scale models of the Chesapeake Bay, the San Francisco Bay, and the Mississippi River are used by the U.S. Army Corps of Engineers for hydraulic modeling.

The application of models to obtain information to define the extent of contamination requires a substantial amount of information on the water body, the status of the situation, and properties of the substances. Monitoring studies may be necessary to obtain appropriate data. Further, the user must be trained and a substantial amount of time must be spent collecting and analyzing the data. Therefore, predictive studies are most applicable to complex environmental situations or where sufficient evaluation time is available.

2.4 DETERMINATION OF EXPOSURE AND IMPACTS

The final data collection and analysis step involves determining the exposure and the impacts associated with the spill situation. In analyzing exposure, identified receptors are evaluated with respect to the extent of present and future contamination. In analyzing impacts, exposure is evaluated with respect to regulatory standards and criteria (for environmental concentrations of the chemicals involved), as well as chemical data that define the potential for harm (e.g., carcinogenicity, toxicity, etc.).

Together, these analyses address the following questions, for both the present and the future:

- Who or what are the affected receptors?
- What are the substances to which the receptors are (will be) exposed?
- To what extent are the receptors being (going to be) exposed to the substances?

The answers to these questions form the basis for deciding the significance of the spill situation, the immediacy of the need for response, and the most appropriate response methods.

2.4.1 Information Requirements and Analysis

Figure 2-11 is an example completed worksheet for collecting and organizing exposure and impact data. A blank worksheet is provided in Appendix I. For each chemical involved in a spill of sinking substances or a situation of contamination, the exposure and impacts analysis requires identification of each potential resource or receptor that may be affected as determined in Sections 2.2.2 and 2.3. For each receptor or resource, the following data are needed: (1) type of exposure (ingestion, direct contact, etc.), and (2) the exposure level for the media involved (sediment, water, contaminated fish, etc.) at the present and over time. This information can be extrapolated from the data collected, as identified in Sections 2.1 through 2.4.

Finally, for each situation identified, the relevant regulatory exposure level should be identified; in the absence of regulatory standards, other exposure indices, such as carcinogenic levels or lethal dose (LD_{50}) levels, should be used. These standards and criteria establish a level that, when compared to the contamination problem (present or future), may be used to assess the potential damage or harm to public health and to the environment that may result. These standards can only be applied to situations relevant to the standard.

This analysis must also consider acute exposure and chronic exposure because the potential for harm or damage will be different for these situations (e.g., the acute exposure may result in some damage, but the chronic exposure may result in severe damage to public health or to the environment). Bioaccumulation and biomagnification should also be considered.

Because chemicals transform in the environment over time, this analysis process should be repeated for each transformation product, as identified in earlier steps.

FIGURE 2-11. EXAMPLE EXPOSURE AND IMPACT DATA WORKSHEET

RESOURCE/ RECEPTOR	TYPE OF EXPOSURE	EXPOSURE LEVEL CURRENT (1200) Day 1	TIME 1 (1400) Day 1	TIME 2 (1800) Day 1	TIME 3 (0200) Day 2	REGULATORY STANDARD OR OTHER EXPOSURE CRITERIA	COMMENT ON POTENTIAL FOR HARM
Thompson State Park beach (1 mile)	Water/ swimmers	-0-	700 ppm	100 ppm	25 ppm	No dermal contact criteria available.	Peak water conc. at 1230 hrs, Day 1; swimmers at risk for acute exposure.
	Sediments/ swimmers	-0-	200 ppm	200 ppm	200 ppm		
Midville water intake (2 miles)	Water/ drinking	-0-	600 ppm	100 ppm	10 ppm	Human oral LD_{LO} = 60 mg/Kg. CWA Water Quality Criterion for drinking = 0.4 mg/l.	Peak water conc. at 1400 hrs, Day 1; water system at risk of exceeding criterion; consider temporary shutdown of intake.
Trout spawning (5 miles)	Water/ trout	-0-	-0-	200 ppm	50 ppm	Aquatic Toxicity Rating: TL_m 96: 100-10 ppm	Peak water conc. at 1800 hrs, Day 1; trout at risk for acute exposure.
	Sediments/ trout	-0-	-0-	50 ppm	50 ppm		

2.4.2 Information Sources

The information used as input to the analysis of exposure and impacts will have been collected or generated during earlier analyses, as outlined in Sections 2.1 through 2.3. New data requirements are those regulatory standards and criteria that are relevant to the situation under analysis. Particular standards and criteria of interest include:

- State water quality criteria
- Clean Water Act water quality criteria
- Safe Drinking Water Act maximum concentration limits and health advisories
- Sediment contamination criteria
- Aquatic toxicology data
- National Institute for Occupational Safety and Health (NIOSH) and Occupational Safety and Health Administration (OSHA) exposure levels
- Human toxicology:
  - International Agency for Research on Cancer (IARC)
  - Food and Drug Administration (FDA)
  - NIOSH.

These data are available through local offices of relevant Federal and State agencies; computer information data bases; and numerous EPA, NIOSH, and OSHA publications.

2.5 LEVEL OF APPLICATION OF CHARACTERIZATION PROCESS

The data collection and analysis process described throughout this section focuses on the important information and analytical considerations that form the basis of the decisionmaking process described in subsequent sections. To this end, the process and information parameters have been described in detail.

This data collection and analysis process can be conducted at any level of detail, depending on the amount of time considered feasible given the existing spill situation. The process described previously can be conducted on a relatively cursory level, so long as these important questions are considered in the analysis:

- What is the present spill situation?

- What chemicals are involved?
- How harmful are the chemicals and what will happen to these chemicals in the environment?
- Where are the chemicals and their transformation products going?
- What/who will be affected by the spread of the chemicals?
- What levels of exposure will occur? What impacts will result?

SECTION 3

DETERMINATION OF RESPONSE NEEDS

Once the spill characterization data have been collected and analyzed and exposure and impacts have been evaluated, the response decision process begins. The first step in the decision process is to assess the need for response. If a response is necessary, then the objectives of the response can be established. These objectives set the framework for identifying response options and for selecting an appropriate remedy.

Figure 3-1 illustrates the overall decision process and identifies those areas addressed in this section. Section 3.1 focuses on the general assessment of response needs. Section 3.2 addresses the establishment of response objectives. Section 3.3 addresses the establishment of immediate response objectives.

3.1 ASSESSMENT OF NEED FOR RESPONSE

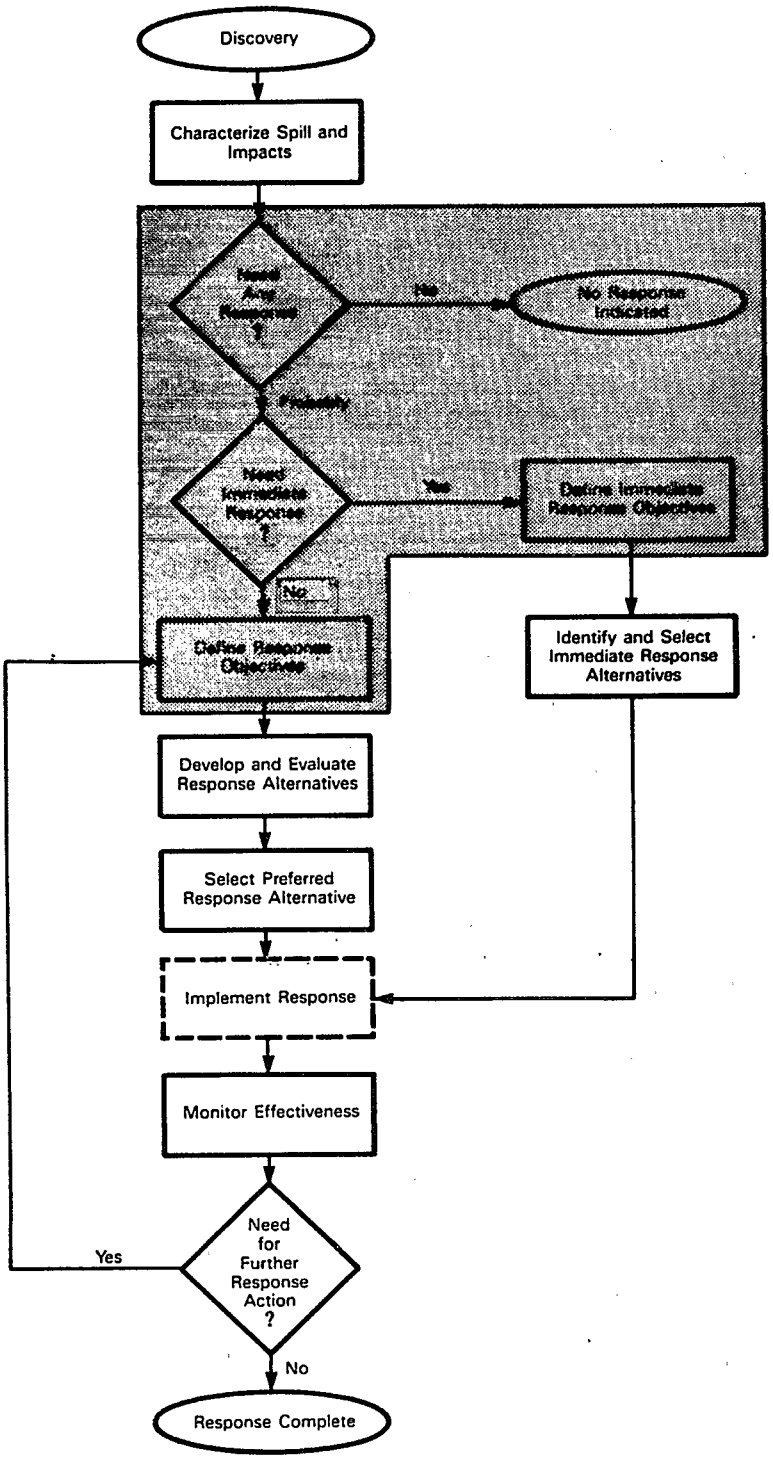
The major question examined in assessing response needs is whether the identified impacts of the spill are significant and, if so, whether they warrant a response. In some situations, particularly small volume spills of relatively low-toxicity materials, no response may be needed as long as short-term and long-term impacts on public health and the environment are minimal. In other situations, an immediate response may be necessary to stabilize or to rapidly clean up (partially or fully) a worsening or highly toxic spill.

The need for response is assessed by judging the significance of the impacts identified in Section 2. This assessment should incorporate an evaluation of what damages may occur (short- or long-term) and their potential for harm. In general, the assessment should consider the stability of the situation, volume and toxicity of the substances involved, and potential for transformation and long-term effects. With the exception of stability, these factors were addressed in analyzing impacts in Section 2.4.

In evaluating the need for immediate action, the following questions regarding the situation stability and magnitude and immediacy of the harm need to be assessed:

- Are spilled sinking substances moving either along the water column to bottom materials or along the bottom of the water body?

FIGURE 3-1. SEQUENCE OF RESPONSE EVENTS



If yes, should the movement be controlled or halted to prevent downstream contamination or to facilitate cleanup?

- Is one area of contaminated bottom materials more harmful than other areas:

  - As an area of high chemical concentration?
  - As an area of more highly toxic substances?
  - As an existing source of environmental or human health impacts?

Together, these questions consider the "seriousness" of the situation relative to human health (a judgment of magnitude of harm) and the stability (rate of worsening of conditions) of the situation, both or either of which can indicate the need for immediate protective measures.

From these analyses, it can be determined whether a cleanup response to the spill is needed or whether no response is necessary (no action). If a need for response is indicated, the analysis can determine whether an immediate response is necessary in conjunction with or in place of a cleanup response.

3.2 ESTABLISHMENT OF RESPONSE OBJECTIVES

Response objectives should be formulated to establish a framework for evaluating, selecting, and implementing a response. The response objectives are the guidelines for the level of cleanup and the phasing of components of the action. As such, response objectives involve identifying priorities for cleanup and the criteria governing the response.

3.2.1 Priorities

Once the spill situation is characterized, the impacts are identified, and the need for response is established, cleanup priorities can be identified. These priorities establish what must be protected in the response in order to prevent adverse impacts to public health or the environment, property as a result of the spill or in order to minimize adverse impacts that may result from a response action. This involves consideration of shortterm and long-term contaminant movement, transformation, and concentration; anticipation of decisionmaking time frame and the timeframe of response (i.e., urgency of response); and location of nearby receptors and sensitive environmental or commercial areas. All of these factors are identified in the data collection and evaluation activities and are summarized in the impacts evaluation step in Section 2.

Cleanup priorities are established by ranking the identified impacts. This ranking is based on a judgment of the magnitude of the impacts relative to one another. For example, at a given site, the protection of a drinking

water intake may have to be evaluated against the protection of a drinking water source, a recreational area, or a sensitive waterfowl breeding ground. Decisions on the relative importance of these areas and on priorities for protecting the areas will depend upon the likelihood of damage, the progression of the zone of contamination, and the magnitude of the impact (population affected, recreational value, etc.). Short-term impacts must be balanced against long-term impacts. However, the protection of human health will generally warrant the highest priority.

3.2.2 Response Criteria

Once priorities have been established, projected levels of cleanup must be considered; that is, the extent to which contaminants are to be removed, contained, and/or treated. This decision involves establishing acceptable levels of residual contamination remaining in the environment.

Ideally, all contaminants should be separated from the environment either by removal, chemical transformation, or isolation, thereby leaving no contaminants in the environment. In practice, this may not be feasible or cost-effective because of the volumes of sediment and water involved.

Cleanup criteria should focus on reducing contaminant levels in the environment to protect human health and aquatic and terrestrial life, The criteria should be consistent with the designated uses of the water body under consideration. For example, cleanup levels for an isolated water body with little environmental, human, or commercial value may allow for higher levels of residual contamination than a water body used for drinking water or for commercial fisheries.

Regulatory standards for sediment contamination levels are the most appropriate cleanup criteria. However, few standards have been developed. In general, water quality standards will provide a guide for establishing appropriate cleanup levels. These standards establish water concentration limits for numerous chemicals based on human ingestion of drinking water and fish. These standards provide an acceptable guide in situations of spills of substances that sink because the initial effects of a spill and a major long-term effect of contaminated sediments are contamination of the water column.

Water quality standards, established by the states, consist of water quality criteria and designated uses of the water body. Under the Clean Water Act, states are required to adopt water quality criteria sufficient to protect the designated use. The Federal government offers guidance to the states in developing water quality criteria through the publication of National ambient water quality criteria for 65 classes of priority pollutants (45 CFR 79318, November 28, 1980; 48 CFR 51400, November 8, 1983; 49 CFR 4551, February 7, 1974). A compilation of State water quality standards (October 1984) is available from the Criteria and Standards Division of the Office of Water Regulations and Standards of USEPA.

Water quality standards do not exist for all substances. In such circumstances, other criteria, advisories, and guidance (as described in Section 2.4) should be considered. Maximum Contaminant Levels (MCLs) promulgated under the Safe Drinking Water Act, may serve as guidelines in establishing cleanup objectives (48 CFR 45502; October 5, 1983; 49 CFR 24330, June 12, 1984). MCLs are enforceable standards promulgated by the EPA Office of Drinking Water (ODW). ODW makes additional nonenforceable guidelines for other contaminants in drinking water available. These suggested-no-adverse-response-levels (SNARLs) are health advisories that incorporate a safety margin to protect the most sensitive members of the general human population from adverse toxicological effects.

Other relevant Federal programs/requirements for setting cleanup criteria include: (1) Clean Water Act Section 301 and 403(c) criteria for ocean discharge, and Section 404 criteria for the disposal of dredged or fill material; (2) Marine Protection Research and Sanctuaries Act criteria for ocean dumping of waste; (3) Toxic Substances Control Act, Section 6, PCB requirements for disposal; and (4) Department of Transportation hazardous materials transport rules.

3.3 ESTABLISHMENT OF OBJECTIVES FOR IMMEDIATE RESPONSE

An immediate response may be necessary to stabilize a rapidly changing contamination situation or to protect resources that are immediately threatened. As shown in Figure 3-1, a separate decisionmaking process is needed for immediate responses. An immediate response may involve limited or temporary measures, such as shutting off a drinking water intake or setting up a containment barrier to provide initial protection prior to a full response to be identified later; alternatively, it may involve a full response that is implemented in a compressed timeframe. In either case, once the need for an immediate response is established, priorities of response and cleanup or control criteria should be established.

3.3.1 Priorities

Priorities for an immediate response are established in a manner similar to that for a less urgent response, as described in Section 3.2.1. However, development of priorities focuses on the question of what aspects of the situation most immediately needs attention and what, if anything, can wait for a later response. This involves an assessment of what is immediately impacted or what will shortly become severely impacted by the spilled substances and a judgment regarding the relative magnitudes of these impacts.

Immediate response priorities are then established by ranking these impacts, as described in Section 3.2.1.

3.3.2 Response Criteria

In an immediate response action, response criteria that set the framework for the response should be established. This process draws on the priorities established for the response to provide the focus. Further, this analysis must consider the rate of contaminant movement, technological limitations or capabilities in controlling the movement, and priority of receptor protection.

An example of this analysis is as follows. A given site situation involves the rapid movement of highly toxic spilled sinking substances along a river bottom; a recreational area (including fishing) is already affected and a drinking water intake is located a short distance downstream. If the water body and the spill conditions are such that the prevention of further contaminant movement is not feasible, then response criteria may include: (1) Prevent contamination of drinking water, and (2) Limit further human exposure at the recreational area. Response measures may include, but are not limited to, shutting off the drinking water intake and temporarily closing the recreational area.

Where appropriate, specific cleanup levels may be established. This would be appropriate where an immediate removal of contaminated sediments or pooled contaminants is conducted. The cleanup levels can be final levels, or interim levels if subsequent response actions are to be conducted. Cleanup criteria and their specification are described in Section 3.2.2.

SECTION 4

SELECTION OF RESPONSE MEASURES

The selection of response measures for a sinkers spill incident involves the detailed evaluation and screening of available response techniques. The evaluation and screening process is conducted using site-specific information gathered during the earlier site characterization effort. Site characterization data are used to determine the applicability of available response techniques and their relative potential performance under existing site conditions. Figure 4-1 presents the selection process and its relationship to the overall response process.

The techniques available for response at sinker spill sites fall within one of the following six response categories:

- Containment
- Removal
- Treatment of removed materials
- Disposal (treated and untreated removed materials)
- In-place (*in situ*) treatment and isolation
- No action.

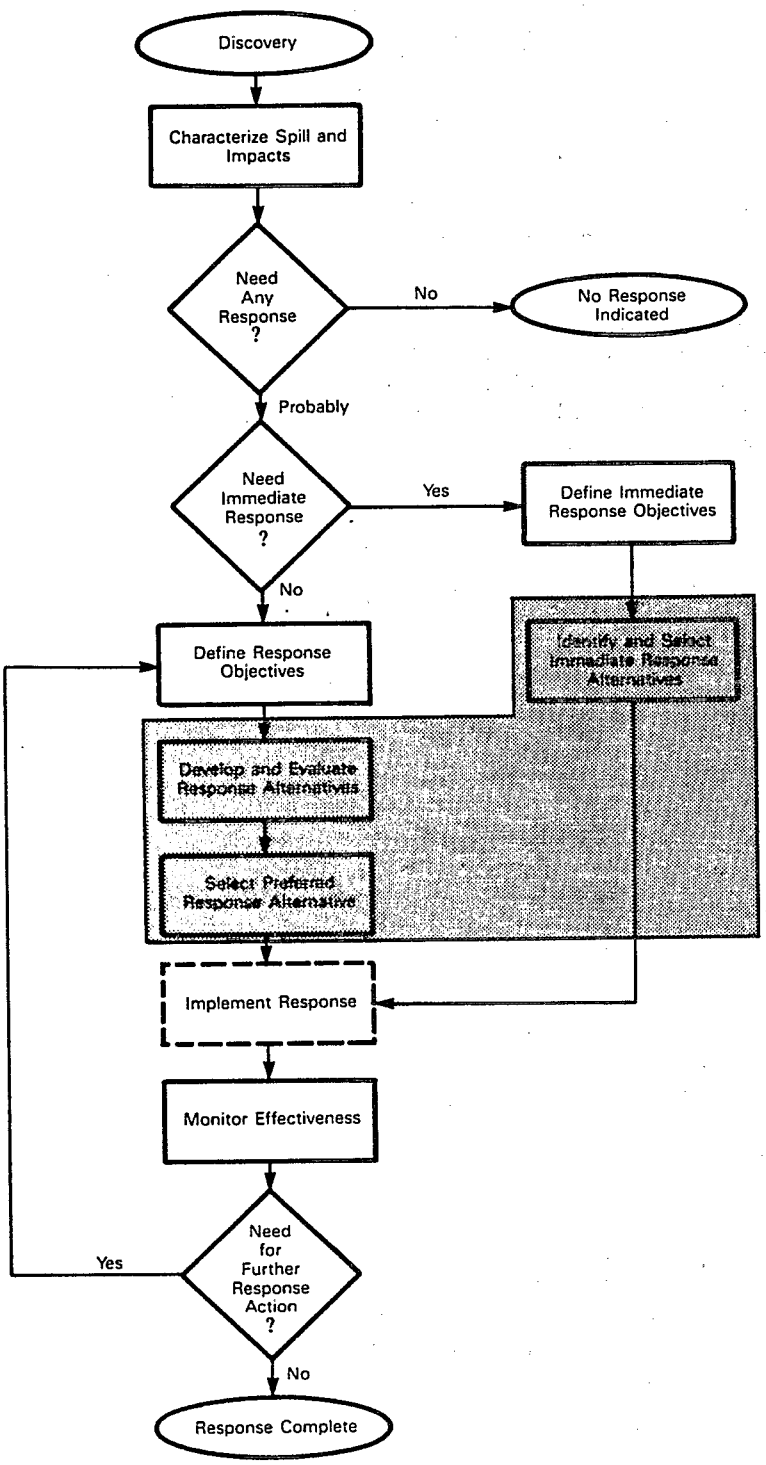
The overall selection process involves four steps that entail various types of analyses and evaluations of these response categories and their respective response techniques.

The four steps are:

- Screening response categories
- Screening response techniques
- Developing response alternatives
- Evaluating alternatives and selecting the preferred alternative.

The first step in the selection process is to identify one or more response categories that are applicable at the spill site. This is

FIGURE 4-1. SEQUENCE OF RESPONSE EVENTS



accomplished through a cursory screening process using information on site characteristics and on limitations of response techniques. Figure 4-2 illustrates how response categories can be (and sometimes must be) combined to form treatment or response "trains" to meet response objectives. For example, if site conditions permit the use of removal techniques, this category must either be followed directly by the disposal category or, if the excavated material requires treatment, it must be followed by the treatment and disposal categories. At another site, the in situ treatment and isolation category alone may be applicable. In contrast, particular site conditions may prohibit the use of any response measure at all; no response is possible. In this type of case, the "no action" response category is the sole option. In general, the purpose of the first step is to identify the response categories that may be applicable at the site. Step 1 is described in detail in Section 4.1

The second step is to screen techniques within each applicable response category identified in Step 1, with the purpose of eliminating those techniques that are not applicable under existing site conditions. The screening conducted in Step 2 involves a more focused analysis than that conducted in Step 1; many more technique-specific factors are used. Step 2 is discussed in Section 4.2.

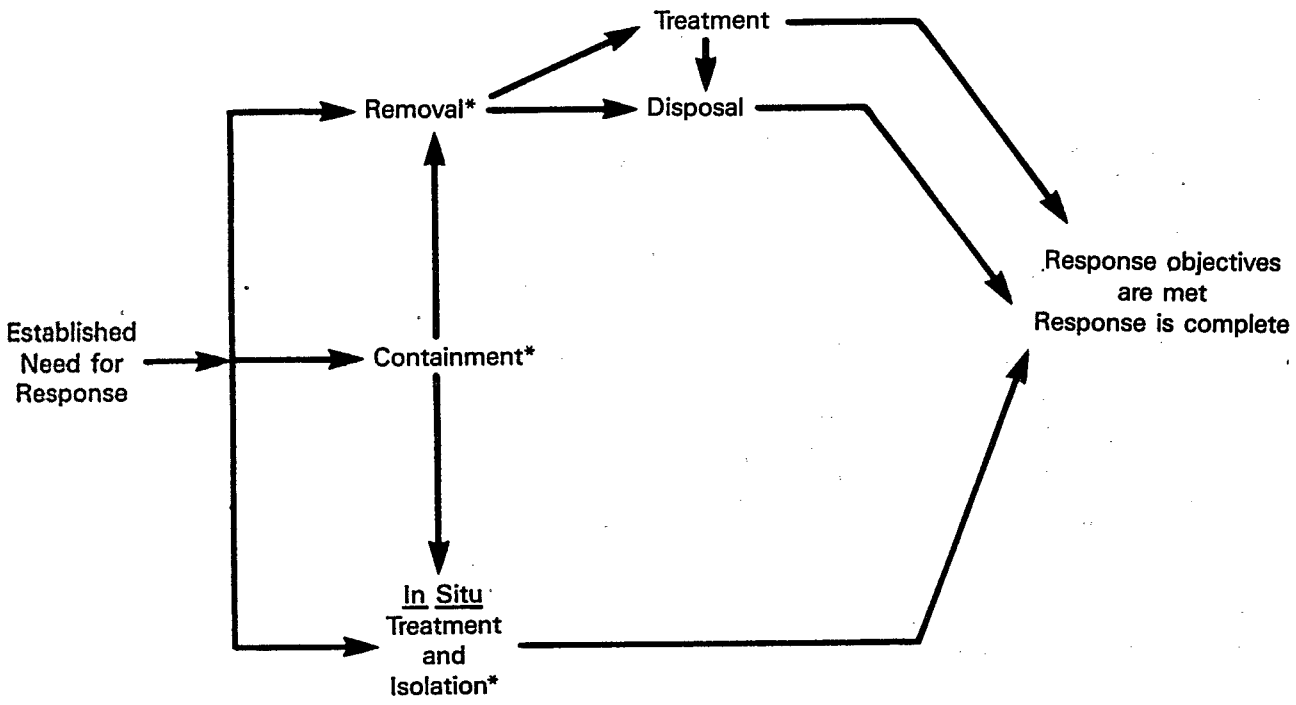
The third step is the development of response alternatives. This involves the formation of compatible combinations of applicable techniques that were identified in Step 2. Each combination, or "response alternative," must be capable of meeting all previously established response objectives. The analysis involved in this step focuses on technique-specific characteristics and how different techniques can best compliment one another. The objective of Step 3 is to combine applicable techniques within and between categories and devise as many working combinations, or alternatives, as possible that meet response objectives. This step is addressed further in Section 4.3.

The fourth and final step is the evaluation of the alternatives that were developed in Step 3 and the selection of the alternative that will best achieve established response objectives. The evaluation involves comparing the alternatives against one another in terms of their potential performance, reliability, cost, the time required for implementation, and the ability to meet response objectives. Step 4 is discussed in detail in Section 4.4.

4.1 SCREENING OF RESPONSE CATEGORIES

The selection of a response for a particular sinker spill site begins by screening the six response categories: removal, containment, in situ treatment and isolation, treatment, disposal, and no action. Each category, with the exception of the no action option, consists of response techniques that are applicable in different situations. For example, the removal category consists of various types of dredging and excavation equipment

FIGURE 4-2. ALTERNATIVE RESPONSE CATEGORIES AND RESPONSE TRAIN USED IN OVERALL SINKER SPILL RESPONSE SELECTION PROCESS



*Where no response category is applicable at the site of interest, then not responding ("No Action") is the sole option.

that are suitable for different material and water conditions. The treatment category consists of a variety of treatment techniques that are used for different types of contaminated materials (liquid and solid).

The screening of these categories requires site-specific data gathered during the spill characterization effort and knowledge of what site characteristics limit the applicability of each category. Using site-specific data and information on the limitations of each response category, those categories that are not applicable under existing site conditions are screened out or eliminated from further consideration. There may be situations where all five "action" response categories (removal, containment, in situ, treatment, and disposal) are not applicable under existing site conditions; i.e., no action is possible. In such cases, the only option is to not respond at all, and the "no action" response category is selected.

A distinction should be recognized between a "no action possible" situation and a case where "no action is best." A decision that "no action is best" is not related to the issue of category applicability and, therefore, would not be made during Step 1. A decision involving "no action is best" requires evaluation of "no action" along with "action" alternatives during subsequent steps. An example of a situation where the decision might be made that "no action is best" would be where the only applicable response category is removal, but all removal techniques would resuspend contaminated, highly toxic material, thus creating a greater hazard than the hazard that existed previously. In such a case, a decision to not respond at all, i.e., "no action is best," may be appropriate.

4.1.1 Screening Process

The screening of response categories proceeds in a series of substeps. Table 4-1 is a decision matrix that is structured to facilitate this screening process and is referenced in the following discussion. This response category screening process applies to all types of surface water bodies except open waters (an ocean or sea setting); i.e., it applies to coastal waters, bays, rivers, streams, and tidal-influenced waters. In the case of a spill in open waters, dispersion and dilution would probably minimize impacts to bottom materials or the response would focus on material suspended in the water column. This handbook does not address techniques used to respond to contaminants within the water column.

Figure 4-3 is an example completed worksheet to be used as an aid for tracking and documenting decisions made during Step 1. A blank worksheet is provided in Appendix I. By completing this form as each substep is carried out, clear documentation is made for later reference regarding decisions and conclusions drawn during Step 1.

The first substep requires that the spill site be classified as one or both of two site scenarios. The information required to characterize a site in Substep 1 includes whether the spilled material is mobile or

TABLE 4-1. DECISION MATRIX FOR SCREENING RESPONSE CATEGORIES

A Site Scenario	B Preferred Response	C Site Conditions Limiting Applicability of Removal and Ancillary Categories
1. Contaminants are relatively stationary	Removal	(a) Highly toxic if sediments distrubed and dispersion occurs, even on small scale (hazardous to either water body and/or water safety) (b) Treatment required but means of treatment unavailable[1] (c) Means of disposing removed material unavailable (d) Means of disposing treatment residuals unavailable (e) Volume of sediments and/or water too large for treatment[3] (f) Volume of sediments and/or water too large for disposal[3] (g) Wave height >7 ft and depth >65 ft (h) Site inaccessible to all removal equipment
2. Contaminants are mobile	Containment[5] and Removal	(a) High water velocity or low water volume limits use of temporary containment techniques (b) Site inaccessible to temporary containment equipment (c) Treatment required but means of treatment unavailable[1] (d) Means of disposing removed material unavailable (e) Means of disposing treatment residuals unavailable (f) Volume of sediments and/or water too large for treatment[3] (g) Volume of sediments and/or water too large for disposal[3] (h) Wave height >7 ft and depth >65 ft (i) Site inaccessible to all removal equipment

FOOTNOTES:

[1] Chemical characteristics of spilled material will affect feasibility of treatment techniques.

[2] Removal equipment is available that is applicable at depths greater than 65 ft, therefore, removal implementation delay is applicable in situations where it is anticipated that wave height will subside to less than 7 ft.

[3] Treatment and/or disposal of excessively large quantities of material may incur infeasible costs.

D Other Response Categories	E Site Conditions Limiting Applicabiity of Other Categories	F Comments
(a) Delay Removal[2]	i. (a) Limiting conditions may persist	i. (a) When wave height subsides removal can be implemented
(b) In Situ (c) In Situ (d) In Situ (e) In Situ	ii. (b,c,d,e,g,i) Many techniques uproven; applicability of techniques depends on chemical nature of contaminants, and sediment characteistics; use of covers and caps limited by high water velocities or low water volume; site inaccessible to In-Situ equipment	ii. (b,c,d,e,g,i) In Situ techniques other than covers and caps are still developmental; mostly untested and unproven
(f) Partial Removal[4] and/or In Situ (g) Partial Removal[4] and/or In Situ (h) In Situ	iii. (f,h) Inability to mitigate hazard with only partial removal of contaminated material; (see ii, above, for conditions limiting In Situ)	iii. (f,h) Partial removal must be followed by Disposal or Treatment and Disposal and limiting conditions on these categories must also be considered (see ii, above, for comments on In Situ)
(a) Removal[6]	(a,b) [see row 1, column C, a through h]	
(b) Removal[6] (c) In Situ (d) In Situ (e) In Situ	(c,d,e,i) [see ii, above]	(c,d,e,i) [see ii, above]
(f) Partial Removal[4] and/or In Situ (g) Partial Removal[4] and/or In Situ	(f,g) [see iii, above]	(f,g) [see iii, above]
(h) Delay Removal[2] (i) In Situ	(h) [see iii, above]	(h) [see iii, above]

[4]Partial removal of contaminant "hot spots" may be applicable if its implementation meets response objectives.

[5]Containment refers to temporary containment techniques including covers, caps, ditches, trenches, dikes, curtains, pits, dikes, and berms.

[6]Direct removal, i.e., removal without initial containment, may be applicable if rate at which material is moving is relatively slow.

FIGURE 4-3. EXAMPLE WORKSHEET FOR SCREENING RESPONSE CATEGORIES

I. Select the site scenario that characterizes the existing site conditions (check one or both):

____ Contaminants are relatively stationary.

✓ Contaminants are mobile.

II. As identified in Table 4-1, Column B, the preferred response category, or "train" of categories, is as follows:

(1) Containment (3) _____

(2) Removal (4) _____

III. Applicability of the preferred response category:

IIIa. Is containment necessary for implementation of removal (circle one)?

(Yes) (go to IIIb) No (go to IIIc)

IIIb. Is containment applicable (circle one)?

(Yes) (go to IIIc) No (go to IVa & d)

IIIc. Is immediate and total removal physically applicable (circle one)?

Yes (go to IIId) (No) (go to IVa, b & c)

IIId. Does removed material require treatment? (circle one)?

Yes (go to IIIe) No (go to IIIf)

IIIe. Is treatment applicable (circle one)?

Yes (go to IIIf) No (go to IVd)

(continued)

FIGURE 4-3. (continued)

IIIf. Is disposal of removed material or treatment residuals necessary (circle one)?

Yes (go to IIIg) No (go to IIIh)

IIIg. Is disposal applicable (circle one)?

Yes (go to IIIh) No (go to IVa & d)

IIIh. The preferred response category is applicable at the site. The reasons for its applicability are as follows:

IV. Other Response Categories:

IVa. Summarize the reasons why the preferred response category is not applicable at the site.

Spread of carbon tetrachloride is too broad to permit total removal

IVb. Is immediate partial removal applicable (circle one)?

Yes (go to IVb1) No (go t IVc)

IVb1. Does partially removed material require treatment? (circle one)?

Yes (go to IVb2) No (go to IVb3)

IVb2. Is treatment applicable (circle one)?

Yes (go to IVb3) No (go to IVd)

IVb3. Is disposal necessary (circle one)?

Yes (go to IVb4) No (go to V)

IVb4. Is disposal applicable (circle one)?

Yes (go to V) No (go to IVd)

(continued)

FIGURE 4-3. (continued)

IVc. Can removal be temporarily delayed (circle one)?

Yes (go to IIId) No (go to IVd)

IVd. Is *in situ* response applicable (circle one)?

Yes (go to V) No (go to IVe)

IVe. "No action" should be considered.

(go to V)

V. Based on existing site conditions, the following other response categories are applicable at the site:

- o Partial removal (accompanied by treatment and/or disposal)
- o Removal implementation delay
- o *In situ* treatment/isolation
- o No action possible
  (go to VI)

VI. Summary:

VIa. The following response categories are applicable at the site:

- o Containment ✓
- o Removal ✓
- o Treatment ✓
- o Disposal ✓
- o In situ treatment/isolation
- o No action

VIb. Comments:

Containment, partial removal, treatment, and disposal appear to be the preferred response train. Apply only to areas containing >200 ppm carbon tetrachloride in sediments. Close beach and monitor Midville intake.

stationary. The second substep refers to Table 4-1, Column B, and identifies the preferred response category that corresponds to the appropriate site scenario. As indicated in Column B, the preferred response category for any site scenario involves removal of all contaminated material. In any situation, when removal of contaminated materials is applicable under the existing conditions and the established objectives can be met, the removal of the contaminants and the contaminated material is the preferred response.

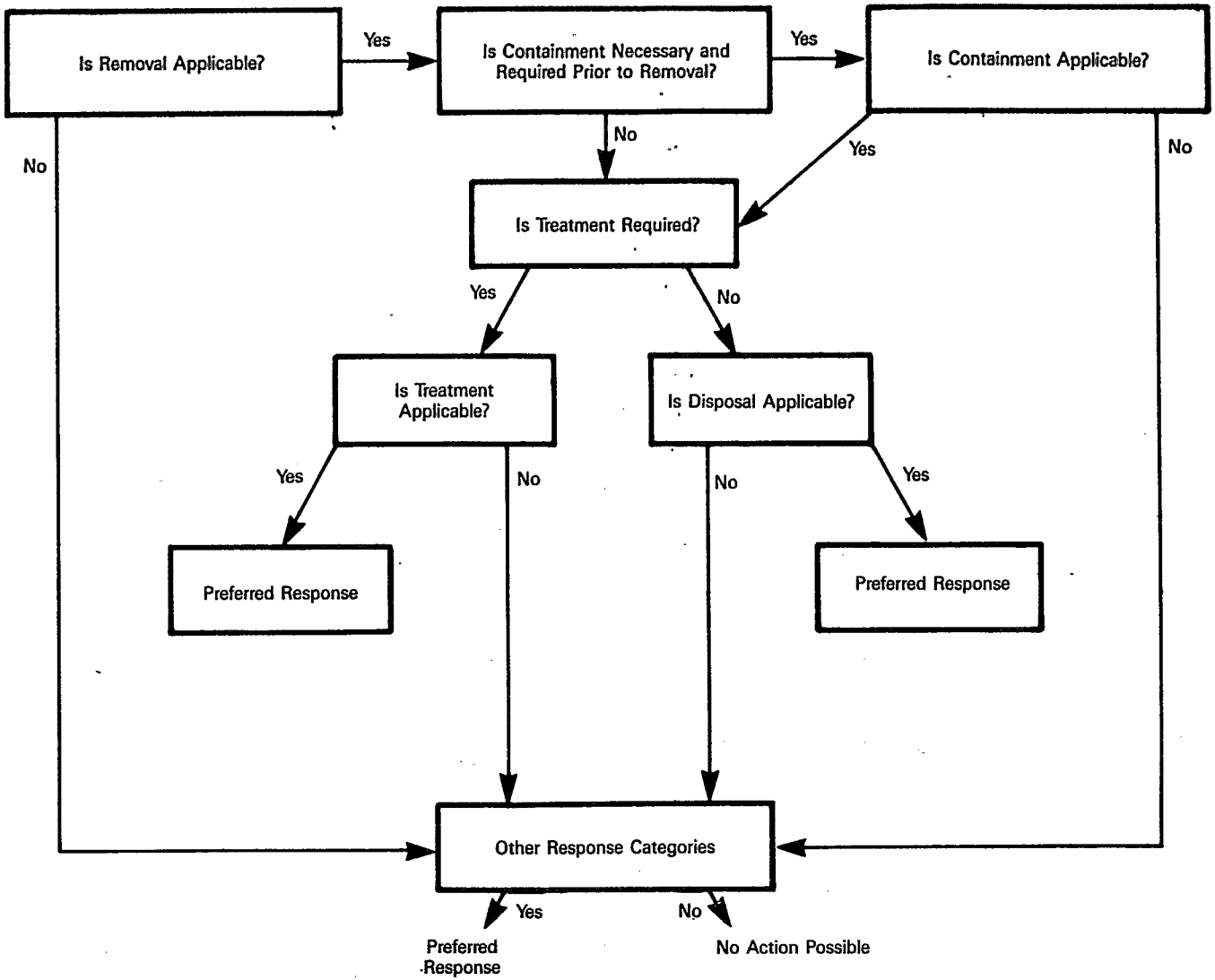
With the removal category being the preferred response, the third substep determines the applicability of the removal category. This determination is based on both physical and chemical site conditions that limit removal, and conditions affecting the applicability of the removal category's ancillary response categories, namely containment, treatment, and disposal. In any situation where removal is considered, one or more of these three ancillary categories will also be necessary to complete the site response. For this reason, the applicability of these categories will affect the applicability of removal.

Substep 3 involves two phases of analysis. In the first phase, the user refers to Table 4-1, Column C, for information regarding limiting site conditions with respect to the preferred removal category. When the removal category is still applicable in light of the limiting conditions identified in Column C, then the user must move to the second phase of the decision process, which involves reviewing the applicability of the ancillary response categories that may be necessary. Where ancillary responses are necessary, and none are applicable, then removal will also not be possible and must be eliminated from further consideration. The limiting conditions for application of these ancillary categories are given in Table 4-1, Column C.

As an example of this two-phased substep, removal is identified as being applicable at a given site. However, no treatment or disposal facility exists that will accept the removed material, nor can any be constructed on site. In such a situation, the removal category is determined to be inapplicable. Another example is a case where site conditions are conducive to removal and there is one disposal facility that will accept the material if it is first treated to attain a specific contaminant level; if there is no treatment technique available that will meet the specified contaminant levels, then the removal category must again be identified as inapplicable. A final example involves a situation where bottom materials are highly mobile. In such a case, containment would be necessary to control contaminant movement and to remove contaminants. If conditions are such that containment cannot be accomplished, then removal also cannot be accomplished.

The overall decision process to determine the applicability of the removal response category is illustrated in Figure 4-4. If removal is applicable at a site, then the user moves directly on to Step 2 (described in Section 4.2). Where removal is not applicable, the user continues to Substep 4 of Step 1. In Substep 4, the user refers to Table 4-1, Columns D and E, which identify other potential response categories and corresponding limiting site conditions for each site scenario. Comments regarding the other response categories are given in Table 4-1, Column F. In cases where

FIGURE 4-4. DECISION PROCESS TO DETERMINE APPLICABILITY OF REMOVAL RESPONSE CATEGORY



one or more of the other response categories are applicable at the site, the user moves to Step 2 (Section 4.2). As stated earlier, in a situation where no action-oriented category is applicable, implying that no response is possible under the existing site conditions, then the "no action" category is the sole option and the response selection process is complete without undertaking Steps 2, 3, and 4.

4.1.2 Alternatives to the Removal Response Category

The response categories consist of a variety of techniques that are applicable in different situations; however, certain site characteristics may limit their applicability. The site-related limiting conditions that affect applicability fall within these factor groups:

- Water conditions
  - Wave height
  - Depth to bottom
  - Water velocity
  - Volume of water
- Site accessibility
- Volume of material
- Availability of treatment and/or disposal facility
- Chemical characteristics of material
  - Compatibility with sealant, grout, etc.
  - Treatability
- Physical nature of bottom materials
- State of development (proven applicability).

Table 4-1, presented previously, describes these factors in more detail in terms of the site-specific limiting conditions for each of the four site scenarios. In cases where limiting site conditions for the removal category and its ancillary categories are identified, other response categories are then considered. Table 4-1 identifies other response categories that may apply for each site condition that limits the use of the removal response. These other responses include in situ treatment and isolation techniques, partial removal, and implementation delay.

The most important factor to consider in determining the applicability of in situ treatment and isolation techniques is whether previous applications have been successful. Most of the available in situ techniques described in this handbook are currently being developed and have not

been implemented at sinker spill sites. Their effectiveness is not proven and they are infrequently selected for such sites. The techniques that fall within this category include many of the sealants, grouts, sorbents, gels, and chemical and biological treatment techniques. Appendix E provides further detail on the in situ category.

Partial removal is considered to be an alternative to total removal in cases where all site conditions are conducive for removal, but where the volume of material to be removed, treated, and disposed, or removed and disposed is so large that costs would prohibit implementation of total removal. In cases such as these, it may be possible to remove only those areas with high contaminant concentrations ("hot spots") and still meet established response objectives; additional measures, such as in situ techniques, may be necessary to treat or to control remaining contaminants. The issue of whether partial removal will meet previously established response objectives enters into the decision process at this point. The modification of response objectives may be considered at this step in the response selection process; however, it is recommended that the decision to modify not be made until specific response alternatives have been developed (Step 3) and evaluated (Step 4), at which time the specific limitations of the alternatives have been thoroughly investigated.

Implementation delay is an alternative to the removal response when site conditions that preclude implementation of removal are only temporary, such as the case where a severe storm is disturbing the site area or receding of tides may improve access. Once adverse conditions have passed, the response can be undertaken.

4.1.3 Process Summary

In summary, results of Step 1 in the response selection process will be the identification of one or more of the six response categories that are applicable under existing site conditions. By closely examining the site conditions and by using Table 4-1, certain response categories can be screened out and eliminated from further consideration. The response categories that are identified as applicable under all existing site-specific conditions are those that will be developed and evaluated further in the steps that follow.

4.2 SCREENING OF RESPONSE TECHNIQUES

In Step 2, the applicable response categories identified from the screening conducted in Step 1 are examined in further detail. Step 2 involves the screening of the response techniques that constitute each applicable response category. Response techniques include equipment, materials, and methods that are available for either removing or for

containing hazardous materials in the surface water body. The purpose of Step 2 is to identify those techniques within each applicable category that are applicable under the existing site conditions and to eliminate those techniques that are not applicable.

The screening process in Step 2 uses a much larger spectrum of site- and technique-specific data than Step 1. Table 4-2 lists the site-related and technological factors that affect the applicability of each category of response techniques. Some of the factors are the same as those used in Step 1; however, the Step 2 screening process involves a much more detailed examination of technological limitations and analysis of the limiting site conditions.

For example, the transportability of a piece of removal equipment could potentially be an important factor in deciding the equipment's applicability at a particular site. If the site is not directly accessible, a piece of equipment that cannot be easily transported would not be considered to be applicable.

Table 4-2 lists the critical factors that affect the application of the response techniques and is included here as a tool to be used in conjunction with the more detailed information included in the appendices. Figure 4-5 is an example completed worksheet that is designed to facilitate documentation and accurate record keeping of the applicability of the various response techniques. A blank worksheet is provided in Appendix I. Space is provided on the worksheet for comments regarding reasons for the applicability or inapplicability of each technique.

The techniques in each applicable response category are evaluated separately. No consideration is given at this point as to how techniques in different categories might work together. The evaluation process involves the comparison of techniques within a given category in terms of the criteria listed in Table 4-2. Detailed descriptions of individual techniques, with respect to these criteria, are given in Appendices A through E. The relative importance of the individual criteria in Step 2 analysis will depend on site-specific characteristics.

In addition to the techniques within the categories listed in Table 4-2, the "no action" response still exists as an option. It may not have been possible during Step 1 to determine whether an applicable response for a site existed. During Step 2, when detailed technical information regarding each technique is examined, the question of whether a response can be made at a site can be better answered.

The result of Step 2 is the identification of one or more groups of techniques that are applicable under existing site conditions. These techniques are then combined into comprehensive alternatives during Step 3.

TABLE 4-2. TECHNOLOGY SCREENING CRITERIA FOR ACTION RESPONSE CATEGORIES

Response Category	Site-Related and Technological Factors Affecting Technology Application
I. Containment Techniques	• Depth of water • Water velocity • Water volume • Bottom currents • Availability of equipment • Performance - effectiveness - useful life • Reliability - operation and maintenance - demonstrated performance • Waste compatibility • Time availability • Space (area) availability • Safety
II. Removal Techniques	• Volume of material • Depth of water • Width of channel • Precision obtainable • Rate of production • Turbidity/Resuspension • Availability • Transportability • Slurry solids content • Auxiliary facilities required • Performance - effectiveness - useful life • Reliability - operation and maintenance - demonstrated performance • Safety • Urgency with which response must be made • Vessel draft • Hindrance to traffic • Method of discharge • Maximum wave height tolerance

(continued)

TABLE 4-2. (continued)

Response Category	Site-Related and Technological Factors Affecting Technology Application
	• Ability to operate near structures • Ability to operate in open water • Ability to dredge consolidated sediments • Susceptibility to debris damage • Suitability for liquid or solid removal
III. Treatment Techniques for Removed Materials	• Treatment system mobility • Land area to construct facility • Groundwater protection requirements • Pretesting requirements for system optimization • Suitability for chemical constituents (e.g., treatability) • Solids concentration • Treatment component availability • Operation and maintenance requirements • Availability of appropriate treatment facilities • Availability of nearby treatment facilities • Safety
IV. Disposal Techniques	• Land area to construct facility • Regulatory restrictions (storage, transport, disposal) for on-site and off-site facilities • Regulatory design restrictions • Volume of materials • Suitability for chemical constituents • Availability of nearby disposal facilities • Availability of appropriate disposal facilities • Safety
V. In Situ Treatment and Isolation Techniques	• Sediment type • Waste compatability • Durability/strength • Permeability • Benthos sensitivity • Reactivity with water • Performance - effectiveness - useful life • Reliability - operation and maintenance - demonstrated performance

(continued)

FIGURE 4-5. (continued)

Treatment Techniques for Removed Material	
Sediment/water separation	
- Settling basins	Could be used
- Hydraulic classifiers	Gradation not needed
- Spiral classifiers	Gradation not needed
- Cyclones	Could be used
- Filters	Could be used
Sediment dewatering	
- High-rate gravity settlers	Could be used
- Centrifuges	Could be used
- Belt press filters	Could be used
- Vacuum filters	Could be used
- Pressure filters	Could be used
Water treatment	
- Adsorption	Likely to be applicable
- Ultrafiltration	Not needed
- Reverse osmosis	Not needed
- Ion exchange	Not needed
- Biological treatment	May be applicable
- Precipitation	Not needed
- Wet air oxidation	Not needed
- Ozonation	Not needed
- Ultraviolet radiation	Not needed
- Discharge to publicly owned treatment works	May be applicable
Sediment treatment	
- Contaminant immobilization	May be applicable
- Contaminant treatment	May be applicable

Disposal Techniques	
Sediments	
- Land disposal	Likely to be applicable
- Open water disposal	Not applicable to inland
Water	
- Discharge to surface water	Likely to be applicable
- Land application	May be applicable
- Deep well injection	No deep wells near site
Treatment residuals	
- Land disposal	Likely to be applicable
- Incineration	May be applicable
- Land application	May be applicable
- Deep well injection	No deep wells near site

(continued)

Figure 4-5. (continued)

In Situ Treatment and Isolation Techniques	
Treatment	In situ treatment not being considered
- Sorption	
- Chemical treatment	
- Biological treatment	
Isolation	
- Capping	
- Covering	
- Fixation	

4.3 DEVELOPMENT OF RESPONSE ALTERNATIVES

In Steps 1 and 2, a determination is made as to which response categories are applicable and which techniques within those categories are applicable under existing site conditions. The result of Steps 1 and 2 consists of one or more groups of techniques, depending on the number of applicable categories, which can potentially be used at the site. In Step 3, these applicable techniques are used to develop response alternatives.

Alternatives development is the formation of compatible and applicable combinations of response techniques, each of which contributes to meeting established response objectives. An alternative consists of one or more techniques from one or more response categories. The purpose of Step 3 is to develop several alternatives, all of which substantially meet the established response objectives. The development of each alternative involves combining applicable categories and techniques; however, the objective of this effort is to derive only those combinations that will meet site response objectives. In other words, the objective of Step 3 is not to develop as many alternatives as are possible, but rather to develop only those alternatives that can potentially achieve the objectives established earlier in the spill response process (see Section 3).

4.3.1 Combination of Response Categories

There are seven possible approaches, or combinations of response categories, that define the general alternatives that can be derived. These are:

- Removal - Disposal
- Removal - Treatment - Disposal
- *In Situ* Treatment/Isolation
- Containment - *In Situ* Treatment/Isolation
- Containment - Removal - Disposal
- Containment - Removal - Treatment - Disposal
- No Action.

For a particular site situation, the applicability of one or more of these approaches will depend on the determination made in Step 1 regarding the applicability of the available categories. For example, if removal, treatment, and disposal were identified in Step 1 as the only applicable

categories, then at this point in Step 3, only the following three approaches would be identified for use in alternatives development:

- Removal - Disposal
- Removal - Treatment - Disposal
- No Action.

The "no action" approach will remain an alternative throughout the selection process for any site situation because the possibility that "no action" may be the best response will remain until the detailed evaluation is conducted in Step 4.

4.3.2 Combination of Techniques to Form Alternatives

Following the identification of potential approaches for the site, the next part of Step 3 involves the examination of applicable techniques within the categories that constitute the identified approaches. The purpose of this examination is to identify and combine those techniques that, together as one alternative, will substantially meet response objectives. It should be noted that the user is not obligated to use all of the applicable techniques identified in Step 2. There may be applicable techniques that, when combined with techniques from other categories, are either unnecessary or do not aid in achieving response objectives. In these types of situations, such techniques should not be included in the alternatives.

Every alternative developed will consist of one or more techniques, depending on the general approach and response category involved. For example, if the removal-treatment-disposal approach were applicable at the site, the alternatives representative of this approach would consist of at least three techniques, i.e., one technique from each category. However, often more than one technique from one response category may be used in a single alternative. This is frequently the case when treatment and disposal are necessary as part of a response. For example, a hydraulic dredge might be applicable at a site to remove contaminated sediments. Treatment techniques would, in all likelihood, have to address both contaminated water and contaminated sediments. In this situation, a response alternative might involve a settling basin for the purpose of separating the water and the sediments that are removed by the dredge, followed by filtration to ensure solid/liquid separation. Water treatment might consist of carbon adsorption. Sediment treatment would involve a different technique, such as centrifugation of sediment removed from the settling basin. Disposal techniques would also differ for the water and the sediments. Treated water might be discharged to a nearby surface water body whereas the used carbon would be disposed of at an appropriate off-site landfill. The treated sediments, on the other hand, might be disposed of in an on-site landfill. As an alternative example, in a situation where removal is not applicable,

but in situ response applies, there might be a single, applicable in situ technique (isolation or treatment) that would meet all established response objectives.

The decisionmaking in Step 3 involves examining techniques in terms of how they complement one another, their compatibility, and, most importantly, whether the techniques, together as alternatives, will meet the previously established response objectives. The result of Step 3 is one or more alternatives that can meet response objectives. Figure 4-6 is an example completed worksheet to be used as a tool during Step 3 to clearly present the potential alternatives. A blank worksheet is provided in Appendix I. The specific techniques proposed for each alternative should be listed under the appropriate category heading. As explained earlier in this section, there may be more than one technique required for any one alternative within a single category. Therefore, in completing the worksheet shown in Figure 4-6, there may be several techniques listed under "Treatment" for Alternative A, or there may be more than one disposal technique necessary and so listed in the "Disposal" column. The worksheet provides a clear and consistent way of presenting the potential alternatives for a particular site.

The number of potential alternatives that result from Step 3 depends on the site conditions and the established response objectives. In some cases, it may not be possible to develop an alternative in Step 3 that will meet response objectives. The "no action" approach is still a viable alternative at this point in any site situation. However, modification of existing objectives should be considered prior to making a decision to take no action. In situations where all combinations of techniques have been explored and developed and the decision is made that "no action is possible given the existing response objectives," then modification of the objectives should be considered. Re-establishing objectives requires an in-depth re-evaluation of response needs and the potential effects on human health and the environment of such a modification as compared to the effects of "no action." Only after this re-evaluation is conducted, and it is found that some type of action is better than no action, should objectives be modified and less effective response alternatives be evaluated. This will require repeating Steps 2 and 3 based on the new objectives.

The issue of "no action is best" may also arise at this point in the selection process. If there are no alternatives that will meet the response objectives and modification of the objectives will make no significant difference (e.g., implementation of all existing and applicable alternatives will create a greater hazard than the hazard that existed prior to a response), then the "no action" alternative should be selected. In such a situation, the selection process would be complete at the end of Step 3, without having carried out Step 4.

Step 3 is complete when either all applicable alternatives that meet the final response objectives have been developed or the decision is made to take no action at all. In cases where alternatives that meet response objectives are developed, these alternatives then undergo the detailed evaluation described in Section 4.4.

SECTION 5

DETERMINATION OF RESPONSE COMPLETION

The selected response to a spill of sinking hazardous substances is implemented with the intention of accomplishing the response objectives. However, the extent to which the objectives have been met can be difficult to judge because of a lack of information on the status of the situation. Although the response implementation may superficially appear to be complete, additional response effort may be warranted. A final response-related activity is needed to make a determination of the "completeness" of the implemented response. This activity, as indicated in Figure 5-1, is intended to determine: (1) whether the response effectively mitigated the problems, and (2) whether further response actions are needed.

The effectiveness of the response is generally determined through the monitoring of site conditions following the response and comparing these conditions with pre-response conditions. This comparison provides the basis for determining the extent to which response objectives have been met. This process is discussed in Section 5.1.

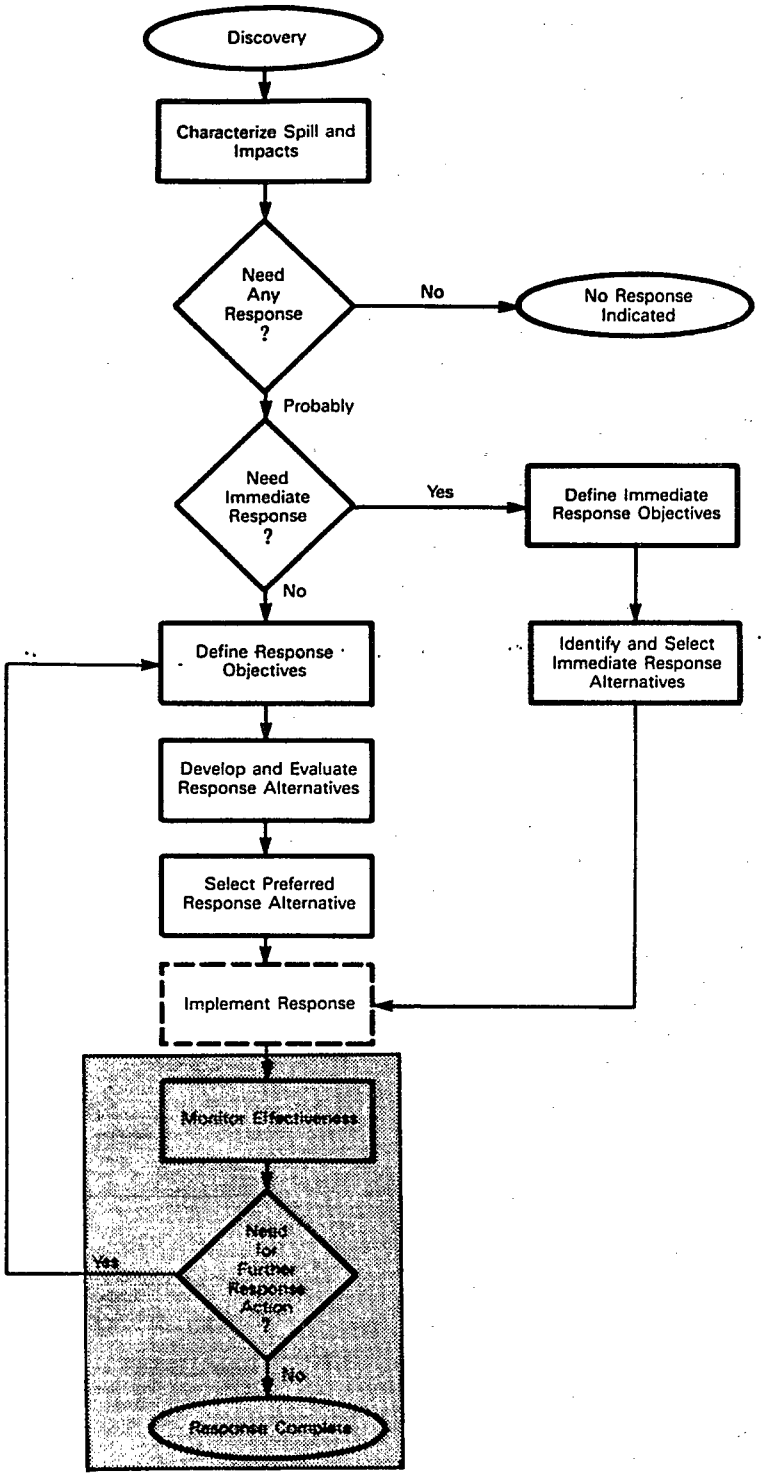
The judgment of the need for further response action is based on the determination of response effectiveness. When response objectives have clearly been met, the response can be considered complete, as indicated in Figure 5-1. However, if the objectives have not been met and further response action is needed, the response selection and implementation process must be repeated until objectives have been substantially met and no further response action is needed. Only then is the response considered complete. This process is discussed in Section 5.2.

5.1 ASSESSMENT OF RESPONSE EFFECTIVENESS

The assessment of the effectiveness of response measures that have been implemented at a site requires the following:

- Pre-response site background data (collected earlier in the response process, see Section 2)
- Response objectives (developed earlier in the response process, see Section 3)
- Post-response site data.

FIGURE 5-1. SEQUENCE OF RESPONSE EVENTS



Post-response site data remain to be collected at this point in the process and are discussed in Section 5.1.1. These data are then compared with pre-response (i.e., before cleanup) site data to determine what improvements the response has accomplished. These post-response conditions are then compared with the response objectives, which were essentially the "desired effects" to be accomplished. These comparisons are discussed in Section 5.1.2.

5.1.1 Data Collection

The collection of post-response site data is accomplished using many of the same data-collection techniques that are used to characterize a spill and to determine response needs (see Sections 2 and 3). Monitoring will generally be necessary in order to measure the effects of the response. Monitoring techniques are discussed in detail in Section 2.3.2.1. Sampling and analysis, direct instrument measurement, and remote sensing may all be applicable to this purpose.

The technique used to initially characterize the contamination will often be the most appropriate for monitoring the cleanup. However, the sensitivity of the technique to relatively low concentrations that are likely to remain following a response must be considered. For example, visual observation of the presence of elemental mercury or polychlorinated biphenyl (PCB) oils may be used for pre-response analysis in defining zones of contamination, and sampling and analysis may be needed to monitor post-response residual concentrations. After response measures have been applied and time has passed at a spill site, any remaining problem most likely will not be easily observed by sight. Therefore, the focus of post-response data collection will be on sampling and remote sensing as the primary data collection methods. These methods are designed to detect low concentrations and trace movement of contaminants and are therefore more suitable for effectiveness monitoring.

The selection of the appropriate monitoring techniques for a particular site depends on the initial extent of contamination and the exposure and impacts identified for the site area and its inhabitants. The more extensive and complex the contamination problem was initially, the greater the variety of monitoring data will be required to determine the response effectiveness.

A variety of parameters may need to be monitored for post-response site data, including:

- Contaminant levels in the water body (near the original spill site and downstream)
- Contaminant levels remaining in the bottom materials
- Contaminant concentrations remaining (for exposure of humans, plants, animals)

- Integrity of any containment measures applied
- Effectiveness of treatment processes in removing or destroying chemicals of concern.

The specific parameter measurements required for evaluating response effectiveness depends on the initial contamination problem and the selected response measures.

In cases where both bottom materials and surface water were initially contaminated, data collection for an effectiveness assessment would involve both sediment sampling and surface water. Similarly, both sediments and water should be sampled in cases where there was initially only sediment contamination, but where removal caused resuspension and subsequent surface water contamination or where partial removal of contaminants was conducted.

5.1.2 Assessment of Meeting Response Objectives

The post-response site data, when compared with the pre-response data, allow an assessment of the extent to which response objectives have been met. Post-response data can be compared to: (1) the pre-contamination situation to assess to what extent the site has been "restored"; (2) the post-contamination, but pre-response situation, to assess the extent of contaminant removal; (3) regulatory or subjectively selected numerical cleanup criteria; or (4) some combination of the three. The situation and criteria used for the comparison is entirely dependent on what was used as the basis for developing the original response objectives.

In some cases, particularly where numerical criteria are applied, the assessment of meeting response objectives is relatively straightforward. For example, for the response objective of "Remove contaminated bottom materials to the deeper of: (1) a two-foot cut, or (2) contaminant concentrations not exceeding 50 ppm," monitoring can be conducted to determine whether the criteria have absolutely been met. However, if zones remain where the criteria have not been met, a judgment must be made as to whether the criteria have substantially been met. Similarly, non-numerical objectives and numerical objectives for which data are not available require a further degree of judgment in deciding whether response objectives have been met. These comparisons and judgments are integral to determining whether further actions are needed.

5.2 DETERMINATION OF NEED FOR FURTHER RESPONSE

If the post-response assessment reveals that the response objectives have not been satisfactorily met and residual contamination continues to pose a hazard, there is cause to consider the need for further response action. This situation is similar to the recognition of the need for "any

response", as occurred earlier in the response decisionmaking process (see Figure 3-1 and Section 3). Should further response be necessary, the response selection process should be repeated, as indicated in Figure 5-1.

This repeated process begins with redefining the response objectives, which is conducted as described in Sections 3.2 and 3.3. The objectives may remain identical to those objectives established for the already-implemented responses, or the objectives may be modified because of changed circumstances or because the original objectives have been found to be overly stringent, unachievable, or impractical.

Based on available site data and redefined objectives, response techniques and alternatives (including "no action") are screened, developed, and selected, as described in Section 4. The selected alternative is implemented and its effectiveness is monitored for meeting the redefined objectives, as described in Section 5.1.

If the redefined response objectives have been met, the response may be considered to be complete. If the redefined objectives have not been met, the process described in Section 5.2 is repeated until the response is judged to be complete (i.e., the objectives have been met).

APPENDIX A

CONTAINMENT TECHNIQUES

In responding to a spill or discharge of sinking substances, prompt containment of the material is often of primary concern. Containment measures can be implemented to minimize damage to the environment until a permanent response is determined and implemented. In some cases, permanent containment of contaminants is appropriate; this method is discussed in Appendix E, In Situ Treatment and Isolation Techniques.

There are two reasons for applying containment techniques at a spill site. The first reason is to protect adjacent areas that have not been contaminated by the discharge. The second reason is to minimize the amount of contaminated material and the corresponding response effort.

A number of containment techniques are suitable for temporary or short-term use. These techniques (discussed in this appendix) include containment curtains, trenches and pits, dikes and berms, temporary covers, pneumatic barriers, floating breakwaters, and cofferdams.

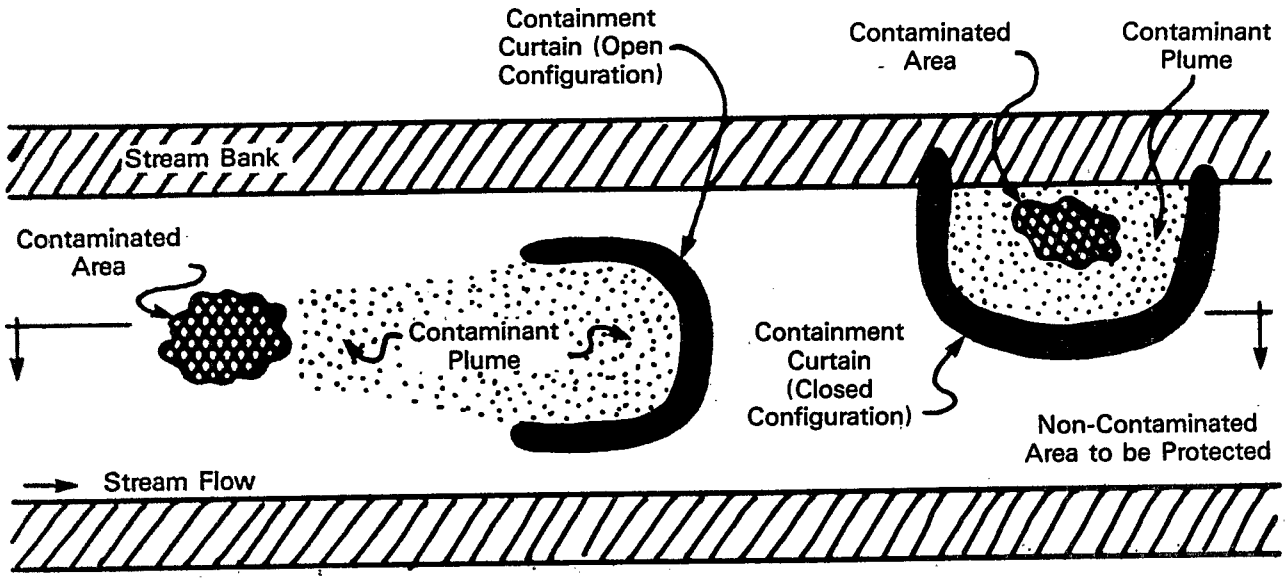
A.1 CONTAINMENT CURTAINS

A.1.1 Description

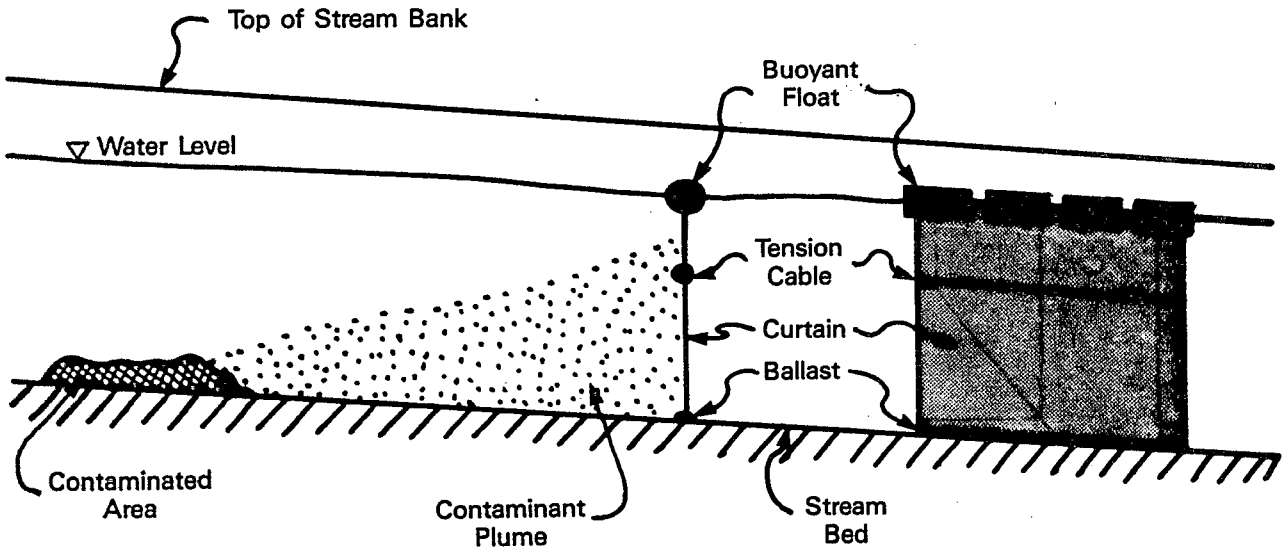
In general, a containment curtain consists of a flexible skirt supported by foam jacket floats. Ballast is provided using weights, chains, or a tube filled with water. By reducing the flotation and increasing the weight of the ballast, the curtain will sink. The curtain is then anchored to the bottom of the water body to contain the spill. This type of containment curtain has been custom-made by various manufacturers to contain spills of sinking substances.

There are several ways of configuring containment curtains, depending on the size and location of the spill. Figure A-1 illustrates the most common configurations. One configuration is a closed system, which may be a full circle, an ellipse, or open-ended and attached to shore, as shown. Another configuration is an open system, which is often used in situations where the curtain must be moved frequently, such as in rivers with heavy boat traffic (JBF Scientific 1978).

FIGURE A-1. APPLICATIONS OF CONTAINMENT CURTAINS TO CONTROL RESUSPENDED MATERIAL



Top View



Section View

Several variations of containment curtain systems are commercially available. These include the use of different grades of permeable mesh curtain that allow water to flow fully through the curtain while retaining the spilled substance, preventing the curtain from flailing or lifting around the edges.

Containment curtains are deployed directly into the water from shipping containers by pulling one end away from the container using a small boat. Once in the water, the curtain is moved to the deployment position by towing it with a work boat. Curtains tow easily at 2 to 3 knots and track well behind the tow boat through normal maneuvering. Curtains over 2000 feet long have been towed in this manner (Hand et al. 1978).

A.1.2 Applications

Containment curtains are used to contain and control spills or discharges of materials into a water body and to control resuspension of sediments during dredging operations. They are best suited to application in quiescent waters, such as low-current, near-shore areas of rivers and harbors. However, containment curtain systems have been applied effectively in 1-knot currents, 40-knot winds, 6-foot waves, and in water depths up to 25 feet (Hand et al. 1978).

Containment curtains (as well as other containment techniques) are also best applied to spills that are relatively confined. If the spill has already dispersed greatly to surrounding areas, the usefulness of the containment curtain for protecting non-contaminated areas and for minimizing the amount of contaminated material is limited.

A.1.3 Limitations

Containment curtains cannot be effectively used in swift currents and high wave action. The effectiveness of a containment curtain decreases as the current velocity in the area increases, due to curtain flare that causes resuspension of sediments. A practical upper limit for current velocity is approximately 1.5 feet per second (Hand et al. 1978). In waters with significant wave action, there is a tendency for near-surface spilled materials to overtop the barrier.

A.1.4 Special Requirements/Considerations

Containment curtains must be deployed from a support vessel, which can also be used for periodically repositioning the curtain. Costs associated with containment curtains are medium relative to other containment techniques.

A.2 TRENCHES

A.2.1 Description

Trenches are areas of sediment excavation in the bottom of a water body. The configuration of a trench can vary from long and narrow (such as a utility trench), as shown in Figure A-2, to short and wide (such as a pit). Trenches can be excavated with conventional digging and dredging equipment (described in Appendix B, Removal Techniques).

Trenches contain sinking contaminants and sediments by: (1) increasing the local cross-section of flow, thereby decreasing flow velocity and encouraging settling, (2) providing a low-lying area that allows settling to a level below the normal level of bed transport, and (3) providing a storage volume for trapped substances. In effect, a containment trench is a temporary in-stream settling basin.

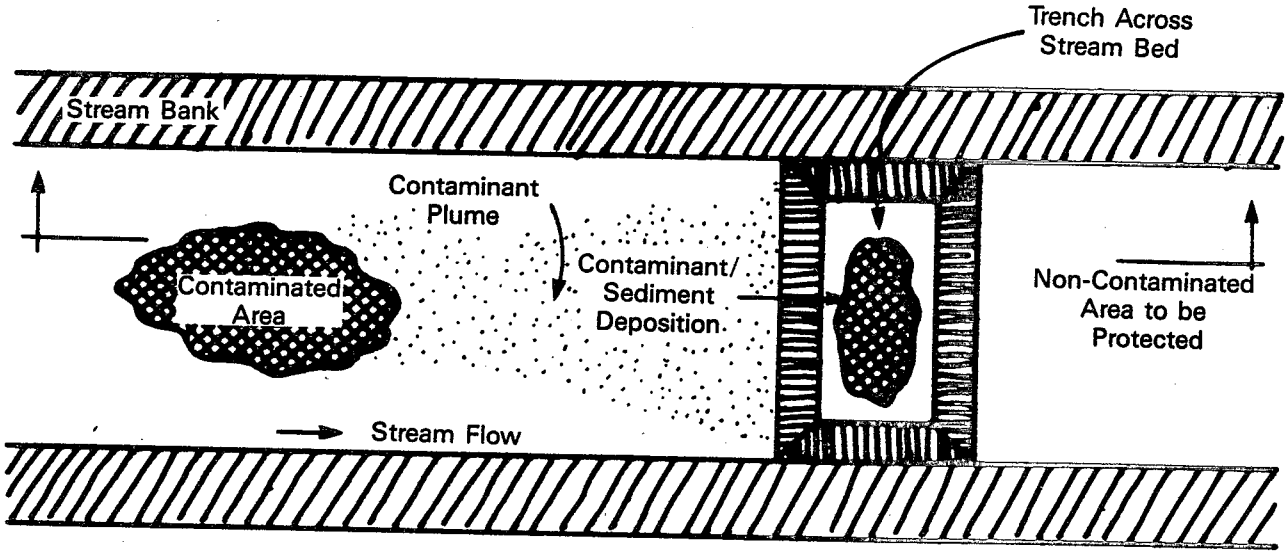
Trenches are generally excavated downstream of a spill and perpendicular to the direction of flow. However, some trenches are dug both upstream and downstream of a spill, such as in areas of reversing tidal flow. In some cases, such as harbors or shallow open waters, trenches are dug completely around a spill (Hand et al. 1978). Trenches may be used to arrest movement of a spill or a discharge in order to protect adjacent areas from becoming contaminated; they may also be used to facilitate subsequent cleanup of the site by minimizing the amount of contaminated material. Containment of spills with trenches can also be used as a remedial action technique in conjunction with treatment techniques, such as neutralization, precipitation, or the application of cover materials (see Appendix E).

A.2.2 Applications

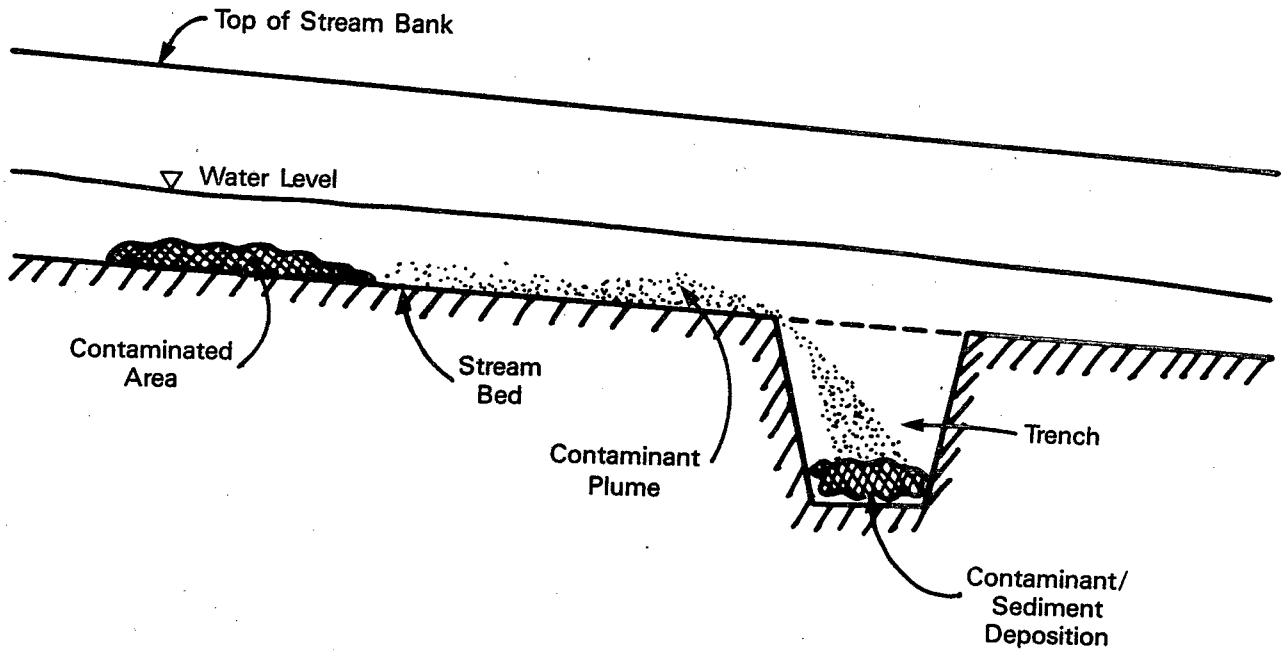
Trenches are best suited to use in rivers or other water bodies with predictable currents. This is necessary in order to achieve proper placement of the trenches to interrupt the transport of contaminated sediments. Trenching is most readily accomplished in water bodies with relatively calm currents, although some special equipment can operate in extreme sea conditions (Banzoli et al. 1976). Generally, trenches can be excavated in any type of sediment, although clays and silts provide better stability than coarser sediments.

Two physical characteristics of the spilled substance or the contaminated sediments are important in evaluating the applicability of trenching: specific gravity (substance must be a sinker) and particle size (which is related to settling velocity). Relatively wide trenches are needed to contain spilled substances and sediments with relatively low specific gravity and/or small particle size. Conversely, narrow trenches may be used for "heavy" substances and/or those with large particle size.

FIGURE A-2. APPLICATION OF A SPILL CONTAINMENT TRENCH TO CONTROL SINKING SUBSTANCES



Top View



Section View

Conventional dredging and its associated equipment can be used for trench excavation (discussed in Appendix B). More specialized excavating equipment may also be used, although its availability is limited. This equipment includes underwater ploughs and submersible trenchers.

A number of underwater ploughs can be used for trenching and are effective for excavating trenches up to 10 feet deep. Generally, they are suitable for use only in silty clays. Underwater ploughs can also be used to cover over trenches after a spill has been contained (Reynolds, Seamans, and Van der Steen 1977).

Various types of submersible trenchers may also be used for excavating operations. They include both manned and unmanned models. Submersible trenchers offer a high degree of operational control and can be used in very deep waters (up to 650 feet). Thus, they are able to operate in extreme sea conditions. More sophisticated submersible trenchers employ a mechanical/hydraulic dredging system, combining the action of cutterheads and suction pumps to enable trencher operation in sediments of varying characteristics. Some submersible trenchers can dig trenches up to 13 feet deep with a trench width of 25 feet at the mud line and 13 feet at the bottom (Banzoli et al. 1976).

A.2.3 Limitations

Trenching may be impractical in spill situations where one or more of the following conditions exist:

- Hard bed materials (e.g., rock, hardpan, etc.).
- Soft or granular bed materials that tend to flow and collapse when excavated.
- High water body velocity or currents where positioning and maneuvering of equipment would be difficult or where little settling would occur.
- High natural rates of sediment transport that may rapidly exhaust the trench capacity with non-contaminated materials.
- Extensive area of contamination, requiring large lengths and volumes of trench excavation.

A.2.4 Special Requirements/Considerations

Resuspension of bottom materials can result from in-stream trenching, and secondary containment methods may be warranted. Support equipment, such as trucks and barges, may be needed for hauling excavated trench

materials from the stream. Costs associated with containment trenches are low relative to other containment techniques.

A.3 DIKES

A.3.1 Description

Dikes, as applied to containment of spilled substances that sink, are underwater embankments of materials placed on the bed of a water body. Dikes are generally constructed of earthen material, sand bags, or some other material that can be mounded and that can maintain structural integrity. Dikes can be installed using conventional excavation and earth-moving equipment. Manual placement is possible in small-scale, shallow applications. Specialized underwater ploughs or bulldozers can also be used for trenching.

Dikes contain sinking contaminants and sediments in a manner similar to that of containment trenches, i.e., effectively creating a temporary in-stream settling basin. The effects of dikes on the water body and sediment transport are: (1) raising the local water level upstream of the dike, thereby increasing the cross-section of flow, decreasing flow velocity, and encouraging settling; (2) providing a trapping, low-lying area (relative to the top of the dike) upstream of the dike that allows settling of sinking materials; and (3) providing a storage volume for trapped substances.

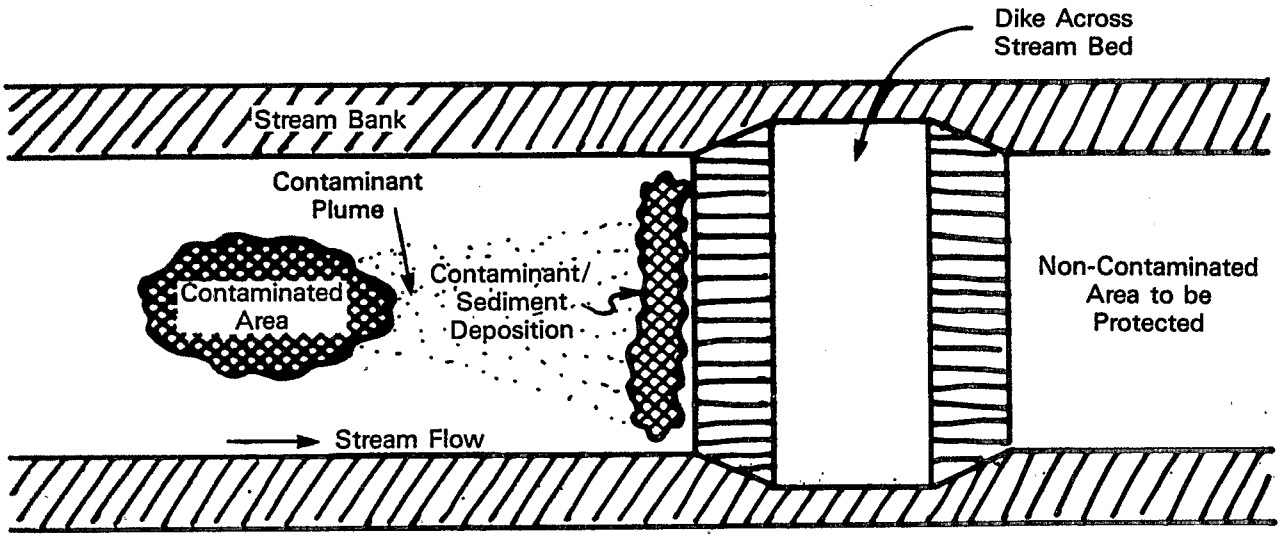
As a temporary control measure, dikes create the effect of a holding pond or reservoir, which prevents flow downstream and also promotes the settling of fine particles. Contaminated sediments can later be removed from the restricted area or can be treated in place.

Dikes generally extend across a stream channel, perpendicular to the direction of flow. Figure A-3 illustrates such a configuration. In some cases, dikes are built parallel to a river or a stream bank to prevent contaminated deposits along a river bank from entering the deeper river channel and traveling downstream.

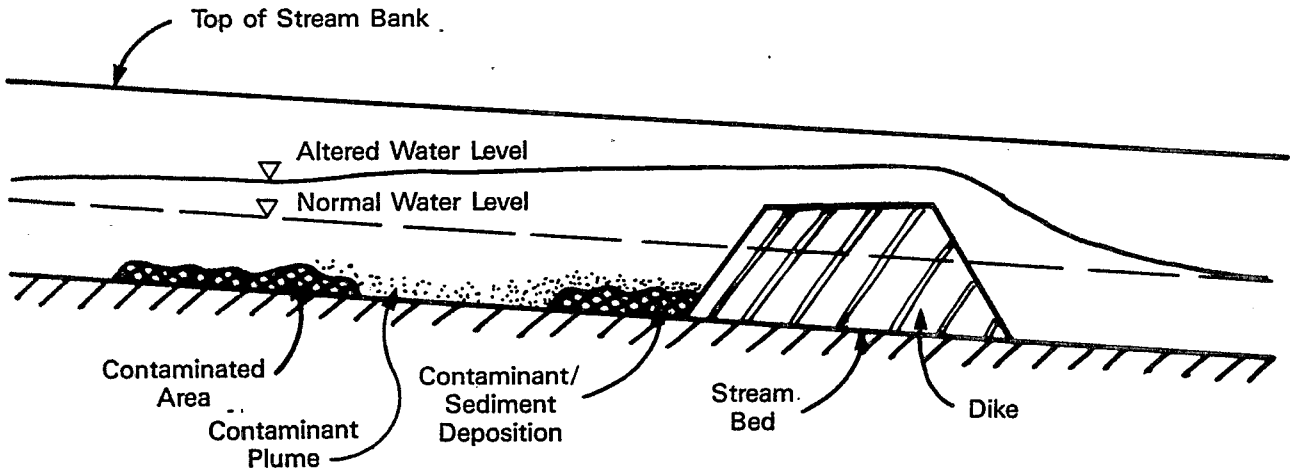
A.3.2 Applications

As a temporary containment measure, dikes are best suited for use in drainage ditches or small streams with low flow and low volume. However, shallow, submerged dikes may also be used to temporarily prevent bottom spreading of a spill or to minimize erosional losses of cap material after a capping operation. Dikes are also used to minimize erosion of contaminated deposits along the banks of streams and rivers in order to minimize the amount of contaminated material entering the river and spreading further.

FIGURE A-3. APPLICATION OF A SPILL CONTAINMENT DIKE TO CONTROL SINKING SUBSTANCES



Top View



Section View

Dikes are well suited to situations in which prompt containment of a spill or discharge is necessary because they can be constructed quickly using manual labor, hand tools, front-end loaders, bulldozers, or dredging equipment.

As a permanent containment measure, dikes can be combined with capping, vegetation, trenches, and other methods for stabilizing contaminated sediments.

A.3.3 Limitations

Dikes are impractical to construct and have little effectiveness in situations involving high-flow velocity or strong currents. Also, effective placement of berm materials is hampered by deep water depths. Compaction equipment and monitoring of placement may be needed to ensure that a continuous dike of adequate structural integrity has been constructed.

A.3.4 Special Requirements/Considerations

Construction of containment dikes requires that a source of suitable material be made available. Ideally, the source should be close to the spill site so that large volumes can be made available in a short time period. The material should be sufficiently coarse to resist erosion and downstream transport. Monitoring by sounding or diver observation may be warranted when dikes are installed in deep water to ensure proper dike placement. Costs associated with containment dikes are low to medium relative to other containment techniques.

A.4 COFFERDAMS

A.4.1 Description

Cofferdams are barriers that are placed in a stream to cut off a section of the stream and to divert partial or full water flow through a pipe or an excavated channel to re-enter the stream channel at a point further downstream. Cofferdam stream diversion can be used for one or more of the following purposes:

- Permanent stream relocation to allow extensive rehabilitation of the stream bed.

- Hydraulic isolation of contaminants or sediments in order to:

  - Facilitate treatment or removal of contaminants or sediments
  - Eliminate exposure of the downstream water column to the contaminants.

Cofferdams may be constructed of a variety of materials, including soil, sheet piling, earth-filled sheet pile cells, and sand bags. Sheet-pile cofferdams are generally constructed of black steel sheeting from 5 to 12 gauge in thickness and from 4 to 40 feet in length. They may be single walled or cellular and earth-filled in sections. Single-wall, sheet-pile cofferdams are most applicable for shallow water flows. For depths greater than 5 feet, cellular cofferdams are recommended.

There are various configurations of stream diversion schemes using cofferdam construction, depending on the desired effect. For example, Figure A-4 illustrates full-stream flow diversion using two cofferdams and a diversion channel in order to allow sediment dewatering and excavation with conventional earth-moving equipment.

Another arrangement is shown in Figure A-5, which illustrates stream-flow diversion for sediment excavation using a single cofferdam and taking advantage of the proximity of the stream bank to the contaminated sediments.

A.4.2 Applications

Cofferdams are most easily constructed for flow containment or diversion in shallow ports, streams, and rivers, or in water bodies with low-flow velocities (less than 2 feet per second). Cofferdam construction may be feasible for relatively wide and deep rivers (up to about 10 feet deep), providing that the velocity of flow is not excessive (JRB 1982).

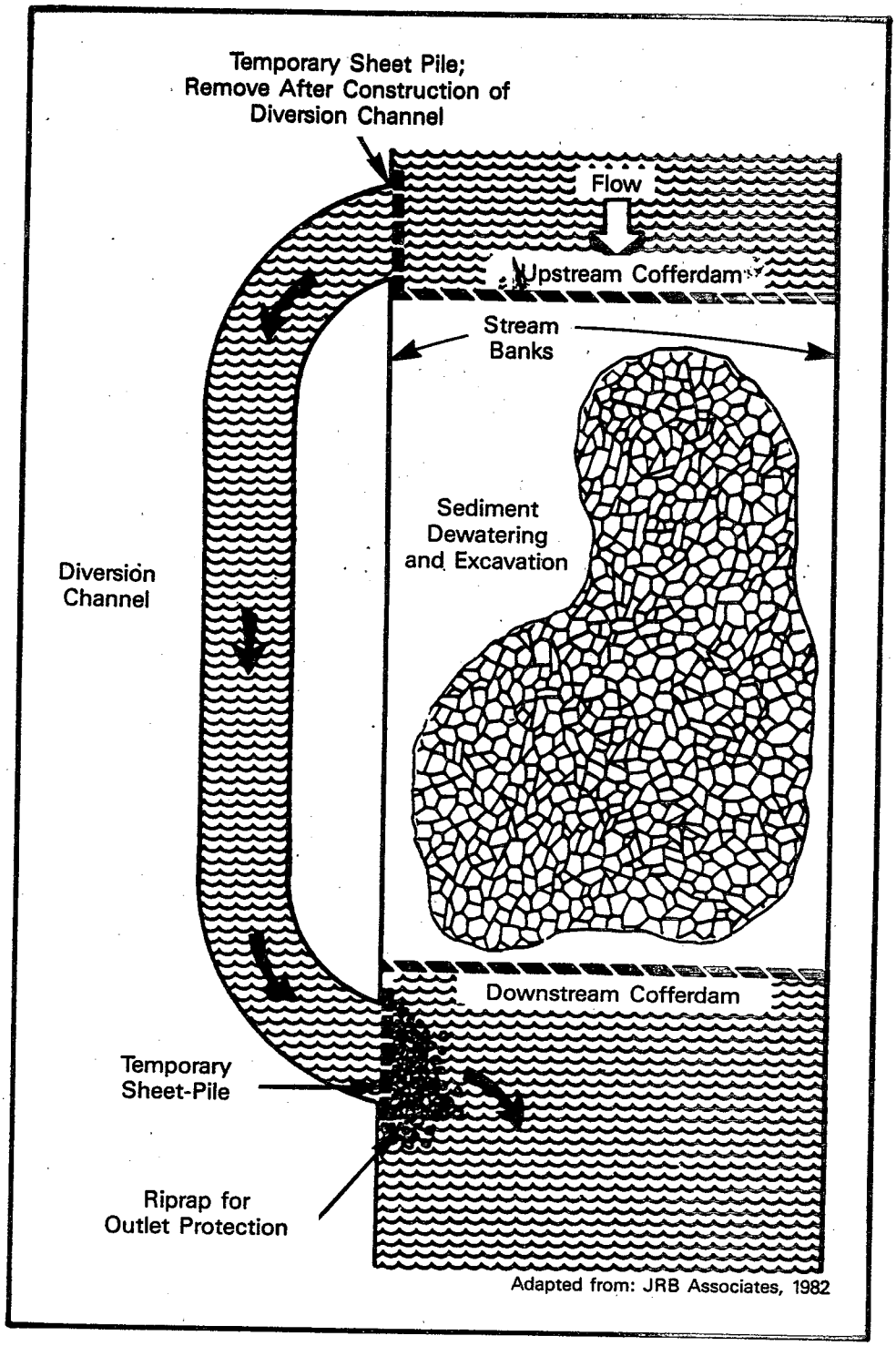
A.4.3 Limitations

Cofferdam construction is limited to water bodies with relatively low volume and flow velocity, such as shallow ports, streams, and small rivers. Where flow velocity exceeds 2 feet per second, cofferdam construction is not recommended because of the difficulties in driving sheet piling and placing and compacting soil embankments (JRB 1982).

A.4.4 Special Requirements/Considerations

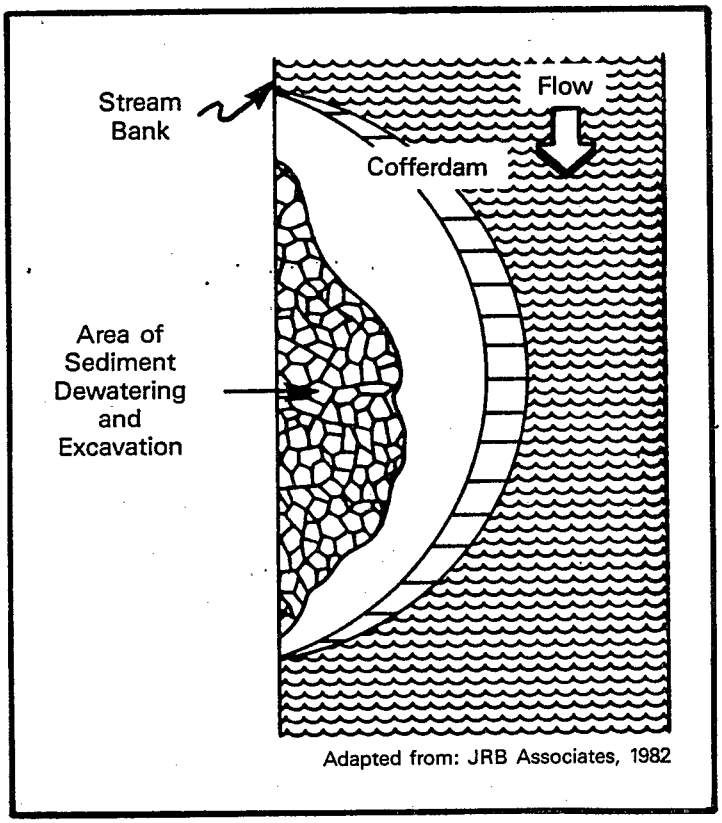
Cofferdams are most frequently used in stream diversion and in dewatering of the working area. Some form of lining material (such as pavement, rip rap, or piping) may be needed to protect diversion channels

FIGURE A-4. STREAMFLOW DIVERSION FOR SEDIMENT EXCAVATION USING TWO COFFERDAMS AND DIVERSION CHANNEL



Adapted from: JRB Associates, 1982

FIGURE A-5. STREAMFLOW DIVERSION FOR SEDIMENT EXCAVATION USING SINGLE COFFERDAM



Adapted from: JRB Associates, 1982

from scour. Dewatering of the working area is generally accomplished by continuous or periodic pumping. Pumping is also sometimes used to divert flow around the working area.

The Environmental Emergency Response Unit of the EPA at Edison, New Jersey, has available a mobile stream diversion unit for such operations, which consists of submersible pumps, booster pumps, generators, a crane, and aluminum irrigation pipe with ancillary fittings. The system is capable of pumping 5,600 gallons per minute for a distance of 1,000 feet over level terrain. Additional capacity can be provided with supplemental piping and pumps (USEPA 1980).

A.5 PNEUMATIC BARRIERS

A.5.1 Description

A pneumatic barrier, or air barrier, is created by a curtain of rising air bubbles that spread laterally in the water body. Artificially induced water currents are generated by the air curtain that counter the normal currents, thus confining suspended sediments or spilled substances within a desired boundary. An illustration of a pneumatic barrier is shown in Figure A-6.

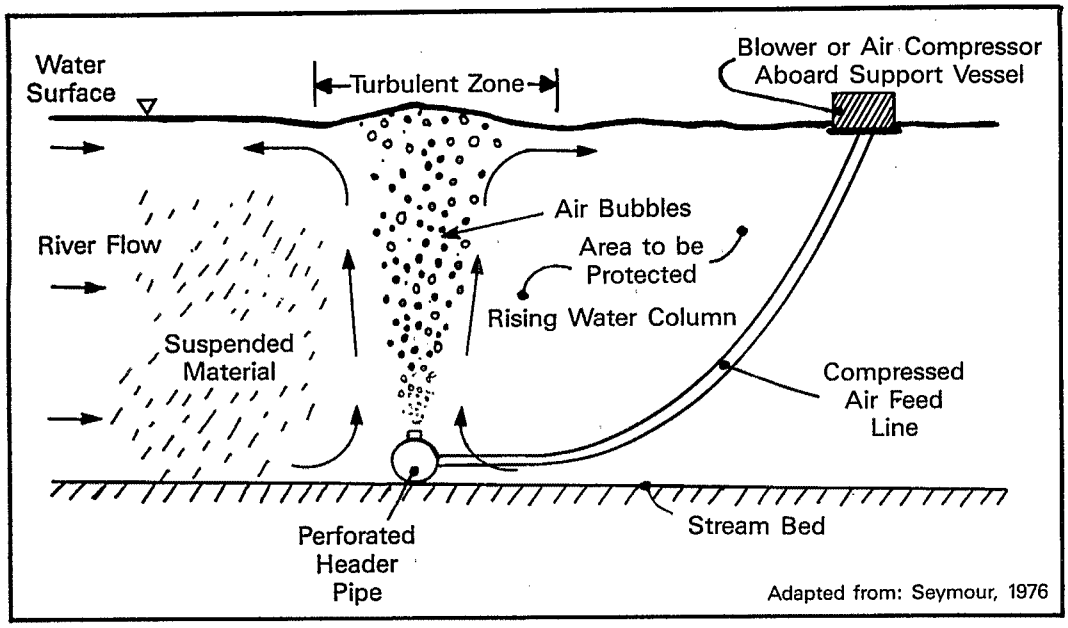
The barrier is deployed by laying a weighted perforated header pipe on a river or harbor bottom in a configuration similar to that employed for containment curtains (see Section A.1 and Figure A-1). Compressed air is transmitted from blowers or air compressors through a flexible feed line to the header pipe. The air is forced through the header pipe and is released to the water column through the perforations.

A.5.2 Applications

The conventional application of pneumatic barriers is control of turbidity generated during dredging operations. Pneumatic barriers are similarly applied in the removal of spilled substances and contaminated sediments in order to contain suspended contaminants within a confined area. Pneumatic barriers are also used at a spill site to prevent suspended particles from moving downstream until another response can be implemented. Because pneumatic barriers can be deployed quickly, they are particularly suited to situations demanding immediate action.

Pneumatic barriers can be applied in water bodies that are fairly quiescent. They are most efficient when used in deep waters because shallow water demands a greater volume of air for effective operation.

FIGURE A-6. CROSS-SECTION OF A PNEUMATIC BARRIER APPLICATION



Pneumatic barriers are also well suited for use in waters with boat traffic because their presence does not impede navigation.

A.5.3 Limitations

Pneumatic barriers are not effective in water bodies with substantial turbulence or current. The barrier is effective only if the current of the water body and the wind do not overcome the forces created by the barrier. Natural currents will affect the rising air plume by causing it to "lean," creating a flow pattern that will allow some of the suspended material to escape the barrier. This problem can be overcome to some extent by increasing the velocity of the rising air bubbles. However, for a given nozzle, there is a critical velocity above which additional increases in air volume have little effect on the artificially generated current. Pneumatic barriers are not as efficient in shallow water because greater volumes of air are necessary to maintain an effective curtain.

A.5.4 Special Requirements/Considerations

Pneumatic barriers utilize air compressors or blowers, which require a nominal supply of energy (electricity, fuel oil, gasoline, etc.) for operation. In larger, open water bodies, the compressor or blower can be operated from a support vessel. Costs associated with pneumatic barriers are medium relative to other containment techniques.

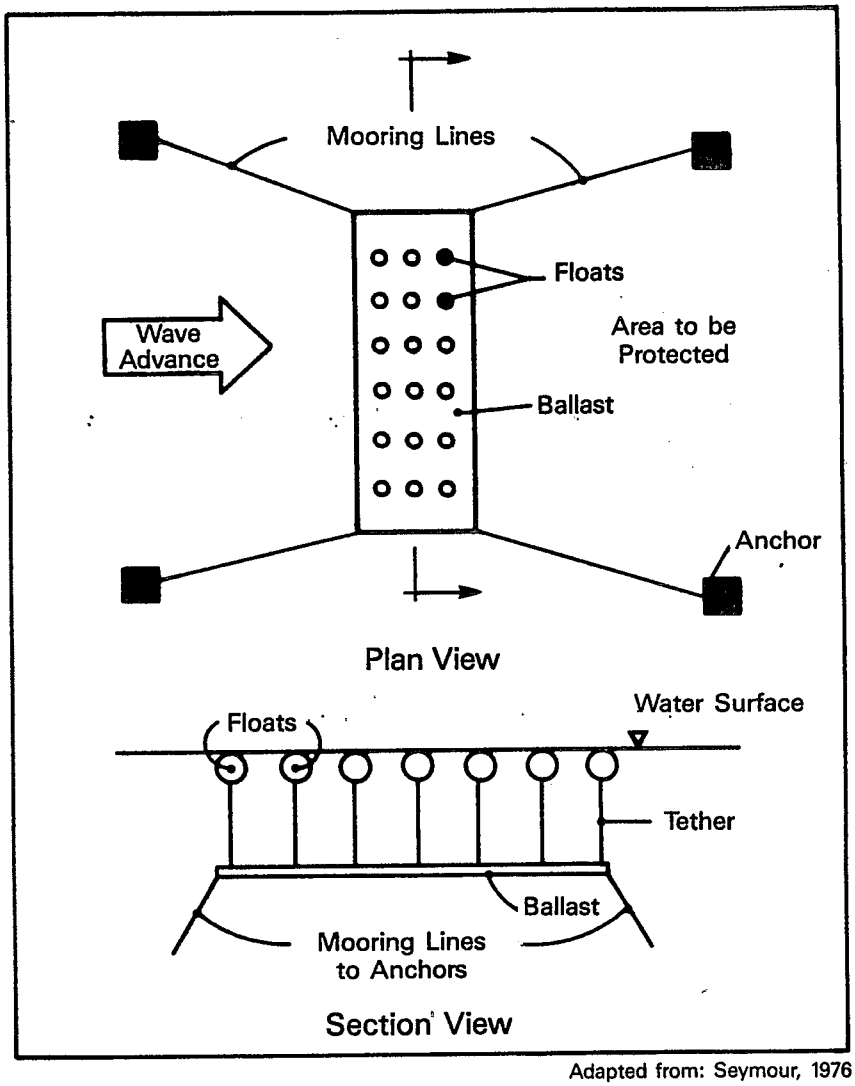
A.6 FLOATING BREAKWATERS

A.6.1 Description

Floating breakwaters consists of flotation devices, obstacles for reducing wave energy, and a ballast structure for stability. Floating breakwaters are used to reduce wave height and energy to facilitate spill response and reduce dispersion of spilled substances.

One such device is a tethered float breakwater, as illustrated in Figure A-7. In this breakwater system, individual buoyant floats are tethered to a submerged, off-the-bottom ballast (a heavier-than-water slab structure). The ballast section provides the mass to submerge the floats to the desired freeboard and also maintains float spacing. Wave energy is attenuated through the drag produced during the rapid and vigorous oscillations of the buoyant floats. The tether length is selected to provide a natural frequency of oscillation that is of the same order as the frequency of the wave action. Mooring lines are used to maintain the breakwater within the desired location limits (Seymour 1976; Essoglou et al. 1975).

FIGURE A-7. TETHERED FLOAT BREAKWATER



Adapted from: Seymour, 1976

Some of the major features of the tethered float breakwater are:

- The level of protection can be selected to meet specific site requirements. Modular construction allows tailoring to meet the specified transmitted wave height limit.

- Performance is predictable if the wave characteristics are known.

- Performance is independent of the mooring system and therefore is independent of depth. The breakwater will give full protection while floating free.

- The small total mass and volume of the breakwater and its modular construction make it easily transportable (Seymour 1976).

Another type of floating breakwater is the sloping float breakwater. This is also a transportable breakwater. It consists of a row of moored flat slabs or panels whose mass distribution is such that, in still water, each panel rests with one end on the bottom of the water body and with the seaward end protruding above the surface. The device is ballasted by flooding one end. For a transportable breakwater, the advantage of a water-ballasted module is that much of the required mass is water. Installation involves assembling the floating unballasted modules (nominally 90 feet by 28 feet), then admitting water to the shoreward end of each float by venting. Flooding continues until the lower end rests on the bottom and the upper end settles to the level that produces the desired freeboard. The controlling factor in reducing wave transmission is the inclination of the breakwater in its at-rest position (Jones et al. 1979).

Floating breakwaters can be fabricated using readily available marine and construction materials, such as buoys, anchors, cables, concrete slabs, and steel plates.

A.6.2 Applications

Floating breakwaters are used to decrease erosion, control scour, and reduce dispersion of spilled material caused by wave-induced bottom surge. Floating breakwaters are used in open waters, such as oceans, bays, or lakes where locally generated wind waves and ship waves occur. The tethered breakwater system can be used in shallow or deep water since it is free-floating and independent of depth; however, it is more economically used in deep water.

Sloping float breakwaters are best applied to near-shore uses for water depths on the order of 20 to 30 feet (Jones et al. 1979).

A.6.3 Limitations

Floating breakwaters are large in size and weight and are not readily transported on land, although the use of modular arrangement can improve the transportability of breakwaters. There are no depth limitations associated with breakwaters, provided that the proper scale of depth-related components (tethers, mooring lines, etc.) are provided.

A.6.4 Special Requirements/Considerations

Support vessels must be used to tow the breakwater to the point of use. Cranes and divers may be needed to properly position the breakwater. Costs associated with floating breakwaters are high relative to other containment techniques.

A.7 TEMPORARY COVERING AND CAPPING

Covering and capping involves the placement of protective materials over contaminated materials to: (1) reduce erosion and transport of contaminants, (2) reduce dissolution and migration of contaminants into the water column, (3) alter the contaminants chemically or physically, or (4) provide some combination of these effects. Covering and capping is normally used as a permanent response, as described in Appendix E, In Situ Treatment and Isolation Techniques. The methods described in Appendix E can also be used for temporary containment; the primary difference is that the covering and capping materials are removed when they are used temporarily and are contaminated by contact with the contaminated bottom materials.

A.8 SUMMARY

Temporary or short-term containment of contaminated sediments include containment curtains, trenches, dikes, temporary covers, pneumatic barriers, cofferdams, and floating breakwaters. A summary of the characteristics and applications of these techniques is given in Table A-1.

TABLE A-1. SUMMARY OF CONTAMINANT CONTAINMENT TECHNIQUES

Technique	Applications	Limitations	Secondary Impacts	Ease of Implementation	Relative Cost
Containment Curtains	Control resuspension of sediments during dredging operations; temporary containment of spills or discharges; use in quiescent waters and low-current, near-shore areas of rivers and harbors; use for relatively confined spills	Not effective in swift currents (greater than 1.5 feet/second); overtopping may occur by wave action	None	Storage and transport requires special attention; deployment can be accomplished with relative ease; varies from relative ease with conventional excavating equipment to more difficult with special submersible trenchers and underwater ploughs	Medium
Trenches	Temporary containment of spills or discharges; use in conjunction with other treatment techniques, such as neutralization; use primarily in calm waters depending on type of equipment used for excavation	Not effective in swift currents; may not be practical in excessively hard or soft bottom materials	Resuspension of bottom materials may result	Construction is accomplished with relative ease where depth and current velocity are not excessive	Low
Dikes	Control resuspension of sediments during dredging operations; temporary containment of spills or discharges use in conjunction with other stabilization techniques; use in waters with low-flow velocity and low volume, such as small streams and drainage ditches	Impractical to construct in swift currents	Suspension of dike materials may result	Construction is accomplished with relative ease, especially through use of hand tools in small water bodies	Low to medium

(continued)

TABLE A-1. (continued)

Technique	Applications	Limitations	Secondary Impacts	Ease of Implementation	Relative Cost
Cofferdams	Used in conjunction with stream diversion to isolate contaminated sediments from stream flow; use in shallow waters with low-flow velocity	Difficult or impractical to construct in swift currents	Resuspension of bottom materials may result	More difficult than other temporary containment measures	Medium
Pneumatic Barriers	Control resuspension of sediments during dredging operations; temporary containment of suspended particles from spills or discharges; use in relatively deep waters for efficient operation; use in quiescent waters such that current does not overcome forces set up by compressed air	Not effective in swift currents; less effective in shallow water bodies	None	Construction is more difficult than other temporary containment measures	Medium
Floating Breakwaters	Reduce erosion of bottom sediment caused by surface waves; use in oceans, bays, and lakes	Cannot be used during severe weather storms	None	Transport and deployment can be accomplished with relative ease	High
Temporary Covering and Capping	Control transport or dissolution pending other response	Covering and capping materials may become contaminated by contact with contaminants, increasing the ultimate cleanup effort	Suspension of covering and capping materials and resuspension of bottom materials may result	Readily implemented with granular material applied by dumping; special materials (membrane, cement, etc.) require special techniques and equipment	Low to high

APPENDIX B

CONTAMINATED MATERIAL REMOVAL TECHNIQUES

The process by which bottom sediments are removed from bodies of water is commonly known as dredging. This process has been used for many years to widen or deepen harbors and navigable rivers. In recent years, dredging has also been employed in the removal of sediments that have been contaminated through discharges of hazardous and harmful substances. Other techniques have been developed for removal of contaminated sediments.

This appendix discusses the equipment and techniques that may be used in the removal of contaminated sediments. Three types of dredging equipment are discussed: mechanical, hydraulic, and pneumatic.

All of the equipment that is placed on site in order to accomplish the removal of sediments make up what is referred to as the dredge plant. In addition to the equipment and the technologies related to the dredge plant, there are also many predredging operations that must be performed before successful dredging can begin. These operations consist of a variety of tasks that are conducted prior to, and in preparation for, the actual dredging of sediments. Predredging operations can include equipment mobilization and demobilization, stream diversion, cofferdam construction, and removal of weeds and bottom debris. Cofferdam construction and stream diversion are discussed in Section B.4.

Divers frequently can be used in predredging operations for monitoring removal of bottom materials and for operation of hand-held dredges. The use of divers in contaminated waters may pose hazards for that necessitate special precautions. Most divers are hesitant to enter water bodies that have been contaminated with hazardous substances. Experiences in these environments have often resulted in injuries, primarily chemical burns, to divers and/or surface support personnel. Little information is available on low-level exposure to chemicals that divers or surface support personnel may receive in these environments. Only acute or immediate effects have been reported. Chronic, long-term toxicity has not been investigated. This is potentially a serious problem that is now being addressed by several government agencies (McLellan 1982).

Diving equipment problems also occur in chemically contaminated water environments, primarily due to petroleum products. Divers frequently enter these environments, resulting in deterioration and failure of equipment. Equipment deterioration has been responsible for fatalities and for incidents

of diver exposure to contaminants (McLellan 1982). Special equipment and procedures all under development for protecting response team divers.

B.1 MECHANICAL DREDGES

Mechanical dredges are equipment used to remove bottom sediment through the direct application of mechanical force to dislodge the material. This physical removal of bottom sediment is usually performed by a bucket that scoops up the material and carries it to the surface. The material is then usually placed in a barge, scow, truck, or impoundment for treatment or disposal.

Mechanical dredges include clamshell, dragline, dipper, and bucket ladder dredges, as well as conventional excavation equipment, such as backhoes and loaders. The mechanical dredges can either be vessel-mounted for offshore use or track-mounted and land-based. The main advantage to mechanical dredges is that they can remove sediments at nearly *in situ* densities, i.e., the water content of sediments is not increased through the dredging process. Removing sediment at the maximum possible solids content thus reduces the scale of facilities necessary for dredged material transport, treatment, and disposal.

Compared to other types of dredges, mechanical dredges generate higher resuspension of bottom materials, particularly in fine-grained sediments, and also exhibit lower production rates, especially in consolidated material.

B.1.1 Clamshell Dredges

B.1.1.1 Description

Clamshell (or grab) dredges are crane-operated dredges that are usually mounted on flat-bottomed barges or pontoons. They may also be mounted on other sea-going vessels or track-mounted and land-based. Most are equipped with a single crane, but multiple crane configurations are not uncommon. Removal is performed with large, hinged buckets ranging in capacity from 1 to 13 cubic yards. Buckets are lowered in an open position on a control cable to the bottom surface and sediment is scooped up as the bucket closes and its two halves come together. Clamshell dredges operate at 20 to 30 cycles per hour, depending on working depth and sediment characteristics (Hand et al. 1978).

Standard clamshell buckets are open at the top and allow considerable loss of sediment by spillage and leakage once the bucket breaks the water surface. The Port and Harbor Institute of Japan and the Corps of Engineers Waterways Experiment Station have each developed watertight buckets in which

the top is enclosed so that the dredged material is contained within the bucket (Hand et al. 1978).

There are approximately 200 clamshell dredges in use nationwide, making them one of the most commonly used dredges in the United States (Hand et al. 1978). In addition, clamshell excavators are common in conventional excavation work.

B.1.1.2 Applications

Clamshell dredges can be used to excavate at in situ densities in all types of material with the exception of highly consolidated sediments and solid rock and can excavate to depths of 100 feet or more. These dredges afford close control of position and depth and are therefore well suited to work in confined areas and surrounding vulnerable structures.

As with other types of mechanical dredges, clamshells are generally used for relatively small-scale operations (up to a few hundred thousand cubic yards).

Clamshell dredges are also used in predredging operations for removal of potentially destructive bottom debris, such as stumps, logs, rubbish, and rocks.

B.1.1.3 Limitations

The major disadvantages of using clamshell and other mechanical dredges are the relatively low rate of production and the relatively high degree of sediment resuspension these dredges produce compared to other dredges. Sediment resuspension occurs as the bucket impacts and pulls free from the bottom and also as hoisting drag forces act to wash away part of the load. Clamshells generally excavate a heaped load of material, and as the bucket clears the water surface, additional losses may occur through rapid drainage of entrapped water and slumping of the material above the rim of the bucket. Concentrations of suspended solids in the vicinity of clamshell dredging may be as great as 500 milligrams per liter, compared with background levels, which do not generally exceed 50 milligrams per liter (Barnard 1978).

Watertight buckets have been shown to reduce resuspension of sediments by as much as 50 percent (Barnard 1978). Disadvantages of watertight buckets are that the rubber gaskets used to create the watertight seal may not stand up to continuous use in a full-scale dredging operation and may present compatibility problems with spilled chemicals in certain spill situations.

B.1.1.4 Special Requirements/Considerations

Clamshell dredges can be land-based or mounted on a support vessel, in which case the vessel must be dedicated to the dredging operation. Support vessels or vehicles (barge or truck) must also be available to accept the sediment as it is being dredged and later transport it to the disposal or treatment area. The resuspension of bottom materials may also warrant the use of containment measures, such as curtains or pneumatic barriers, described in Appendix A. Costs associated with clamshell dredging are low relative to other removal techniques.

B.1.2 Draglines

B.1.2.1 Description

Draglines employ the same basic equipment as clamshell dredges and have many of the same applications and limitations. Dragline buckets excavate material as the buckets are pulled by a drag cable toward the crane. Draglines are operated by the same type of crane as clamshell dredges and can be similarly mounted on sea-going vessels or can be operated from land. A 2.5-cubic-yard bucket will excavate approximately 300 cubic yards of loosely compacted material per hour (Church 1981).

Draglines are commonly used in general earthwork applications and are widely available in the United States.

B.1.2.2 Applications

Draglines can be used in the same instances as clamshell dredges (see Section B.1.1.2) with slightly less control of depth and position. However, dragline dredges generally offer a longer reach than clamshell dredges operated by the same crane (Merritt 1976). They are generally used for operations of up to several hundred thousand cubic yards of sediments.

B.1.2.3 Limitations

Draglines generate resuspension of sediment similar to that of clamshell dredges (see Section B.1.1.3). It is not possible to develop a watertight bucket because of the dragline operating characteristics. Draglines also provide relatively low rates of sediment removal.

B.1.2.4 Special Requirements/Considerations

The special requirements and considerations of draglines are the same as those described for clamshell dredges (see Section B.1.1.4). Costs associated with dragline dredging are low relative to other removal techniques.

B.1.3 Conventional Earth Excavation Equipment

B.1.3.1 Description

Backhoes, power shovels, and front-end loaders are sometimes used to remove bottom sediments in certain restricted situations. All three pieces of equipment operate in roughly the same manner; a bucket scoops up the material to be excavated and transfers the material to a vehicle for transportation.

Such excavation equipment is widely available and usually mounted on tracks or rubber tires. Backhoes and power shovels may also be barge-mounted for off-shore applications.

B.1.3.2 Applications

Conventional earth excavation equipment can be used on a limited scale to remove sediments in shallow waterways. Backhoes are normally used for trench and other subsurface excavation and are capable of reaching 40 feet or more below the level of the machine (Merritt 1976; Church 1981). Power shovels are normally used to load rock into hauling units and do not have as long of a reach as backhoes.

Loaders are normally used to excavate loose or soft materials in a narrow vertical range of operation a few feet above and below grade. Operation in shallow water may be practical if sediments are sufficiently loose or soft. Loaders are useful in removing sediments from dewatering portions of water bodies where track-mounting of equipment allows mobility in soft materials. Specially fabricated wide tracks (called "low-earth-pressure" tracks) provide added support and traction under such conditions.

B.1.3.3 Limitations

Conventional earth excavation equipment is greatly limited in removing contaminated sediments from water bodies. Their reach in both the lateral and vertical directions is restricted by the length of the boom to which

the excavation bucket is attached. Therefore, the equipment must be in close proximity to the material being dredged and, in most cases, this is not a practical restriction. Also, because the load bearing capacity of submerged sediments and soils surrounding water bodies is frequently low, it is often difficult or impossible for conventional equipment to maneuver under such conditions. Conventional equipment also provides relatively low rates of sediment removal.

B.1.3.4 Special Requirements/Considerations

Stream diversion and dewatering of the work area are generally needed for conventional earth excavation equipment to reach and maneuver in bottom materials. Stream diversion is discussed under Section B.4, Cofferdams. Other requirements and considerations of conventional earth excavation equipment are the same as those described for clamshell dredges (see Section B.1.1.4). Costs associated with removal of bottom materials by conventional earth excavation equipment are low relative to other removal techniques.

B.1.4 Dipper Dredges

B.1.4.1 Description

Dipper dredges are capable of exerting great mechanical effort and are used in subaqueous excavation of soft rock and dense sedimentary deposits, such as clay and glacial till. Excavation is accomplished by the use of a bucket attached to a long boom, which is forcibly thrust into the material to be removed. Dipper dredges are commonly mounted on flat-bottomed barges or other vessels. Vertical columns called spuds are anchored into the bottom sediments to hold the dredge in position. The swing of the boom limits the lateral range of motion from this fixed position. The dredge vessel is repositioned when dredging within this range is completed. Vertical control is restricted to the depth of the "bite" of the excavating bucket (Hand et al. 1978).

Dipper Bucket capacity is 8 to 12 cubic yards and a production rate of between 30 to 60 cycles per hour is usually achieved. There are about 20 dipper dredges being used nationwide (Hand et al. 1978).

B.1.4.2 Applications

Dipper dredges are capable of exerting great force and are well-suited to excavation of soft rock and highly consolidated sediments. They can achieve good lateral and vertical control and are often used in confined areas where control of position and depth is required to avoid damaging or

undermining marine structures. Dipper dredges are inherently better adapted for working in horizontal rather than vertical planes. They have a working depth of up to 50 feet and are applicable to volumes of up to several hundred thousand cubic yards (Hand et al. 1978).

B.1.4.3 Limitations

The violent mechanical dredging action of the dipper dredge causes considerable turbidity through sediment disturbance during digging and a significant loss of the material from the bucket during the hoisting process. This results in even greater resuspension of sediment than with clamshell dredges and, therefore, dipper dredges are expected to be of limited use in the removal of spilled hazardous materials sinking to the bottom of water courses (Hand et al. 1978). Dipper dredges also provide relatively low rates of sediment removal.

B.1.4.4 Special Requirements/Considerations

Special requirements and considerations of dipper dredges are the same as those described for clamshell dredges (see Section B.1.1.4). Costs associated with dipper dredging are low relatively to other removal techniques.

B.1.5 Bucket Ladder Dredges

B.1.5.1 Description

The dredging action of bucket ladder dredges is provided by an inclined submersible ladder that supports a continuous chain of buckets that rotate around pivots at each end of the ladder. As the buckets rotate around the bottom of the ladder, they scoop up sediment, which is then transported up the ladder and dumped into a storage area as the buckets round the top pivot. Most bucket dredges are mounted on pontoons and are not self-propelled. Bucket ladder dredges can store dredged material on board and can also load barges for transport. Only four of these dredges, all for mining operations, are known to be operating in the United States (Hand et al. 1978).

Production rates are generally higher for bucket ladder dredges than for other mechanical dredges. Bucket volumes range between 0.1 and 1.3 cubic yards and several hundred cubic yards per hour can be excavated under good conditions (calm water, loose sediment, etc.) (Hand et al. 1978).

B.1.5.2 Applications

Bucket ladder dredges are most commonly used aboard in mining operations, such as sand and gravel production. They are capable of handling many different kinds of material, including highly consolidated sediments.

Bucket ladder dredges can handle larger operations than other types of mechanical dredges. Their normal operating depth is approximately 60 feet and some dredges are capable of reaching depths of up to 100 feet (Hand et al. 1978).

B.1.5.3 Limitations

Bucket ladder dredges generate a high degree of resuspension by the continuous mechanical agitation of sediments and bucket leakage. Bucket dredges depend on a great deal of support equipment (tow boats and barges) and are held in place by a complicated configuration of mooring lines, potentially causing obstruction to navigation routes. However, the most limiting factor in using bucket ladder dredges for the removal of contaminated sediments is that they are relatively unavailable in the United States at the present time (Hand et al. 1978).

B.1.5.4 Special Requirements/Considerations

Bucket ladder dredges require a great deal of support equipment for proper operation. They are not self-propelled and must be towed into position. These dredges also require a complicated system of mooring lines to hold them in place and barges are needed to hold and remove the dredged material. Resuspension of bottom materials may also warrant the use of containment measures, such as curtains or pneumatic barriers, described in Appendix B. Costs associated with bucket ladder dredging are medium relative to other removal techniques.

B.2 HYDRAULIC DREDGES

Hydraulic dredges are usually barge-mounted systems that use centrifugal pumps to remove and to transport sediment in liquid slurry form. Pumps may be either barge-mounted or submersible. The suction end of the dredge is mounted on a moveable ladder that may be lowered or raised to a specific dredging depth. Often a cutterhead is fitted to the suction end of the dredge to assist in dislodging bottom materials. Slurries of 10 to 20 percent solids by weight are common in standard hydraulic dredge plants. These slurries may be pumped many thousands of feet through floating or

pontoon-supported pipeline to a dredged material treatment/storage area. The major disadvantage of hydraulic dredges has been the relatively large flow rates associated with pumping at low solids concentrations and the resulting need for large areas of land to serve as settling/dewatering areas for dredged material (see Appendix C). Recent development of hydraulic dredges has emphasized the capability of removing sediments at near in situ solids concentrations, minimizing the water content of the pumped slurry. Lowering the water content for a given volume of sediment reduces the land requirement for sediment dewatering (Hand et al. 1978).

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; thus, they require more extensive pre-dredging work than mechanical dredges.

This section describes the following hydraulic dredging systems: portable dredges, hand-held dredges, plain suction dredges, cutterhead dredges, dustpan dredges, and hopper dredges.

B.2.1 Portable Hydraulic Dredges

B.2.1.1 Description

Portable hydraulic dredges are defined herein as dredge vessels that can be moved easily over existing roadways without major dismantling. The U.S. Army Corps of Engineers Waterways Experiment Station has prepared a "Survey of Portable Hydraulic Dredges" (Clark 1983), which is a compilation of models of portable dredges that are available in the United States and their characteristics, including ratings of "portability." Conventional cutterheads, horizontal cutters, bucket wheels, chain cutters, vertical cutters, and dustpans are available on portable dredges, and dredging capabilities range from 10 to 50 feet. Vessel draft is generally less than 5 feet (many less than 2 feet). Production rates average between 50 to 500 cubic yards per hour depending on model, size, and site conditions (Clark 1983).

Portable hydraulic dredges come in a wide range of sizes. The average dredge is approximately 10 feet wide and from 25 to 50 feet long and can weigh from 6 to 25 tons (Clark 1983). One very small unit designed to pump industrial ponds is 7 1/2 feet wide, 18 to 24 feet long, and weighs only 4,500 pounds.

Methods of launching portable dredges vary and include amphibious/self-launching, launching by crane, launching from transport trailers, and launching at boat ramps from transport trailers. Most portable dredges are positioned and tracked using cable-and-winch arrangement anchored on land.

weight is drawn in through the dredge head and is transported up the suction line to be discharged into a scow or through a pipeline for treatment. The production rate is dependent upon the pump size, pump horsepower, and type of material being dredged. During normal working conditions, dredging is performed at 1,000 to 10,000 cubic yards per hour, depending on discharge velocity and pipe diameter (Hand et al. 1978).

Plain suction dredges are normally pulled along a straight line fixed by a cable-and-winch arrangement anchored on land or on the bottom of the water body. The dredge vessel moves along the line of the cable and the cable is repositioned to establish a new line as dredging progresses. There is no capability of lateral manipulation beyond the positioning and movement of the dredge vessel. Vertical control of sediment removal is maintained by raising and lowering the suction pipe and dredge head supporting ladder using a cable-and-winch arrangement. Vessel draft is on the order of 5 to 6 feet (Hand et al. 1978).

There are approximately 20 plain suction dredges in operation nationwide, all located on interior waterways (Hand et al. 1978).

B.2.3.2 Applications

Plain suction dredges are most effective in the removal of relatively free-flowing sediments, such as sands, gravels, and unconsolidated material. They are commonly used for sand mining, beach restoration, general river channel maintenance, and scow unloading. They can be used in relatively shallow waters and are best suited to relatively calm inland waterways (Hand et al. 1978).

B.2.3.3 Limitations

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. These dredges cannot generally be employed in rough waters (i.e., waves greater than 3 feet). The anchoring cables and pipelines can cause obstructions to river traffic. The suction line is also subject to blockage or damage by underwater debris.

B.2.3.4 Special Requirements/Considerations

As with all hydraulic dredging methods, the dredged slurry must be pumped through a pipeline to a dewatering or other treatment facility (see Appendix C). Resuspension of bottom materials may also warrant the use of containment measures, such as curtains or pneumatic barriers, described in

Appendix A. Costs associated with plain suction dredging are medium relative to other removal techniques.

B.2.4 Cutterhead Dredges

B.2.4.1 Description

The configuration and principle of operation of the cutterhead dredge are similar to those of the plain suction dredge; however, a mechanical device is added to dislodge material. The device, called 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 of 10 to 20 percent solids by weight are typically achieved, depending upon the material being dredged. Production rates vary according to pump size and can be as large as 2,500 cubic yards per hours. Cutterhead dredges range from 50 to 225 feet in length and can weigh up to 350 tons. Vessel draft is between 3 and 5 feet (Hand et al. 1978).

Cutterhead dredges move in a pattern different from other hydraulic dredges by alternately anchoring on one of two spuds. The anchored spud is used as a pivot and the vessel is drawn along an anchored cable, swinging the cutterhead in a short horizontal arc about the spud. Repeatedly swinging the cutterhead in arcs while alternating anchored spuds results in partially overlapping cuts, which form a wide effective cut through the area being dredged.

Cutterhead dredges are among the most popular in the world for maintenance dredging because of their versatility and ability to make uniform cuts. They are also the most commonly used maintenance dredge in the United States and approximately 300 are in use nationwide (Hand et al. 1978).

B.2.4.2 Applications

Cutterhead dredges are highly efficient in removing all types of materials, including very hard and cohesive sediments. They are capable of reaching materials up to 50 feet below the water surface. Cutterhead dredges are best used in calmer waters, but because of their large size and self-propulsion, they are better able to operate in rough waters than the smaller portable dredges or plain suction dredges (Hand et al. 1978).

B.2.4.3 Limitations

Cutterhead dredges are not capable of removing bottom sediments at depths greater than 50 feet below the water surface because of the length

of the dredge ladder that supports the cutterhead. The dredge vessel cannot operate in water depths of less than 5 feet (Hand et al. 1978).

The cutterhead and suction line are susceptible to debris damage, which can hinder the removal of bottom materials. In addition, infestations of aquatic weeds may obstruct dredging and cause further delays due to both reduced cutterhead mobility and dredge pump clogging.

The cutting and grinding action of the cutterhead presents a potential problem with resuspension of sediment. A properly designed cutterhead will efficiently cut and guide the bottom material toward the suction, although the cutting action and the turbulence associated with the rotation of the cutterhead can resuspend a portion of the bottom material (Raymond 1983).

B.2.4.4 Special Requirements/Considerations

The dredging site must be cleared of debris and weeds prior to commencement of dredging in order to prevent malfunction of the cutterhead. This may require the use of cranes, clamshells, or divers.

As with all hydraulic dredging methods, the dredged slurry must be pumped through a pipeline to a dewatering or other treatment facility (see Appendix C). Resuspension of bottom materials may also warrant the use of containment measures, such as curtains or pneumatic barriers, described in Appendix A. Costs associated with cutterhead dredging are medium relative to other removal techniques.

B.2.5 Dustpan Dredges

B.2.5.1 Description

Dustpan dredges are similar in configuration and operation to plain suction dredges. The sediment collection head, called a "dustpan", is a widely flared head containing high-pressure water jets that loosen and agitate sediments; the sediments are then captured in the dustpan as the dredge is winched forward into the bottom materials. This high-pressure jetting slightly improves efficiency (in terms of slurry density) and allows cohesive sediments to be dredged (Hand et al. 1978).

The collected sediments are conveyed by suction into the suction pipe. Slurries of 10 to 20 percent solids by weight are typically achieved. Production rates range between 500 to 15,000 cubic yards per hour, depending on the discharge pipe diameter and the discharge velocity. Vessel draft varies between 5 to 14 feet (Hand et al. 1978).

There are about 10 dustpan dredges in the United States, all owned by the U.S. Army Corps of Engineers. They are used primarily for channel maintenance in interior waterways (Hand et al. 1978).

B.2.5.2 Applications

Dustpan dredges are best suited for dredging free-flowing granular bottom material, but will also dredge cohesive sediments. They are used primarily in calmer interior waterways with depths up to 50 feet. The vessels can operate in waters deeper than 14 feet, and some can be operated in shallow waters (Hand et al. 1978).

B.2.5.3 Limitations

Dustpan dredges are not capable of removing sediment at depths greater than 50 feet below the water surface because of the length of the dredge ladder that supports the dustpan. The dredge vessel cannot operate in water depths of less than 5 feet (Hand et al. 1978).

The jetting action of the dustpan dredge will cause resuspension of bottom materials comparable to the cutterhead dredge (Raymond 1983). The dustpan head is also susceptible to clogging and damage by bottom debris.

B.2.5.4 Special Requirements/Considerations

The dredging site should be cleared of underwater debris to prevent blockages within the dredge head, pump, and pipeline. As with all hydraulic dredging methods, the dredged slurry must be pumped through a pipeline to a dewatering or other treatment facility (see Appendix C). Resuspension of bottom materials may also warrant the use of containment measures, such as curtains or pneumatic barriers, described in Appendix A. Costs associated with removal of bottom materials by dustpan dredges are medium relative to other removal techniques.

B.2.6 Hopper Dredges

B.2.6.1 Description

Hopper dredges differ from other hydraulic dredges primarily in the type of vessel used and the methods of attachment and operation of the dredge head. Hopper dredge vessels are normally large, self-propelled, sea-going vessels, rather than barges. Vessel drafts range from 12 to 31 feet.

The vessels can operate in waves up to 7 feet. Hopper dredges are positioned and moved by the propeller/rudder navigating equipment of the host vessel and can travel at speeds up to 8 miles per hour while dredging. Production rates normally range between 500 to 2,000 cubic yards per hour (Hand et al. 1978).

Suction pipes are hinged on either side of the vessel and extend downward toward the stern of the vessel. Dredge heads, attached at the ends of the suction pipes, drag along the bed of the area being dredged as the vessel moves forward; the head is sometimes called a "trailing" head for this reason. Dredging is accomplished by the vessel making progressive passes over the project area.

Dredged material is transported up the suction pipe and is discharged for storage into a hopper portion of the vessel. Coarse-grained material settles to the bottom of the hopper. Water and fine-grained sediment is normally allowed to overflow the hopper into the water body; overflow would usually not be acceptable in the removal of contaminated sediments. Once fully loaded, the vessel moves to an unloading area where the hopper is emptied by opening bottom doors or by pumping the contents to a treatment or disposal area. There are 15 oceangoing, trailing, suction hopper dredges operated by the U.S. Army Corps of Engineers, and there are several privately owned hopper dredges in the United States. These dredges are located primarily on coastal waters and in the Great Lakes region (Hand et al. 1978).

B.2.6.2 Applications

Hopper dredges are intended for large-scale maintenance dredging of deep, rough-water shipping channels, and are normally most efficient in excavating loose, non-cohesive materials. Bottom materials can be dredged to depths of 62 feet. Hopper dredges are capable of operating in rough, open waters, in relatively high currents, in and around marine shipping traffic, and in adverse weather conditions (Hand et al. 1978).

B.2.6.3 Limitations

Hopper dredges cause resuspension of bottom materials into the water column; this is primarily caused by hopper overflow in the near-surface water and by draghead agitation in near-bottom water. Hopper dredges cannot be used in inland shallow waters because of the large vessel size and draft. Because conventional hopper dredge operating methods (hopper overflow and open-water disposal of dredged material) are not normally acceptable for hazardous materials, continuous or periodic removal of dredged material must be accomplished by frequent trips to an unloading area, pumping to a treatment facility, or pumping to transport vessels.

B.2.6.4 Special Requirements/Considerations

Hopper dredges are self-contained vessels and, under normal operating conditions, require no support equipment. However, support equipment, such as hauling vessels, transport pipelines, and pump-out dredges, may be needed for containing and transporting contaminated materials to a dewatering or other treatment facility (see Appendix C). The resuspension of bottom materials may also warrant the use of containment measures, such as curtains or pneumatic barriers, described in Appendix A. Costs associated with removal of bottom materials by hopper dredges are high relative to other removal techniques.

B.3 PNEUMATIC DREDGES

Pneumatic dredges are a special category of hydraulic dredge that use compressed air and/or hydrostatic pressure instead of centrifugal force to draw sediments to the collection head and through the transport piping. Pneumatic dredges are commonly barge-mounted. Dredged material is normally discharged to hopper barges or scows.

Pneumatic dredges generally produce slurries of higher solids concentration than hydraulic dredges and cause less resuspension of bottom materials. They are capable of dredging both solids and liquids.

B.3.1 Airlift Dredges

B.3.1.1 Description

Airlift dredges use 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 that carry both water and sediment up the pipe. The applied air pressure must be sufficient to overcome water 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 that can be vibrated or rotated to dislodge more cohesive sediments. Lateral control of the dredge is achieved by swinging the boom of the crane in a manner similar to mechanical dredging. Vertical control is achieved by raising and lowering the open end of the vertical transport pipe and by varying the pressure of the air released at the end of the pipe (Hand et al. 1978).

Dredged material is usually discharged from the airlift pipe (which includes elbows or flexible pipe for changes in direction) into a hopper barge or scow. The material is then transported in the barge or by

pumping through a pipeline to a treatment or disposal area. Slurries of 25 percent solids can typically be achieved with airlift dredges (d'Angremond et al. 1978).

Airlift dredges are usually operated from barges with drafts between 3 and 6 feet, although other vessels can be used. Barges are normally not well suited for rough, open waters. Airlift dredges are not widely used in the United States.

B.3.1.2 Applications

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.

B.3.1.3 Limitations

Airlift dredges cannot dredge cohesive bottom materials because the agitation of the released air is the primary means of dislodging the material.

B.3.1.4 Special Requirements/Considerations

Airlift dredges require barges, pipelines, and/or pump-out capabilities for containing and transporting contaminated materials to a dewatering or other treatment facility (see Appendix C). The resuspension of bottom materials may also warrant the use of containment measures such as curtains or pneumatic barriers, described in Appendix A. Costs associated with airlift dredging are medium relative to other removal techniques.

B.3.2 Pneuma Dredges

B.3.2.1 Description

The "Pneuma" (trade name) dredging system consists of a pneumatic pump that is lowered by a barge-mounted crane to contact the sediments being dredged. The pump is driven by an air compressor and operates by positive displacement. The body of the pump contains three cylindrical vessels, each with an intake opening on the bottom and an air port and discharge outlet on top. The air ports can be opened to the atmosphere through air hoses and valves. The cylinders are filled with sediment and water when

the intake opening is open and water pressure causes bottom materials to flow into the vessels. The opening is closed when the vessel is filled. The vessel is emptied by the application of compressed air to force the contents into a discharge line. Using this process, the Pneuma system can dredge bottom materials at near in situ densities with a minimum intake of water (Richardson et al. 1982; Toa Harbor Works undated). Pneuma dredges are capable of discharging directly to disposal or treatment areas through a discharge pipeline.

Pneuma dredges are normally suspended from a crane cable and pulled into the sediments being dredged by a second cable. The dredging head is scoop-shaped and produces relatively little sediment resuspension (i.e., only slightly greater than normal operating background levels). The dredge head is fixed relative to the vessel so that lateral manipulation is limited to the positioning and movement of the vessel. The dredge head can weigh from 3 to 15 tons and the dredges may be as large as 12 feet by 12 feet, but are readily dismantled and transported by truck or air (Richardson et al. 1982).

Pneuma dredges have limited availability in the United States and are available only through distributors authorized by the Japanese manufacturer.

B.3.2.2 Applications

Pneuma dredges do not contain devices for breaking up consolidated material and are most applicable to loosely packed sediment. Shovel attachments are available to aid in the penetration of sediments. Extremely deep applications are possible, provided that sufficient discharge line, air line, air pressure, and dredging control can be provided.

B.3.2.3 Limitations

Pneuma dredges cannot be effectively used in shallow water because of their dependence on water depth for the differential pressure that induces flow. Pipelines and cables may present temporary obstructions in navigable water channels.

B.3.2.4 Special Requirements/Considerations

Pneuma dredges require a great deal of support equipment, such as air distributors and compressors, to control the cycling of the three pump chambers and to provide pressure for emptying the chambers. Booster pumps may be required for pipeline transport of dredged material to treatment and disposal facilities. Costs associated with removal of bottom materials by Pneuma dredges are high relative to other removal techniques.

B.3.3 Oozer Dredges

B.3.3.1 Description

"Oozer" (trade name) dredges, developed in Japan, are pumps similar in concept to the Pneuma. Ooozer dredges use negative (vacuum) pressure in filling the chambers in addition to the pressure difference between water pressure at the depth of operation and atmospheric pressure, which drives the Pneuma dredge. This allows dredging in more shallow waterways (Barnard 1978).

The pump is usually mounted at the end of a ladder. The pump body consists of two cylinders to which a vacuum is applied to increase the differential pressure and induce the flow between the sediment and cylinders. Discharge is accomplished by positive air pressure, similar to the Pneuma dredge (see Section B.3.2). Sediment thickness detectors, underwater television cameras, and a turbidimeter are attached near the suction mouth for monitoring turbidity. Suspended oil can be collected by an attached hood and cutters can be attached for dislodging hard soils (Barnard 1978; Toyo Construction Co. undated).

Oozer dredges are capable of pumping slurries of 30 to 70 percent solids (near *in situ* densities) at rates of 500 to 800 cubic yards per hour, while keeping resuspension of sediments low (Barnard 1978). Dredged material is normally discharged to a hopper barge or a scow.

Oozer dredges have no capability of lateral manipulation beyond the positioning and movement of the dredge vessel. Vertical control of sediment removal is maintained by raising and lowering the suction pipe and the dredge head supporting the ladder using a cable-and-winch arrangement.

Oozer dredges are manufactured in Japan and have limited availability in the United States through authorized distributors.

B.3.3.2 Applications

Oozer dredges are designed for effective suction of soft sediments from riverbeds or harbor bottoms. The use of vacuum pressure allows Oozer dredges to dredge in shallower waters than the Pneuma system.

B.3.3.3 Limitations

Oozer dredges are capable of only modest production rates compared to hydraulic dredges. They also require cables for movement and anchoring, which can obstruct navigation traffic. Availability of the Oozer dredge is

extremely limited and its use in rapid response situations may not be practical because of the logistics of mobilization.

B.3.3.4 Special Requirements/Considerations

Oozer dredges generally require the support of hopper barges for discharge of dredged material and transport to a treatment or disposal facility. Costs associated with removal of bottom materials by Oozer dredges are high relative to other removal techniques.

B.4 SUMMARY

Table B-1 provides a summary of information presented in this appendix for each of the dredges. This summary can be used to compare and screen dredges for specific applications.

TABLE B-1. SUMMARY OF CONTAMINATED MATERIAL REMOVAL TECHNIQUES

Technique	Applications	Limitations	Secondary Impacts	Availability/ Transportability	Vessel Length/Draft (Feet)	Production (yd^3/hr)	Maxium Depth of Use (Feet)	Relative Cost
MECHANICAL DREDGES								
Clamshell	Small volumes of sediments; confined areas and near structures; removal of bottom debris; nonconsolidated sediments; interior waterways, harbors	Low production rates; cannot excavate highly consolidated sediments or solid rock	Considerable resuspension of sediments	Dredge head can be moved over existing roads as-is and mounted on conventional crane; widely available	Depends on support vessel	30-600	100	Low
Dragline	Small volumes of sediments; confined areas; non-consolidated sediments, harbors, and interior waterways	Low production rates; cannot excavate highly consolidated sediments or solid rock	Considerable resuspension of sediments	Dredge head can be moved over existing roads as-is and mounted on conventional crane; widely available	Depends on support vessel	60-700	100	Low
Conventional Excavation Equipment	Small volumes of sediments in shallow or dewatered areas	Restricted capacities and reach; limited to very shallow water depths	Considerable resuspension of sediments	Can be moved over existing roads; widely available	Highly variable	Up to 600	30	Low
Dipper	Small volumes of sediments; up to highly consolidated sediments, confined areas; harbors and interior waterways	Low production rates	Considerable resuspension of sediments	Not easily transported over roads; limited availability	Depends on support vessel	30-600	50	Low
Bucket Ladder	Small volumes of sediments; up to highly consolidated sediments; interior waterways	Low production rates	Considerable resuspension of sediments	Not easily transported over roads; very limited availability	100/5	300	60	Medium

(continued)

TABLE B-1. (continued)

Technique	Applications	Limitations	Secondary Impacts	Availability/ Transportability	Vessel Length/Draft (Feet)	Production (yd^3/hr)	Maximum Depth of Use (Feet)	Relative Cost
HYDRAULIC DREDGES								
Portable Hydraulic	Moderate volumes of sediments; lakes and inland rivers; very shallow depths	Limited to waves of less than one foot; depending on model, have low production rates and limited depth	Moderate resuspension of sediments	Readily moved over existing roads, may require some disassembling; widely available	25-50/2-5	50-1850	50	Low
Hand-held Hydraulic	Small volumes of solids or liquids in calm waters; for precision dredging	Operated from above water units only in shallow waters; under-water units require diver operation	Moderate resuspension of sediments	Easily moved over existing roads; can be assembled using commonly available equipment	N/A	10-250	1000	Low
Plain Suction	Large volumes of free-flowing sediments and liquids; shallow waters and interior waterways	Dredged material is 80-90% water; cannot operate in rough, open waters; susceptible to debris damage; can cause traffic disruption	Moderate resuspension of sediments	Transport in navigable waters only; only 20 in use in the United States	100/5-6	25-10,000	60	Medium
Cutterhead	Large volumes of solids and liquids; up to very hard and cohesive sediments; calm waters	Dredged material is 80-90% water; cannot operate in rough, open waters; susceptible to debris damage and weed clogging	Moderate resuspension of sediments	Transport in navigable waters only; wide availability	50-250/3-14	25-10,000	50	Medium
Dustpan	Large volumes of free-flowing sediments and liquids; calm, interior waterways	Dredged material is 80-90% water; cannot operate in rough, open waters; susceptible to debris damage	Moderate resuspension of sediments	Transport in navigable waters only; only about 10 in use in the United States	100/5-14	25-10,000	60	Medium

(continued)

N/A - Not Applicable

TABLE B-1. (continued)

Technique	Applications	Limitations	Secondary Impacts	Availability/ Transportability	Vessel Length/Draft (Feet)	Production (yd^3/hr)	Maximum Depth of Use (Feet)	Relative Cost
Hopper	Solids and liquids in deep harbors; rough, open water; high currents; adverse weather; in and around shipping traffic	Not for highly consolidated sediments	Moderate resuspension of sediments; normal operation involves large overflow of dredged material	Can be moved only in deep waters; only about 20 in use in the United States	200+/12-31	500-2,000	65	High
PNEUMATIC DREDGES								
Airlift	Deep dredging of loose sediment and liquids; for use in interior waters	Not for consolidated sediments; dredged material is 75% water	Resuspension of sediment is low	Dredge head can be moved over existing roads; not widely available in the United States	100/3-6	60-390	None	Medium
Pneuma	Nonconsolidated solids and liquids in interior waterways	Not for consolidated sediments; not for shallow waters; may cause obstruction to water traffic	Resuspension of sediment is low	Dredge head can be moved over existing roads; not widely available in the United States	100/5-6	60-390	150	High
Oozer	Soft sediments and liquids from river beds or harbor bottoms; relatively shallow depths	Modest production rates; may cause obstruction to traffic	Resuspension of sediment is low	Dredge head can be moved over existing roads; not widely available in the United States	120/7	500-800	None	High

APPENDIX C

TREATMENT TECHNIQUES FOR REMOVED CONTAMINATED MATERIALS

This appendix addresses methods and equipment used for treatment of contaminated bottom materials that have been removed from water bodies. Figure C-1 shows the major activities that are typically undertaken in treating contaminated bottom materials and indicates the subsections under which each of these activities is addressed. The major steps in sediment treatment include:

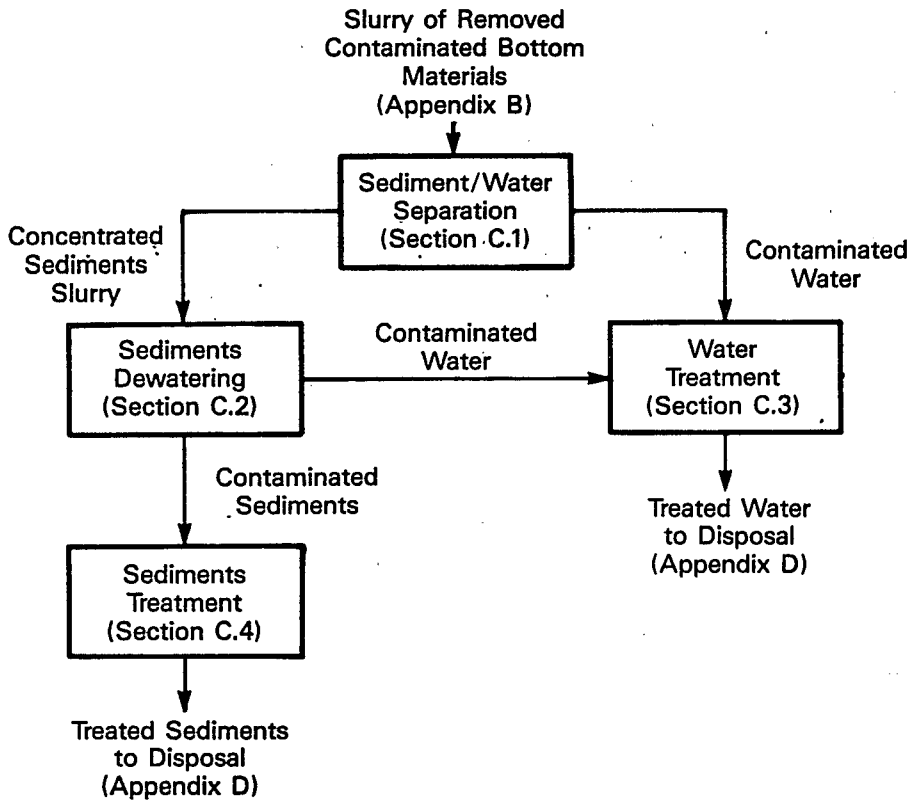
- Sediment/water separation - separates the solids from the dredged material slurry and results in a contaminated water stream and a concentrated slurry, either of which may require further treatment (Section C.1).
- Sediment dewatering - further concentrates solids by removing water in order to facilitate subsequent treatment, handling, and disposal (Section C.2).
- Solids treatment - degrades, immobilizes, extracts, or encapsulates contaminated solids in order to make them acceptable for final disposal (Section C.3).
- Water treatment - degrades or removes dissolved or suspended contaminants to produce an effluent suitable for disposal (Section C.4).

The methods used to treat contaminated bottom materials have been adapted from methods used in a variety of industries. However, experience in treating contaminated sediments with these methods has been limited and performance must be evalauated on a case-by-case basis. This appendix presents an overview of potentially applicable treatment techniques. It is intended to assist in the selection of treatment techniques and is not intended for use as a source of design information. Also, when combining treatment techniques in series to accomplish desired treatment, care should be exercised to assure hydraulic (pressure and flow) compatability of the techniques.

C.1 SEDIMENT/WATER SEPARATION

This section describes equipment and methods used to separate solids from dredge slurries. The objective of sediment/water separation is to

FIGURE C-1. TYPICAL SEQUENCE OF STEPS FOR TREATMENT OF REMOVED CONTAMINATED BOTTOM MATERIALS



attain two distinct waste streams: a liquid waste stream that can be subsequently treated for removal of dissolved and fine suspended contaminants and a concentrated slurry of solids and minimal liquid that can be dewatered and treated.

Sediment/water separation techniques can also be used to selectively remove a relatively narrow range of grain sizes from a slurry, effectively separating one sediment grain size from another. Classification of sediments according to grain size may be undertaken for one of two reasons: 1) economy of space and equipment use, and 2) concentration of contaminants into a relatively small mass of sediments. More efficient use can be made of equipment and land area by taking advantage of the differences in settling velocity of different sized particles. For example, where limited land space is available, sand and gravel may be removed in settling basins, and high-rate gravity settlers could be used to remove fine-grained particles.

There is also evidence to suggest that classification by grain size can be useful in managing contaminated sediments because of the apparent tendency of contaminants to adsorb preferentially onto fine-grained sediments such as clay and organic matter. The separation of sediments by grain size and level of contamination could prove to be extremely beneficial to the overall management (treatment, transport, and disposal) of contaminated dredged material. Sediments exhibiting low-level contamination may be disposed of in sanitary landfills or returned to the water body, whereas highly contaminated sediments must be disposed of in hazardous waste landfills, incinerated, or treated to render them non-hazardous.

Sediment/water separation techniques consist of settling basins, conventional clarifiers, high-rate clarifiers, hydraulic classifiers, granular media filters, and hydrocyclones. An overview of each is presented in the following sections.

C.1.1 Impoundment Settling Basins

C.1.1.1 Description

A settling basin is an impoundment, basin, or other container that provides conditions to allow suspended particles to settle by gravity, or sedimentation. A slurry of dredged material is introduced at one end of the basin and settling of solids occurs as the slurry slowly flows across the length of the basin. The flow resulting at the opposite end of the basin has a greatly reduced solids content. Particles settle according to their settling velocity, which varies according to a particle's diameter and specific gravity.

In practice, settling basins are designed to retain particles of a selected diameter and larger in order to limit settling basins to practical sizes. The basin surface area, detention time, and rate at which the

dredged material is delivered to the basin are factors that determine the degree of solids removal that can be achieved.

Settled solids accumulate on the bottom of settling basins where they are temporarily stored. As the volume of accumulated solids increases, the effective size of the basin decreases, reducing the basin's effectiveness or efficiency. Accumulated solids must be periodically or continuously removed by scrapers or dredges in order for the basin to perform as intended.

Impoundment basins are most commonly used in dredging applications. An impoundment basin is an earthen impoundment or diked area that is lined in a manner that is appropriate for protecting underlying groundwater. The overflow rate in the basin is controlled by an adjustable weir. Bulkheads that separate a single basin into compartments or smaller individual basins, can be used to allow continuous sediment/water separation while accumulated solids are being removed from the individual basins.

C.1.1.2 Applications

Impoundment basins are used to remove particles in the size range of gravel down to fine silt (10 to 29 microns) (Mallory and Nawrocki 1974). They are also used to provide temporary storage of material and to classify sediment particles according to grain size. This can be accomplished by providing multiple separation basins connected in series, each of which is designed to retain sediments of successively smaller grain sizes in the downstream direction of flow.

Impoundment basins are particularly well suited for large-scale dredging operations, provided there is adequate land space available for their construction.

C.1.1.3 Limitations

Flocculants must be used to achieve removal of particles less than 30 microns in size and no removal can be achieved for particles less than 10 microns. Impoundment basins are not suitable at locations where insufficient land space is available for their construction or where adequate measures cannot be taken to protect groundwater (e.g., high water table).

C.1.1.4 Special Requirements/Consideration

Influent to an impoundment basin is introduced to the system through a "scalping" box, with widely spaced inclined screen bars to remove large debris. The slurry can also be fed through a rock box, which can be designed with a submerged outlet to permit skimming and removal of floating materials

and to decrease the velocity of the slurry before it enters the basin (Mallory and Nawrocki 1974).

Flocculants are required to remove particles less than 30 microns in diameter. Chemical feed pumps, mixing equipment, and storage tanks are required to support flocculation.

Accumulated solids are usually removed using secondary dredges or mechanical scrapers. Small hydraulic dredges, clamshell dredges, and dragline dredges are commonly used for this purpose (see Appendix B).

Adequate land space must be available for construction of impoundment basins and appropriate permits must be obtained for their construction. Measures must also be taken to protect underlying groundwater. The extent of these measures is determined on a site-specific basis and should comply with the intent of RCRA regulations governing the design and operation of impoundments (40 CFR Part 264.221-222). This requires that the impoundment be lined in such a way that contaminants will not leach into the underlying soils or groundwater. Compliance with the intent of RCRA may require use of a double liner system and a leak detection system to detect migration of contaminants to the space between the liners.

C.1.2 Conventional Clarifiers

C.1.2.1 Description

Conventional clarifiers are settling basins that are commonly used in the treatment of domestic sewage and industrial wastewater. Pre-fabricated clarifiers can be made of steel or fiberglass, and large concrete clarifiers are normally cast in place. Typically, a flow with relatively high suspended solids is introduced at one end of the clarifier, solids settle along the length of flow, and a flow with relatively low suspended solids leaves the clarifier through trough-type overflow weirs. Some clarifiers introduce inflow at the center of a cylindrical basin, and flow occurs radically outward to overflow weirs around the perimeter of the basin. Clarifiers are typically equipped with built-in solids collection and removal mechanisms that continuously remove accumulated solids, allowing continuous operation of the clarifier. Many clarifiers are equipped with separate zones for chemical mixing and precipitation, flocculation, and settling (DeRenzo 1978).

Clarifiers are able to remove particles down to 10 to 20 microns (Mallory and Nawrocki 1974) in diameter with the use of flocculants. They are also able to produce a thickened sludge with a solids concentration of about 4 to 12 percent (Metcalf and Eddy 1979).

C.1.2.2 Applications

Conventional clarifiers are best suited to small- to moderate-scale cleanup operations, but can be applied to large-scale operations where construction of earthen impoundment basins will not adequately protect groundwater.

C.1.2.3 Limitations

Clarifiers are not capable of removing solids with a diameter of less than about 10 to 20 microns. They are not suitable for locations with severe space limitations.

C.1.2.4 Special Requirements/Considerations

Chemical conditioning, including chemical feed pumps, mixing equipment and storage tanks, are required to remove particles smaller than 10 microns. Clarifiers with capacities greater than 0.1 mgd must be disassembled for transport to a cleanup site.

C.1.3 High-Rate Clarifiers

C.1.3.1 Description

High-rate clarifiers use multiple "stacked" plates, tubes, or trays to increase the effective settling surface area of the clarifier and decrease the actual surface area needed to effect settling. High-rate clarifiers allow a higher flow rate per unit of actual surface area (loading rate) than do conventional clarifiers, thus the name "high-rate" clarifiers. The trays, plates, or tubes also induce optimum hydraulic characteristics for sedimentation by guiding the flow, reducing short circuiting, and promoting better velocity distribution.

High-rate clarifiers are able to handle between 2 and 10 times the loading rate of conventional clarifiers and therefore require limited land use (Jones, Williams, and Moore 1978). Package units capable of handling 1,000 to 2,000 gpm are available and are easily transported by truck or barge.

C.1.3.2 Applications

High-rate clarifiers are best suited to small- to moderate-scale cleanup operations and to large-scale operations where construction of earthen impoundments will not adequately protect groundwater. High-rate clarifiers are particularly applicable to cleanup operations where land use is limited.

C.1.3.4 Limitations

High-rate clarifiers are not suitable for removal of particles larger than 0.1 inch or less than 10 microns. Use of high-rate clarifiers has not been demonstrated for applications in sediment/water separation; they are generally used in applications with lower solids concentrations (Mallory and Nawrocki 1974). There is also the possibility that cohesive sediments may clog the channels, tubes, or plates (Jones, Williams and Moore 1978).

C.1.3.4 Special Requirements/Considerations

High-rate clarifiers require prescreening to remove debris. Chemical conditioning is required to remove particles of 30 microns or smaller and, for these applications, chemical feed pumps, mixing equipment, and storage tanks are required.

C.1.4 Hydraulic Classifiers

C.1.2.1 Description

Hydraulic classifiers are commonly used to separate sand and gravel from slurries and classify them according to grain size. These units consist of elevated rectangular tanks with V-shaped bottom hoppers that collect various particle sizes along the length of the tank. Slurry is introduced into the feed end of the tank. As the slurry flows to the opposite end, solids settle to the bottom. Because of differences in settling rates of different grain sizes, each hopper collects a progressively smaller range of grain size along the tank length. Motor-driven vanes are used to sense the level of solids and activate discharge valves as the solids accumulate in each hopper. Manually adjusted splitter gates below the discharge valves can be used to selectively direct each range of grain size to subsequent handling and treatment (Eagle 1981; Mallory and Nawrocki 1974).

Classifying tanks normally have widths of 8 to 12 feet and lengths of 20 to 48 feet. The solids-handling capabilities are generally limited to

250 to 300 tons per hour. The heaviest loading generally occurs at the inflow end of the tank where the larger particles drop out (Mallory and Nawrocki 1974).

For conditions of high flow or high solids concentration, several classifiers may be required. A single classifier with dimensions of 48 feet by 12 feet can typically handle the following flow rates depending upon material grain size: 8000 gpm for 100 mesh material (149 microns); 4200 gpm for 150 mesh (105 microns), and 2150 gpm for 200 mesh (74 microns).

C.1.4.2 Applications

Hydraulic classifiers are used to remove sand and gravel size particles (approximately 74 to 149 microns) from slurries and for classifying the removed materials according to particle size. They are well suited to applications where separation of sand and gravel is desired to allow different handling, treatment, and disposal methods for the separated fractions.

C.1.4.3 Limitations

Hydraulic classifiers are not suitable for removing particles larger than about 0.1 inch (fine gravel) or smaller than 74 microns (fine sand) (Mallory and Nawrocki 1974). They have a low solids handling capacity and are not well suited for handling large volume of high solids concentrations. They are not capable of producing sharp size classification. Screens also tend to dissipate the energy and reduce the velocity of the inflowing slurry (Mallory and Nawrocki 1974).

C.1.4.4 Special Requirements/Considerations

Before hydraulic scalping and classifying can be used, it is necessary to remove particles greater than about 0.1 inch in diameter. Bar screens and vibrating screens are generally used for this purpose.

Spiral classifiers are frequently used together with hydraulic classifiers. The spiral classifier consists of one or two long rotating screws mounted on an incline within a rectangularly shaped tube and is used primarily to wash any adhering clay or silt from sand and gravel fractions (Mallory and Nawrocki 1974). Portable systems that incorporate hydraulic and spiral classifiers are available.

Where multiple hydraulic classifiers are needed, splitter tanks can be used to distribute the flow to the units and cross flumes to collect the solids from the regular flumes. This permits use of a smaller number of large capacity spiral classifiers.

C.1.5 Granular Media Filters

C.1.5.1 Description

Filtration is a physical process whereby suspended solids are removed from suspension by forcing the fluid through a permeable medium. Granular media filtration is typically used for treating liquid waste streams. The filter media consist of a bed of one or more sizes of granular particles (typically sand or sand with anthracite coal). The bed is contained within a basin and is supported by an underdrain system that allows the filtered liquid to be drawn off while the filter media remains in place. As water laden with suspended solids passes through the bed of filter media, the particles become trapped on top of and within the bed. This reduces the filtration rate and, in order to prevent plugging, the filter is back-flushed at high velocity to dislodge the particles. The backwash water contains high concentrations of solids and requires further treatment (DeRenzo 1978).

Granular media filters are usually operated at a throughput rate of 2 to 6 gpm per square foot of filter media.

Filtration equipment is relatively simple, readily available in a wide range of sizes, and easy to operate and control.

C.1.5.2 Applications

Granular media filters are most applicable to liquid streams containing less than 100 to 200 mg/l suspended solids. They are normally used after the use of other techniques that remove settleable solids and for treatment of drinking water. The suspended solids concentration of the filtered effluent depends a great deal on particle size distribution, but typically, granular media filters are capable of producing a filtered liquid with suspended solids concentrations as low as 1 to 10 mg/l.

Because of its small space requirements and relatively simple operation, filtration is well suited to mobile treatment systems as well as on-site construction. There is extensive experience with the operation of granular media filters at hazardous waste sites.

C.1.5.3 Limitations

Granular media filtration is not well suited for treating liquid waste streams with suspended solids levels in excess of about 200 mg/l. It is also not suitable for treating colloidal size particles unless they can first be

flocculated. Because granular media filters must be backwashed to remove accumulated solids, they cannot be used continuously. Treatment either must be interrupted or multiple filters must be used to maintain continuous treatment.

C.1.5.4 Special Requirements/Considerations

Settling, or sedimentation, is commonly used to reduce suspended solids levels prior to filtration. Suspended solids concentrations greater than about 200 mg/l may result in excessively frequent backwashing of the filter media. Backwash water is generally 1 to 4 percent of the original volume of contaminated water filtered (DeRenzo 1978). The backwash may contain high concentrations of contaminants and require subsequent treatment. In some cases, flocculants can be used to increase the effective particle size of colloids and to improve the effectiveness of filtration.

C.1.6 Hydrocyclones

C.1.4.1 Description

The hydrocyclone, or simply cyclone, consists of a cylindrical/conical shell with a tangential inlet for feed and outlets for the separated streams. Cyclones contain no moving parts. The process stream is fed to the unit with sufficient velocity to create a "vortex" action that forces the slurry into a spiral and, as the rapidly rotating liquid spins about the axis of the cone, it is forced to spiral inward and then out through a centrally located overflow outlet. Larger and heavier particles of solids are forced outward against the wall of the cone by centrifugal force within the vortex. The solids spiral around the wall of the cyclone and exit through the apex at the bottom of the cone. Smaller particles remain suspended in the liquid as it spirals inward and is discharged (Dorr-Oliver undated).

Cyclones are available in a wide range of sizes. Units are available that can handle flows of only a few gallons per minute and large cyclones can handle flows of 2000 to 7000 gpm depending upon slurry composition (Dorr-Oliver undated; Krebs Engineers undated). However, cyclones do not "scale up" as many other equipment items do. Smaller, lower-capacity cyclones are capable of removing smaller solids from slurries. In order to remove small particles from slurries with high flow rates, multiple cyclones can be used in parallel. Banks of multiple cyclones, manufactured as a single unit with a single feed pipe, are commercially available. A high degree of particle size separation can also be achieved by employing a bank of cyclones in series, with decreasing cyclone size and particle size removal in the direction of flow.

C.1.6.2 Applications

Cyclones are designed to separate and classify solids in the size range of 2,000 microns to 10 microns (Dorr-Oliver undated; Krebs Engineers undated). Cyclones are most applicable to situations where space is limited. They are most appropriately used to remove smaller size particles from slurries and where a sharp separation by particle size is needed.

C.1.6.3 Limitations

Cyclones are generally not effective for slurries with a solids concentration of greater then 30 percent or for handling particle sizes larger than about 0.1 inch. They are not suitable for separating solids from viscous slurries (Krebs Engineers undated). Cyclones are highly vulnerable to clogging by oversize particles, and a high degree of prescreening (or the use of progressively smaller cyclones in series) may be needed to avert clogging. The performance of cyclones is highly dependent on flow rate and is sensitive to variations in flow rate.

C.1.6.4 Special Requirements/Considerations

Feed to cyclones must be regulated and prescreened to remove particles that are larger than those that the cyclone is designed to handle (based on the diameter of the cyclone). Although a bank of cyclones can separate and classify solids over a broad range of grain sizes and flow rates, each individual cyclone is capable of handling only limited variability in flow rate and grain size. Therefore, the system must be carefully designed for a particular application. However, many cyclones are able to handle changes in flow rate, solids concentration, and grain size through adjustment and changes of parts. Cyclone liners, which are prone to wear as a result of abrasion by the materials being separated, require periodic replacement.

C.1.7 Summary

Sediment/water separation techniques and information pertinent to their evaluation and selection are summarized in Table C-1.

TABLE C-1. SUMMARY OF SEDIMENT/WATER SEPARATION TECHNIQUES

Technique	Applications	Limitations	Secondary Impacts	Relative Cost
Impoundment Basin	Used to remove particles down to a grain size of 20 to 30 microns without flocculants, and down to 10 microns with flocculants. Provide temporary storage of dredged material. Allow classification of sediments by grain size.	Requires large land areas. Requires long set-up time. Removal of settled solids by secondary dredging is labor intensive.	Potential for groundwater contamination. Potential for localized odor and air emissions.	High
Conventional Clarifier and Sedimentation	Used to remove particles down to a grain size of 20 to 30 microns without flocculants, and down to 10 microns with flocculants. Provide temporary storage of dredged material. Able to be barge mounted or installed on land where groundwater cannot be adequately protected by an impoundment basin.	Requires large land areas unless barge mounted.	Potential for localized odor and air emissions.	Low to Medium
High-Rate Clarifier	Used to remove particles down to a grain size of 20 to 30 microns without flocculants and down to 10 microns with flocculants.	Not demonstrated for sediment/water separation, but this application is similar to conventional applications.	Potential for localize odor and air pollution problems.	Low to Medium

(continued)

TABLE C-1. (continued)

Technique	Applications	Limitations	Secondary Impacts	Relative Cost
High-Rate Clarifier (continued)	Able to be barge-mounted, installed in areas where groundwater cannot be adequately protected by impoundment basins.			
Hydraulic Classifier	Used to remove particles from slurries in size range of 74 to 149 microns (fine sand to coarse sand).	Hydraulic throughput is limited to about 250 to 300 tph regardless of size.	No significant impacts.	Medium
	Classify particle according to grain size.	Not capable of producing a sharp size distinction.		
		Requires use of large land area for large scale dredging or where solids concentrations are high.		
Cyclones	Used to separate and classify solids in size range of 2,000 microns or more down to 10 microns or less.	Not suitable for dredged slurries with solids concentrations greater than 10 to 20 percent.	No significant impacts.	Medium
Filtration	Used to remove suspended solids down to low levels (1 to 10 mg/l) required for effluent discharge.	Not cost-effective for treating waste streams with suspended solids concentrations 200 mg/l.	No significant impacts provided backwash is properly treated.	High
		Not effective for colloidal sized particles.		

C.2 SEDIMENTS DEWATERING

Dewatering is used to reduce the moisture content of sediments for one of the following reasons:

- Dewatered sediments are more easily handled
- Dewatering is normally required prior to incineration to reduce fuel requirements
- Dewatering is required prior to land disposal
- The cost of transporting sediments to ultimate disposal is markedly reduced by reducing the volume and weight of material.

Commonly used methods for dewatering sludges, which may also be used for sediments, include: dewatering lagoons, filtration, centrifugation, and gravity thickening.

The selection of the most appropriate dewatering method depends on the volume of sediments, land space available, grain-size distribution of the sediments, and the degree of dewatering required.

C.2.1 Dewatering Lagoons

C.2.1.1 Description

Dewatering lagoons use a gravity or vacuum-assisted underdrainage system to remove water from sediments. The lagoons are lined with clay or other appropriate liner material to prevent migration of contaminants into the underlying soils and groundwater. The underdrainage system can be designed and operated using one of the following approaches:

- Gravity: Water infiltrates by gravity through a permeable underdrainage layer to a perforated collector pipe network (Haliburton 1978). The underdrainage layer consists of a well-graded sand, fine uniform sand, or fabric filter placed over a permeable and free-draining gravel layer (Haliburton 1978; Mallory and Nawrocki 1974).
- Vacuum Pumping: Wells or well points are sunk into the sediments and water is pumped from the wells under a vacuum head (Mallory and Nawrocki 1974).
- Vacuum-Assisted: A permeable media filter plate set above an aggregate filled support plenum drains to a sump. A relatively small vacuum pump is connected to draw a vacuum from the sump (USEPA 1982).

- Electro-osmosis: A direct current electrical potential is applied in the soil by means of electrodes. This electrical potential induces the flow of water in the pores of the fine-grained sediment toward the negative pole, or cathode. A line of wells or wellpoints can be installed to intercept and remove the water (Mallory and Nawrocki 1974).

C.2.1.2 Applications

Dewatering lagoons are capable of dewatering sediments of any grain-size. They also provide temporary storage for dredged materials.

Dewatering lagoons employing a gravity underdrainage system are capable of achieving a solids content of up to 40 percent after 10 to 15 days (based on municipal sludge, under favorable conditions). These systems have the advantage of very low operating costs. Vacuum-assisted and vacuum pumping dewatering systems can dewater sediments at a much more rapid rate and are capable of dewatering finer grained sediments than gravity dewatering. Vacuum-assisted systems increase the dewatering rate by about 50 percent (with a vacuum of 8 psi or less) (Haliburton 1978).

Electro-osmosis is applicable primarily to dewatering very fine-grained sediments (2 to 10 microns). The process is theoretically independent of the cross-sectional area of the pore structure of the filter media and therefore can dewater very fine grained sediments without clogging (Mallory and Nawrocki 1974).

C.2.1.3 Limitations

Requirements for large land areas and long periods of time for construction or mobilization may preclude the use of dewatering lagoons under situations where space and/or time are limiting factors.

Gravity drainage systems are the most prone to clogging, particularly if the underdrainage system is not properly designed. Vacuum pumping systems require a higher degree of maintenance and are considerably more costly to operate than gravity systems. Electro-osmosis is very costly and requires continuous monitoring and therefore has limited application.

C.2.1.4 Special Requirements/Considerations

Provisions must be taken to protect underlying groundwater supplies through installation of a liner system. The design of this system will need to be determined on a case-by-case basis depending upon such factors as how

long the lagoon will be in use and the mobility of the contaminants. In some cases lagoons may need to be constructed above ground to avoid contact with a high groundwater table. Decay of organic matter in dewatering lagoons can result in localized odor and air pollution problems.

C.2.2 Centrifugation

C.2.2.1 Description

Centrifugal dewatering uses the force developed by fast rotation of a cylindrical drum or bowl to separate solids and liquids by density differences under the influence of centrifugal force. Dewatering is usually accomplished using a solid bowl or basket centrifuge.

The solid-bowl centrifuge consists of a long rotating horizontal cylindrical bowl that is tapered at one end. The bowl contains a screw-type conveyor or scroll that also rotates, but at a slower speed. The material to be dewatered is fed continuously to the bowl through a feed pipe and the solids settle on the bowl wall. The rotating conveyor moves the material toward the tapered end where additional solids concentration occurs. The dewatered material is then discharged (USEPA 1982; Metcalf and Eddy 1979).

In an imperforate basket centrifuge, the feed material is introduced into a vertically mounted spinning bowl and forms a cake on the bowl wall as the unit rotates. The liquid is displaced over a baffle or weir at the top of the unit. When the solids holding capacity of the machine has been reached, the bowl decelerates and a scraper is positioned in the bowl to help remove the accumulated solids (USEPA 1982; Metcalf and Eddy 1979).

C.2.2.2 Applications

Centrifugation can be used to dewater sediments ranging in size from fine gravel to silt. Effectiveness of centrifugation depends upon the particle sizes and shapes and the solids concentration. For dewatering of municipal wastewater sludges (for which extensive information is available), dewatered sludges with a solids content of about 15 to 35 percent are achievable with the solid bowl centrifuge (USEPA 1979). Using the basket centrifuge, solids concentrations of 10 to 25 percent are generally achievable.

The basket centrifuge is not affected by grit to the extent that filtration methods or the basket centrifuge are. Also the basket centrifuge is excellent for hard-to-dewater sludges. The solid bowl centrifuge is easier to install, requires a smaller land area and has a higher hydraulic throughput (USEPA 1982).

Centrifuges are relatively compact and are well suited to areas with space limitations.

C.2.2.3 Limitations

Centrifuges are not as effective as filtration or dewatering beds and high energy costs associated with their operation at least partially offset their low capital cost. The major limitations of the basket centrifuge include a lower dewatering efficiency and its batch (i.e., discontinuous) operation. It also has a high ratio of capital cost to capacity. The major limitation of the solid bowl centrifuge is that the scroll is highly subject to abrasion. This results in the need for degritting the effluent and may result in high maintenance costs associated with maintaining the scroll (USEPA 1982). Since centrifugation relies on settling of particles according to density, the process tends to classify the solids, settling the heavier particles first. Dewatering processes that rely on filtration, on the other hand, achieve a more even distribution of solid capture. It is possible for a buildup of fines to occur in the effluent from centrifugation, particularly if the centrifuge is operating improperly due to inadequate conditioning or due to a malfunction (USEPA 1982).

C.2.2.4 Special Requirements/Considerations

The operation of centrifuges is simple, clean, and relatively inexpensive. Chemical conditioning is required for effective dewatering and therefore chemical storage, mixing, and feeding equipment is needed. Centrifuges, particularly the basket centrifuge, require special structural support. Provisions may also be needed for noise control, particularly with the solid bowl centrifuge. Solid bowl centrifuges generally require use of a prescreening step to avoid excess wear on the scroll.

C.2.3 Filtration

C.2.3.1 Description

Filtration is a physical process whereby fluid is forced through a permeable medium and dewatered solids are retained. Three types of filters are commonly used for dewatering: belt press filtration, vacuum filtration, and pressure filtration.

Belt filter presses employ single or double moving belts to continuously dewater sludges. The belt press filtration process includes three stages: chemical conditioning of the feed; gravity drainage to a nonfluid consistency, and dewatering. A flocculant is added prior to feeding the slurry

to the belt press. Free water drains from the conditioned sludge and the sludge enters a two-belt contact zone where an upper belt is gently set on the forming sludge cake. The belts, with the captured cake between them, pass over rollers of decreasing diameter. This subjects the material to continuously increasing pressures and shear forces. Progressively, more water is expelled throughout the roller section to the end where the dewatered material is discharged. A scraper blade is often employed for each belt at the discharge point to remove the caked material from the belts (USEPA 1982).

A vacuum filter consists basically of a horizontal cylindrical drum that rotates partially submerged in a vat of material to be dewatered. The drum is covered with a continuous belt of fabric or wire mesh. A vacuum is applied to the inside of the drum. The vacuum causes liquid in the vat to be forced through the filter medium leaving wet solids adhering to the outer surface. As the drum continues to rotate, it passes from the cake-forming zone to a drying zone and finally to a cake discharge zone, where the sludge cake is removed from the media (USEPA 1982; Metcalf and Eddy 1979).

Pressure filtration is used to describe a category of filters in which rigid individual filtration chambers are operated in parallel under relatively high pressure. The filter press, the most commonly used pressure filtration device, consists of a series of plates recessed on both sides, that are supported face-to-face in a vertical position on a frame with a fixed and movable head. A filter cloth is hung or fitted over each plate. Material to be dewatered is pumped into the space between the plates and sufficient pressure is applied and sustained to force the liquid through the filter cloth and plate outlet parts. The plates are then separated and the dewatered material is removed.

Diaphragm filters are specially designed filter presses. Instead of the conventional plate-and-frame unit in which constant pumping pressure is used to force the filtrate through the cloth, diaphragm filters combine an initial pumping followed by a squeezing cycle that can reduce the cost and process time.

C.2.3.2 Applications

Filtration can be used to dewater fine-grained sediments over a wide range of solids concentrations. Effectiveness depends on the type of filter, the grain sizes, and the solids concentration in the influent. Information on the use of filtration methods for dewatering sediments is limited and it is difficult to predict their effectiveness for these applications. For dewatering of municipal wastewater treatment sludges, where considerable performance information is available, typical ranges of solids concentrations in the dewatered material are as follow (USEPA 1979; USEPA 1982; Metcalf and Eddy 1979):

- Belt press filtration - 15 to 45 percent

- Vacuum rotary filtration - 12 to 40 percent
- Pressure filtration - 30 to 50 percent.

Data are also available on the performance of filtration methods in dewatering coal slurries. Manufacturers data indicate that the belt press and filter press are able to produce a filter cake of up to 70 to 80 percent solids (Green 1981). Tests conducted by Rexnord, Inc. demonstrated that high-density dredged materials can also be dewatered to a high solids concentration of 70 percent using belt press filtration (Erickson and Hurst 1983). Research has shown that the most important factor in determining the effectiveness of vacuum filtration dewatering of sediments is the specific resistance of the dredged material. The lowest specific resistance occurs at a silt/clay content ranging between 60 and 70 percent and increases as the silt/clay content increases or decreases (Long and Arana 1978).

Although pressure filtration has traditionally been considered the most effective of the filtration methods for dewatering, recent improvements in belt press filtration has also made this method highly effective. Belt filtration is less costly and energy-intensive than pressure filtration and operating and maintenance requirements are typically simpler and less labor-intensive (USEPA 1982). Vacuum filtration has the advantage of a higher hydraulic throughput than the other two methods. Performance is also less dependent on optimal chemical conditioning (USEPA 1982).

C.2.3.3 Limitations

Use of filtration methods requires a considerably higher degree of maintenance and operator supervision than other methods described in this section.

The major limitation of the use of belt filtration is that the process performance is very sensitive to incoming feed characteristics and chemical conditioning. Slurries must be prescreened more carefully than with other filtration methods to remove large objects and fibrous material that can quickly deteriorate the belt. Also, a large amount of wash water can be generated in cleaning the belts (USEPA 1982).

Vacuum filtration is more energy-intensive and less effective in dewatering than is the belt press filter. Another limitation on the use of vacuum filtration is that the incoming feed must have a solids content of at least 3 percent in order to achieve adequate cake formation (USEPA 1982).

The major limitations on the use of filter presses are that they are costly to operate and require more space than the other filtration methods. Filter presses also require high dosages of conditioning chemicals. Replacement of the filter media on a filter press is both costly and time consuming (USEPA 1982).

C.2.3.4 Special Requirements/Considerations

Effective use of filtration methods for dewatering invariably requires chemical conditioning; therefore, feed pumps, mixing equipment and chemical storage tanks are required. Waste streams must be prescreened and degritted to remove abrasive particles that can tear the filter media. Maintenance requirements associated with filters are significant. The filter cloth or belts must be periodically replaced and it is necessary to periodically wash the filter media to remove accumulated solids and prevent filter blinding. Although filtration methods are capable of producing a filter cake with a high solids content, the dewatered material may require further treatment before being acceptable for off-site disposal.

C.2.4 Gravity Thickening

C.2.4.1 Description

Gravity thickening is accomplished in a tank similar in design to a conventional sedimentation tank or clarifier. The material to be thickened is fed to a center well and the solids settle on the bottom of the tank. Water overflows the tank and solids are raked to the center of the tank and withdrawn by gravity discharge or pumping.

Gravity thickeners can be used to concentrate dredge material slurries of any grain size and at nearly any flow rate. They can generally produce a solids concentration ranging from about 2 to 15 percent (USEPA 1982; Metcalf and Eddy 1979). The thickened material is then dewatered using other methods described in this section; use of the gravity thickener reduces the hydraulic load to other dewatering processes.

C.2.4.2 Applications

Gravity thickeners are best used in situations where the hydraulic load to a primary dewatering process needs to be reduced because of availability of equipment and/or costs. The operation of gravity thickeners is simple and maintenance requirements are minimal making them well suited to locations where operator supervision cannot be provided continuously.

C.2.4.3 Limitations

The major limitation to the use of gravity thickeners is that they do not produce fully dewatered material. Slurries with a solids concentration in excess of 6 percent are usually not cost-effectively treated using

gravity thickening methods. Gravity thickeners require use of a substantial amount of land. The requirement for large land areas may preclude use of conventional gravity thickeners in some locations.

C.2.4.4 Special Requirements/Considerations

Effective thickening of dredge slurries frequently requires the use of flocculants and chemical storage tanks, feed pumps, and mixing equipment.

Gravity thickeners generally require large land areas. However, high-rate gravity thickeners designed to provide up to 15 times the throughput of a conventional thickener are available and can reduce land requirements considerably (Dorr-Oliver undated).

C.2.5 Summary

Sediments dewatering techniques and information pertinent to their evaluation and selection are summarized in Table C-2.

C.3 WASTE WATER TREATMENT

Waste water and other liquids generated from the cleanup of contaminated sediments or spills may require treatment to remove dissolved or colloidal contaminants prior to disposal. These streams vary widely with respect to volume and level and type contaminants. The types of liquid streams that are typically encountered include the following:

- Overflow from dredged material settling basins
- Highly concentrated liquids from the recovery of spilled materials
- Effluent from solids dewatering (filtrate, centrate, etc.)
- Leachate from dewatering lagoons and impoundment basins
- Contaminated water from cleaning of equipment.

Because the streams are so diverse in volume and in type and concentration of contaminants, a wide variety of treatment processes and systems need to be considered. This section concentrates on techniques that have the broadest applicability for on-site treatment; these techniques include activated carbon adsorption, biological treatment, ion exchange, neutralization, precipitation, flocculation, ultrafiltration, and ozonation/ultraviolet

TABLE C-2. SUMMARY OF SOLIDS DEWATERING TECHNIQUES

Technique	Applications	Limitations	Secondary Impacts	Relative Cost
Dewatering Lagoons	Dewatering sediment of any grain size to a solids content of up to 40 percent and up to 99 percent solids removal. Generally used for large scale dredging operations where land space is available.	Requires large land areas. Requires long set-up time. Labor costs associated with removal of dewatering sediments are high. Systems using gravity drainage are prone to clogging. Systems using vacuums require considerable maintenance and supervision. Systems based on electro-osmosis are costly.	Potential for groundwater contamination. Potential for localized odor and air pollution problems.	Low to High
Solid Bowl Centrifuge	Thickening or dewatering sediments; able to obtain a dewatered sludge with 15 to 35 percent solid; solid capture typically ranges from from 90 to 98 percent.	Not as effective in dewatering as filtration or lagoons. Process may result in a build up of fines in effluent from centrifuge.	No significant secondary impacts.	Medium to High

(continued)

TABLE C-2. (continued)

Technique	Applications	Limitations	Secondary Impacts	Relative Cost
Solid Bowl Centrifuge (continued)	Suitable for areas with space limitations.	Scroll is subject to abrasion.		
Basket Centrifuge	Thickening or dewatering sediments; able to obtain a dewatered sludge with 10 to 25% solids. Solids capture ranges from 80 to 98%. Suitable for areas with space limitations. Good for hard-to-dewater sludges.	Not as effective in dewatering as solid bowl centrifuge, filtration or dewatering lagoons. Process may result in a build-up of fines in effluent from centrifuge. Units cannot be operated continuously without complex controls.	No significant secondary impacts.	Medium to High
Belt Press Filtration	Used to dewater fine grained sediments. Capable of obtaining relatively dry filter cake containing up to 45 to 70 percent solids, able to achieve solids capture of 85 to 95%. Generally best suited of filtration methods for mobile treatment systems.	Performance is very sensitive to incoming feed characteristics and chemical conditions. Belts can deteriorate quickly in presence of abrasive material.	Generates a substantial amount of wash water that must be treated.	Medium
Vacuum Rotary Filtration	Used to dewater fine grained sediments capable of obtaining a filter cake of up to 35 or 40% solids and a solids capture rate of 88 to 95%.	Least effective of the filtration methods for dewatering. Energy intensive.	Generates a wash water that must be treated.	High

(continued)

TABLE C-2. (continued)

Technique	Applications	Limitations	Secondary Impacts	Relative Cost
Vacuum Rotary Filtration (continued)	Able to operate at high hydraulic throughput.			
Pressure Filtration	Used to dewater fine grained sediments. Capable of obtaining a relatively dry filter cake with a solids content up to 50 to 80%. Also able to achieve a high solids capture rate of up to 98%.	Requires a relatively large amount of space. Costly and energy intensive. Replacement of filter media is time consuming.	Generates a wash water that must subsequently be treated.	High
Gravity Thickener	Thickening of sediment slurries to produce a concentrate that can then be dewatered using filtration or dewatering lagoons. Able to produce a thickened sludge with a solids concentration of 2 to 15%.	Least effective method for dewatering sediment slurries. Requires use of a substantial amount of land.	Potential for localized odor and air pollution problems.	Low to Medium

radiation. This section also addresses discharge of contaminated water to public sewerage systems for treatment by publicly owned treatment works (POTWs).

C.3.1 Activated Carbon

C.3.1.1 Description

Treatment of liquids with activated carbon involves contacting a waste stream with specially prepared carbon, usually by flow through a series of packed bed reactors. The activated carbon adsorbs contaminants by a surface attraction phenomenon in which organic and some inorganic molecules are attracted to the internal pores of the carbon granules. Once the surfaces are saturated with contaminants, the carbon is "spent" and must be either replaced with virgin carbon or removed, thermally regenerated, and replaced. The time required to reach carbon exhaustion, or "breakthrough" of contaminants, is a critical operating parameter.

C.3.1.2 Applications

Activated carbon is suitable for treating a wide range of soluble organics over a broad range of concentrations. As carbon adsorption is essentially an electrical interaction phenomenon, the polarity of the waste compounds largely determines the effectiveness of the adsorption process. The solubility of the waste constituents are important in determining adsorption potential. The less polar and soluble a compound is, the more readily it is adsorbed (Conway and Ross 1980). A total organic carbon concentration of one percent, or 10,000 ppm, is generally considered to be the upper practical limit for treatment by activated carbon (DeRenzo 1978).

Although activated carbon adsorption is used primarily for treatment of organics, some metals and inorganic species have shown excellent to good adsorption potential. These include: antimony, arsenic, cyanide, chromium, silver, mercury, cobalt, chlorine, bromine, and iodine (DeRenzo 1978).

Activated carbon treatment is well suited to mobile treatment systems as well as to on-site construction. Space requirements are low, start-up and shut-down are rapid, and there are numerous contractors that are experienced in operating mobile units.

C.3.1.3 Limitations

Activated carbon is generally not suitable for treating liquid streams with contaminant concentrations in excess of one percent or suspended solids concentrations of greater than 50 ppm; backwash requirements are excessive at higher suspended solids concentrations. Treatment is also limited to liquid streams with oil and grease concentrations of less than 10 mg/l. The process is not effective for low molecular weight compounds.

C.3.1.4 Special Requirements/Considerations

Cost-effective use of activated carbon requires pretreatment to remove suspended solids and oil and grease. Filtration and gravity separation are generally used for these purposes. Adjustment of pH may also be required in order to reduce the level of dissolved inorganics, which can cause scaling and loss of activity during thermal regeneration (DeRenzo 1978). In many instances it is cost-effective to precede carbon adsorption with biological treatment in order to reduce the organic load on the carbon, thereby reducing carbon regeneration costs.

The most obvious maintenance consideration associated with activated carbon treatment is the regeneration of spent carbon for reuse. Regeneration must be performed for each column at the conclusion of its bed life so the spent carbon may be restored as nearly as possible to its original condition for reuse. The services of a commercial regeneration facility are practical for small operations. Carbon columns must also periodically be backwashed to remove accumulated suspended solids. Other operation and maintenance requirements of activated carbon technology are minimal if appropriate automatic controls have been installed.

C.3.2 Biological Treatment

C.3.2.1 Description

Treatment of wastewater by biological methods removes organic matter through microbial oxidation. In the most conventional process, activated sludge, wastewater flows into an aeration basin where it is mixed with active acclimated microorganisms and is aerated for several hours. A portion of the mass of microorganisms is recycled to the basin to maintain an acceptable organic substrate-to-microorganism ratio; the remaining biomass produced during aeration forms a sludge that is settled out in a clarifier.

There are a number of variations of the activated sludge process. These are summarized in Table C-3 (DeRenzo 1978; Metcalf and Eddy 1979).

C.3.2.2 Applications

Many organic compounds are considered to be amenable to biological treatment, although the relative ease of biodegradation varies widely. In addition, recent advances in developing specialized microorganisms for facilitating biodegradation of complex organics has broadened the applications for biological treatment. Specific applications of the activated sludge process are summarized in Table C-3.

C.3.2.3 Limitations

Biological treatment is not suitable for treatment of high-strength organic waste, aqueous waste streams with a suspended solids concentrations in excess of one percent, and high oil and grease concentrations. It is also not suitable for treatment of waste streams with high concentrations of chlorinated compounds, inhibitory concentrations of other organics and inorganics, or pH extremes (less than 6 or greater than 9). Biological processes are also subject to failure from "shock loads" and initial degradation may be inhibited or delayed if the microorganisms need to be acclimated to the wastes.

C.3.2.4 Special Requirements/Considerations

Influents to biological treatment processes must be pretreated to remove constituents that are potentially toxic to microorganisms. Suspended solids should generally not exceed 50 to 125 mg/l and can be removed using sedimentation. Toxic concentrations of metals must be removed by precipitation and sedimentation. Skimming tanks or gravity separators are required to reduce oil and grease levels to less than about 35 to 50 mg/l. Neutralization is required to maintain a pH of greater than 6 and less than 9 (Conway and Ross 1980).

C.3.3 Ion Exchange

C.3.3.1 Description

Ion exchange is a process that removes unwanted ions from wastewater by transferring them to a solid resin material "in exchange" for an equivalent number of innocuous ions stored in the ion exchanger material. The ion exchanger has a limited capacity for storage of ions and eventually becomes saturated. It is then washed with a strong regenerating solution containing the innocuous ions, and these then replace the accumulated undesirable ions, returning the exchange material to a usable condition (Nalco Chemical Company 1979).

TABLE C-3. SUMMARY OF BIOLOGICAL TREATMENT PROCESSES

Process	Description	Application
Conventional (plug flow)	Wastewater and return sludge are mixed at the head of the aeration tank; the so-called mixed liquor flows through the tank in a plug-flow fashion with some longitudinal mixing.	Applicable to low-strength wastes; subject to shock loads.
Completely mixed	Used to equalize load variations and improve distribution of dissolved oxygen; involves operating mechanical aerators in the aeration tank to achieve almost instantaneous distribution of untreated wastes throughout the tank.	More resistant to shock loads than conventional activated sludge.
Step aeration	Used to equalize influent organic loading along the course of flow of the mixed liquor; involves admitting influent wastewater at multiple points along the aeration tank.	Good applicability for a wider range of waste types.
Extended aeration	Used where there are low organic loadings and it is desireable to minimize sludge residue; involves longer aeration retention periods so that endogenous respiration of biomass is achieved.	Requires low organic load and long detention times; low volume of sludge; available as package plant.

(continued)

TABLE C-3. (continued)

Process	Description	Application
Pure oxygen	Used where there are high organic and metal concentrations to maintain a high dissolved oxygen level and a high biomass concentration; involves a closed staged aeration tank with mechanical mixers receiving concurrent flow of wastewater and oxygen gas.	Suitable for high-strength wastes; low sludge volume; reduced aeration tank volume.
Rotating biological disc	Biological growth becomes attached to the surfaces of disks and eventually forms a slime layer over entire wetted surface; rotation of the disk alternatively contacts the biomass with the organic material in the wastewater and then with the atmosphere for adsorption of oxygen.	Can handle large flow variations and high organic shock loads; modular construction provides flexibility to meet increases or decreased treatment needs.

Sources: Conway and Ross 1980; Metcalf and Eddy 1979; DeRenzo 1978.

C.3.3.2 Applications

Ion exchange can be used to remove or concentrate the following groups of contaminants that may be found in spill situations (DeRenzo 1978):

- Inorganics:
  - All metallic elements when present as soluble species, either cationic or anionic
  - Anions such as halides, sulfate, nitrate, cyanides, etc.

- Organics (water soluble and ionic):
  - Acids, such as carboxylics, sulfonics, and some phenols, at a pH sufficiently alkaline
  - Amines when the solution acidity is sufficient to form the corresponding acid salt.

The upper practical limit of exchangeable ions is about 2500 to 4000 mg/l (DeRenzo 1978). Ion exchange units are relatively compact and are not energy intensive. The units can be put into and removed from operation in little time and with little effort (Ghassemi, Yu, and Quinlivan 1981). These features allow for convenient use of ion exchange systems in mobile treatment systems.

C.3.3.3 Limitations

Ion exchange is not suitable for treatment of non-ionic compounds or for the treatment of highly concentrated waste streams (>4000 mg/l) or streams high in suspended solids or oxidants (DeRenzo 1978).

Certain organics, particularly aromatics that may be present in a waste stream, can be irreversibly sorbed by resins, thereby decreasing their capacity.

C.3.3.4 Special Requirements/Considerations

Influent to ion exchange columns must be pretreated using filtration in order to reduce suspended solids concentrations to less than 50 mg/l. Oxidants must also be removed prior to ion exchange.

Although ion exchange columns can be operated either manually or automatically, manual operation is better suited for hazardous waste site applications because of the diversity of wastes encountered. In manual operation, the operator can decide when to stop the service cycle and begin the backwash cycle. However, this requires use of a skilled operator familiar with the process (Ghassemi, Yu, and Quinlivan 1981).

C.3.4 Neutralization

C.3.4.1 Description

Neutralization consists of adding acid or base to a liquid in order to adjust its pH. The most common system for neutralizing acidic or basic waste streams utilizes a multiple-compartment basin usually constructed of concrete. This basin is lined with acid brick or is coated with a material resistant to the expected environment. In order to reduce the required volume of the neutralization basin, mixers are installed in each compartment to provide more intimate contact between the waste and neutralizing reagents, thus speeding up reaction time.

The choice of an acidic reagent for neutralization of an alkaline wastewater is generally between sulfuric acid and hydrochloric acid. Sulfuric acid is usually used due to its lower cost, although hydrochloric acid produces soluble reaction end products (Conway and Ross 1980).

The selection of a caustic reagent is usually between sodium hydroxide and various limes although ammonium hydroxide is also occasionally used (Conway and Ross 1980).

C.3.4.2 Applications

Neutralization can be applied to any waste acid or alkaline liquid stream that requires pH adjustment.

C.3.4.3 Limitations

There are no limitations on the use of neutralization when the process is properly applied.

C.3.4.4 Special Requirements/Considerations

Neutralization is a relatively simple treatment process that can be accomplished using readily available equipment. Only storage and reaction tanks with accessory agitators and delivery systems are required. Because of the corrosivity of the wastes and treatment reagents, appropriate materials of construction are needed to provide a reasonable service life for equipment.

Neutralization of liquids has the potential of producing air emissions. Acidification of streams containing certain salts, such as sulfide for example, will produce toxic gases. Feed tanks should be totally enclosed to prevent escape of acid fumes. Adequate mixing should be provided to

disperse the heat of reaction if wastes being treated are concentrated. The process should be controlled from a remote location if possible.

C.3.5 Precipitation

C.3.5.1 Description

Precipitation is a physiochemical process whereby some or all of a substance in solution is transformed into a solid phase. It is based on alteration of the chemical equilibrium relationships that affect the solubility of inorganic compounds. Removal of metals as hydroxides or sulfides is the most common precipitation application in wastewater treatment. Generally, lime or sodium sulfide is added to the wastewater in a rapid mixing tank along with flocculating agents (chemicals that aid in the settling of precipitates). The wastewater flows to a flocculation chamber in which adequate mixing and retention time are provided for agglomeration of precipitate particles. Agglomerated particles are separated from the liquid phase by settling in a sedimentation chamber and/or by other physical processes such as filtration.

Precipitation is a well established technique and the operating parameters are well defined. The process requires only chemical pumps, metering devices, and mixing and settling tanks. The equipment is readily available and easy to operate.

C.3.5.2 Applications

Precipitation is applicable to the removal of most metals from wastewater including zinc, cadmium, chromium, copper, fluoride, lead, manganese, and mercury. Also, certain anionic species, such as phosphate, sulfate, and fluoride, can be removed by precipitation.

C.3.5.3 Limitations

Precipitation cannot reduce the concentration of a particular metal below the solubility product. In some cases, organic compounds may form organometallic complexes with metals, which could inhibit precipitation. Cyanide and other ions in wastewater may also combine with metals, making treatment by precipitation less efficient. Metals that are precipitated as metal hydroxides and carbonates are stable only over a narrow pH range; a metal reaches a minimum solubility at a specific pH, but further addition of the precipitant causes the metal to become soluble again. The pH at which minimum solubility occurs is different for each metal.

C.3.5.4 Special Requirements/Considerations

The performance and reliability of precipitation depends greatly on the variability of the composition of the liquid being treated. The amount of chemicals added is a function of the species of metals in solution and their concentrations.

Precipitation is nonselective in that compounds other than those targeted may also be removed. The process also generates a large volume of sludge that must be disposed.

Precipitation poses minimal safety and health hazards to workers. The entire system is operated at near ambient conditions, eliminating the danger of high pressure/high temperature operation with other systems. While the chemicals employed in precipitation are skin irritants, they can easily be handled in a safe manner.

C.3.6 Flocculation

C.3.6.1 Description

Flocculation is a process in which small, unsettleable particles suspended in a liquid are made to agglomerate into larger, more settleable particles. The flocculation process entails the following steps (DeRenzo 1978):

- Mixing of a flocculating agent with water (often outside of the wastewater system)
- Rapid mixing of the above mixture with the wastewater stream to disperse the flocculating agent throughout the wastewater
- Slow and gentle mixing to allow for contact between small particles and agglomeration into larger particles.

Once suspended particles have flocculated into larger particles, they can usually be removed by sedimentation, provided that a sufficient density difference exists between the suspended matter and the liquid.

Chemicals that are typically used in flocculation include alum, lime, iron salts, and polyelectrolytes.

C.3.6.2 Applications

Flocculation is applicable to any liquid where it is necessary to agglomerate particles to form larger more settleable particles.

C.3.6.3 Limitations

There are no major limitations to the use of flocculants when they are properly applied.

C.3.6.4 Special Requirements/Considerations

Selection of the optimum flocculant and flocculant dosage must be made on a case-by-case basis. A small number of flocculants that may be effective is selected based on manufacturers' suggestions and jar tests are conducted to determine suitability for treating a specific liquid. Test procedures along with recommendations for potentially effective flocculants can be obtained from manufacturers.

Operation and maintenance of flocculation equipment is relatively simple, since only feed pumps, storage tanks, and feed lines are required.

C.3.7 Ultrafiltration

C.3.7.1 Description

Ultrafiltration is a membrane filtration process that separates high molecular weight compounds and colloids from a liquid solution or suspension. The process operates by applying a hydrostatic pressure, typically between 10 and 100 psig, to the upstream side of a supported membrane allowing the large molecules and colloid particles to be retained by the membrane (DeRenzo 1978). With advances in membrane technology, the membrane porosity can be custom made for filtering specific molecular sizes. For example, "tight" membranes can retain organic solutes of 500 to 1000 molecular weight and allow passage of most inorganic salts. Conversely, "loose" membranes can discriminate between molecules of 1,000,000 to 250,000 molecular weight (DeRenzo 1978).

Mobile units can typically handle flows of 5,000 to 10,000 gpd. Up to nine pressure vessels can be mounted on a trailer flatbed allowing treatment of flows up to 60,000 gpd (Ghassemi 1981).

C.3.7.2 Applications

Ultrafiltration is capable of segregating high molecular weight dissolved and colloidal species from a solution or suspension. The lower and upper molecular weight cutoff limits are around 500 to 500,000, respectively (Ghassemi, Yu and Quinlivan 1981). In terms of particle separation capability, ultrafiltration falls between reverse osmosis, which retains smaller molecules, and conventional filtration. It is considered to be most applicable for treating emulsified oils.

C.3.7.3 Limitations

The primary limitation of ultrafiltration is that it is not applicable to wastes that contain suspended solids or low molecular weight dissolved substances. As with all membrane processes, ultrafiltration units are susceptible to fouling. When the ultrafiltration membrane fouls it is simply taken out of service and cleaned by flushing with detergents or water.

C.3.7.4 Special Requirements/Considerations

Influent to ultrafiltration must be pretreated by granular media filtration to remove suspended solids that can tear the membrane.

The concentrated residue contains high concentrations of toxic substances and must be further treated and disposed.

C.3.8 Ozonation and Ultraviolet Radiation

C.3.8.1 Description

Ozonation in combination with ultraviolet (UV) radiation is a chemical oxidation process in which UV light is used to enhance the oxidation efficiency of ozone. Ozone (O_3) is a very strong oxidizing agent. However, ozone is only slightly soluble in water and, because of its low solubility, supplying ozone at a sufficiently fast rate to the reactor becomes a major mass transfer problem in the treatment of high concentrations of contaminants, especially those containing substances that are rapidly oxidizable with ozone (for example, sulfides, nitrites, bacteria, phenols, and unsaturated organics) (Ghassemi, Yu, and Quinlivan 1981).

While the specific role of ultraviolet radiation in enhancing the efficiency of ozonation is still under investigation, it is currently hypothesized that the major effect of radiation is to bring about a photodecomposition of the substances undergoing oxidation (Ghassemi, Yu, and Quinlivan 1981).

Since the optimization of the O_3/UV contact with the liquid and the O_3 mass transfer are important parameters, the reactor is divided into compartments (created by use of baffles) with cylindrical UV lights (similar to commercial fluorescent lights) placed vertically at equal distances along the flow path in each compartment. Ozone, which is generated on site, is introduced as a gas into the reactor through diffusers that are located at the bottom of each compartment. The excess ozone in the reactor offgas is discharged to the atmosphere (Ghassemi, Yu, and Quinlivan 1981).

C.3.8.2 Applications

O_3/UV is applicable to the treatment of a broad range of difficult to oxidize organics, organometallic complexes, and reduced inorganic substances. The process is most cost-effectively used to oxidize non-biodegradable compounds such as PCBs, kepone and other pesticides, and metal complexes of cyanide.

C.3.8.3 Limitations

Although O_3/UV can be used to oxidize a wide range of contaminants, the process is cost-effective only for dilute solutions of difficult to oxidize contaminants. The O_3/UV process utilizes large amounts of ozone (8 parts of ozone is required to remove one part of TOC in wastewater). The amount of ozone that can be generated on site in a mobile unit may be less than that required for a specific application (Ghassemi, Yu, and Quinlivan 1981).

Given the state of the art of this process, pilot plant studies would need to be conducted to determine optimum reactor design and operating conditions for each application (Ghassemi, Yu, and Quinlivan 1981). This would limit the usefulness of this process in situations where emergency cleanup is needed.

C.3.8.4 Special Requirements/Considerations

Liquids that are to be treated with O_3/UV must be pretreated by granular media filtration to remove suspended solids. Also, in certain applications such as treatment of cyanides, pH adjustment is required to prevent generation of toxic gases.

About five percent of the ozone used in the process is released to the atmosphere (Ghassemi 1981). This requires that the area be well ventilated. A special permit may be required for release of ozone.

C.3.9 Discharge to Publicly Owned Treatment Works (POTW)

C.3.9.1 Description

Contaminated liquids can be discharged to local sewerage systems (or publicly owned treatment works, POTW) in which considerable dilution occurs and treatment is accomplished at a central facility. The owner/operator of the treatment works may require pretreatment of liquids prior to discharge, and a special discharge permit may be required.

C.3.9.2 Applications

Discharge to a POTW is applicable to treatment of low-level contaminated liquids that can be treated at a facility without the facility violating its operating permit conditions. Other factors that the POTW may consider in determining whether to accept a specific discharge are whether the POTW has sufficient hydraulic capacity and what additonal costs the POTW may incur by accepting the discharge (e.g., increased monitoring costs or process changes).

C.3.9.3 Limitations

Discharge to a POTW is not acceptable where it will result in violation of operating permit conditions.

C.3.9.4 Special Requirements/Considerations

In general, treatability studies may be required to determine the capability of the POTW for handling a particular wastestream and necessary pretreatment requirements. Extensive pretreatment may be required prior to discharge to the POTW.

C.3.10 Summary

Wastewater treatment techniques and information pertinent to their evaluation and selection are summarized in Table C-4.

TABLE C-4. SUMMARY OF WASTEWATER TREATMENT TECHNIQUES

Technique	Applications	Limitations	Secondary Impacts	Relative Cost
Activated Carbon	Removal of a broad range of dissolved organics from aqueous streams with TOC concentrations of 10,000 ppm or less, best suited for compounds with low solubility and polarity. Also used to remove some inorganic solutes.	Not cost-effective for waste streams with TOCs in excess of 1%. Not suitable for treating waste streams high in suspended solids (>50 ppm) or oil and grease (>10 ppm). Not effective for low molecular weight compounds or highly soluble compounds.	Process generates an "exhausted" carbon that must regenerated. Regeneration will usually be be conducted off site where adequate controls are taken to avoid secondary impacts. Backwash streams must be treated to remove high concentration of solids.	Medium to High
Biological Treatment (aerobic)	Degradation of oxidizable organics present at non-inhibitory levels.	Not suitable for highly concentrated waste streams or streams containing inhibitory concentration of metals. Not suitable for treatment of aliphatics; chlorinated polyaromatics are degraded slowly. Process is subject to failure from shockloads. Process initiation time can be slow.	Limited localized air emissions may result. Process generates a biomass sludge which contains high concentrations of toxic compounds, sludge must be dewatered and treated.	Low to Medium

(continued)

TABLE C-4. (continued)

Technique	Applications	Limitations	Secondary Impacts	Relative Cost
Ion Exchange	Removal of ions, both organic and inorganic, at concentrations up to 2500 to 5000 mg/l.	Not suitable for highly concentrated waste streams, or streams high in suspended solids or oxidants.	No significant impacts.	High
Neutralization	Adjustment of pH for acid or alkaline waste streams.	No significant limitations when properly applied.	Potential for air pollution problems.	Low to High
Precipitation	Removal of dissolved metals from waste streams; no concentration limit.	Difficult to obtain minimum solubility of a metal due to such factors as formation of organometallic complexes and the tendency of each metal to have its minimum solubility at a different pH.	Process generates a large volume of sludge that must be treated prior to disposal.	Low to High
Flocculation	Agglomeration of particles into larger, more setteable particles that are subsequently settled by sedimentation.	No significant limitations when properly applied.	Process generates a large volume of sludge that must be treated prior to disposal.	Low
Ultra-filtration	Separation of high molecular weight dissolved or colloidal species.	Membranes are prone to fouling. Process is not suitable for suspended solids.	Process generates a highly concentrated wastestream that requires subsequent treatment or incineration.	High

(continued)

C.4.1.1 Cement-Based Solidification

Description--

This method involves mixing the material directly with Portland cement, a common construction material. The material is incorporated into a rigid matrix of hardened concrete. This method physically and chemically binds contaminants (USEPA 1982b). The end product may be a monolithic solid or a crumbly, soil-like consistency, depending upon the amount of cement added. Mixing is accomplished using readily available equipment.

Applications--

Most slurries and sludges can be mixed directly with cement so that solids will be physically incorporated into the rigid matrix. Cement solidification is most suitable for immobilizing metals because most multivalent cations are converted into insoluble hydroxides or carbonates at the pH of the cement mixture. For this reason, Portland cement is often used as a setting agent in other solidification processes described in this section.

Limitations--

Although cement can physically incorporate a broad range of materials, most materials are not chemically bound and are subject to leaching. Metals, which can be immobilized by cement solidification by precipitation as metal hydroxides or carbonates, are insoluble only over a narrow pH range and are subject to solubilization and leaching in the presence of even mildly acidic leaching solutions (e.g., rain). Portland cement alone is also not effective in immobilizing organics.

Because of the tendency of waste constituents to leach, solidification is not acceptable for disposal without secondary containment, regardless of whether the wastes are organic or inorganic. Certain wastes can cause problems with the set, cure, and permanence of the cement waste solid unless the wastes are pretreated. Some of these incompatible wastes are (USEPA 1982b):

- Sodium salts of arsenate, borate, phosphate, iodate, and sulfide
- Salts of magnesium, tin, zinc, copper, and lead
- Organic matter
- Some silts and clays
- Coal or lignite.

Special Requirements/Considerations--

Cement-based solidification processes use equipment and skills that are commonplace and readily available. Most cement-solidified materials are subject to leaching and, therefore, secondary containment is required. Cement solidification increases the weight and volume of the original material and therefore transportation costs can be expected to increase accordingly.

C.4.1.2 Silicate-Based Processes

Description--

Silicate-based processes are a broad range of solidification/stabilization methods that use a silicateous material together with lime, cement, gypsum, and other setting agents. The basic reaction is between the soluble silicates, such as fly ash or cement kiln dust, and water. The polyvalent metal ions that act as initiators of silicate precipitation and/or gelation come either from the waste solution, an added setting agent, or both. The setting agent should have low solubility, and a large reserve capacity of metallic ions so that it controls the reaction rate. Portland cement and lime are most commonly used because of their good availability. However, gypsum, calcium carbonate, and other compounds containing aluminum, iron, magnesium, etc. are also suitable setting agents. The solid that is formed in these processes varies from a moist, clay-like material to a hard, dry solid similar in appearance to concrete (Granlund and Hayes undated).

Applications--

There are a number of commercially available processes that use silicates, and each claims to be able to solidify different waste types. The process is best known for stabilizing sludges containing heavy metal. However, other manufacturers use proprietary processes and additives that permit stabilization of wastes containing oils and solvents. The feasibility of silicate-based stabilization for these waste types needs to be determined on a case-by-case basis.

Silicate-based stabilization processes are suitable for stabilizing large waste volumes because the materials used are inexpensive and are readily available (with the exception of some additives) and the increase in volume of the solidified materials is considerably less than when cement is used alone.

Limitations--

The limitations of silicate-based processes in stabilizing materials are not well known. One known limitation is that large amounts of water, not chemically bound, remain in the matrix after solidification. In open air, this liquid leaches until it comes to some equilibrium moisture content

with the surrounding soil. Because of this water loss, the solidified product is likely to require secondary containment.

Special Requirements/Considerations--

Most silicate-based processes use readily available equipment that is easy to operate. The feasibility and effectiveness of using silicates for stabilizing wastes other than inorganic sludges must be determined on a case-by-case basis. Generally, the services of a firm specializing in the use of silicates is required since many companies claim to use proprietary additives. The stabilized product is likely to require secondary containment to prevent leaching of contaminants.

C.4.1.3 Surface Encapsulation

Description--

Surface encapsulation physically microencapsulates materials by sealing them in an organic binder or resin. At least three surface encapsulation methods are available. These methods are described below.

One process, developed by Environmental Protection Polymers, involves the use of 1,2-polybutadiene and polyethylene (PE) to produce a microencapsulated waste block onto which a high density polyethylene (HDPE) jacket is fused. The 1,2-polybutadiene is mixed with waste particulates which yields, after solvent evaporation, free-flowing dry resin-coated particulates. The resulting polymers are resistant to oxidative and hydrolytic degradation and to permeation by water. The next step involves formation of a block of the polybutadiene/waste mixture. Powdered, high-density PE is grafted chemically onto the polymer backbone to provide a final matrix with ductile qualities. Various combinations of the two resins (polybutadiene and PE) permit tailoring of the matrix's mechanical properties without reduction of system stability when exposed to severe chemical stress. In the final step, a 1/4-inch thick HDPE jacket is mechanically and chemically locked to the surface of the microencapsulated waste (Lubowitz and Wiles 1981).

Another encapsulation method developed by Environmental Protection Polymers involves a much simpler approach. Contaminated soils or sludges are loaded into a high-density polyuethylene overpack. A portable welding apparatus is then used to spin-weld a lid onto the container thereby forming a seam free encapsulate.

A third surface encapsulation method involves use of an organic binder to seal a cement-solidified mass. United States Gypsum Company manufactures a product called Envirostone Cement which is a special blend of high-grade polymer-modified gypsum cement. Emulsifiers and ion exchange resins may be added along with the gypsum cement which hydrates to form a freestanding mass. A proprietary organic binder is used to seal the solidifed mass (United States Gypsum Co. 1982). The process can be used to stabilize both

organic and inorganic wastes. It has been shown to effectively immobilize waste oil present at concentrations as high as 36 percent volume (Clark, Colombo, and Neilson 1982). The volume of waste is smaller than that produced with cement solidification alone.

Applications--

Surface encapsulation is used to completely isolate waste constituents from leaching solutions. Processes are available that can be used for most waste types. Use of surface encapsulation is generally limited to highly hazardous materials or to situations where the waste is to be disposed without secondary containment.

Limitations--

Limitations of surface encapsulation processes for various waste types and concentrations must be determined on a case-by-case basis.

Special Requirements/Considerations--

As compared to cement and silicate-based processes, surface encapsulation is costly, energy intensive, and requires the use of skilled labor and sophisticated equipment.

C.4.2 Chemical and Biological Treatment

Contaminants in solids can be treated by a variety of chemical and biological methods. The most applicable methods, chemical oxidation/reduction, solvent extraction, neutralization, dechlorination, and microbiological oxidation, are described in the following sections.

C.4.2.1 Chemical Oxidation/Reduction

Description--

Chemical oxidation/reduction processes are based on a chemical reaction in which electrons are transferred from one reactant to the other. Such reactions can detoxify, precipitate, or solubilize metals, and decompose, detoxify, or solubilize organics.

Chemical oxidation/reduction systems can be constructed using simple equipment such as tanks or gas cylinders for storing the reagents, a reaction tank which might include mixers to provide contact between the oxidizing agent and waste stream, and metering and monitoring instruments to control the chemical reaction. Alternatively, it may be possible to carry out the reaction within a structure similar to a dewatering lagoon (see Section C.2). This would involve installation of a wellpoint or gravity

drainage system to inject the chemicals into the site, force reaction of the reagents with waste constituents, and pump the treated material to the surface.

Oxidization is widely practiced in the wastewater treatment industry using such oxidizing agents as ozone, sodium or calcium hypochlorite, and hydrogen peroxide. Chemical reduction is not widely practiced, but it is known that ferrous sulfate and certain catalyzed metal powders are effective reducing agents (Sims et al. 1984; Repa et al. 1985).

Applications--

Both organic and inorganic wastes can be treated by chemical oxidation. Examples of compounds that can be treated include cyanides, sulfur compounds, lead, pesticides, phenolics, aldehydes, and aromatic hydrocarbons (Stoddard et al. 1981). Compounds that may be chemically reduced include hexavalent chromium and some chlorinated compounds.

Chemical oxidation and reduction have not been used in the treatment of contaminated sediments. However, considerable research is being conducted on the use of these methods to treat contaminated soils.

For treatment of contaminated sediments, the process would be most applicable for treatment of dilute waste streams that have a sufficiently high water content to provide good contact between the waste constituents and the treatment reagents upon mixing. For sediments that have been substantially dewatered, oxidation and reduction could be employed, provided the sediments are sufficiently permeable to ensure contact between the treatment reagents and the wastes.

Limitations--

The effectiveness of chemical oxidation and reduction is highly dependent on the waste constituents and the nature of the waste being treated. These processes are not effective for highly concentrated wastes or for fine-grained sediments that have been substantially dewatered because it would be difficult to ensure mixing of waste constituents with the treatment reagents under these conditions. It is not known to what extent the processes can treat compounds that are strongly sorbed to the soil.

Special Requirements/Considerations--

The environmental concerns associated with chemical oxidation and reduction reactions can be significant. There is the potential that the products of oxidation/reduction reactions may be more toxic or more mobile in the environment than the original contaminants. Many of the reagents are toxic or hazardous and pose a risk to worker safety if not properly handled. If the wastes are treated in an impoundment basin there is the risk that treatment chemicals or any more soluble or toxic reaction products may be released to the groundwater. However, this risk should be minimal provided a liner system is properly installed and operated.

Another possible problem with these treatment methods is that certain reactions can result in the release of toxic gases. For example, there is the possibility of emission of hydrogen cyandide gas during oxidation of cyanide, if the reaction is allowed to become too acidic. Release of ozone or chlorine gas can also result. Wastes treated by oxidation/reduction processes are likely to require further treatment to immobilize or more fully degrade the contaminants.

C.4.2.2 Solvent Extraction

Description--

Solvent extraction involves injecting or adding acids, bases, surfactants, or other reagents that mobilize contaminants into solution by reason of the contaminant's solubility in the reagent. The reaction can be carried out in a tank or a dewatering lagoon. The waste stream is mixed with the solvent, decontaminated materials are separated from the contaminated solvent, and the contaminated solvent is treated to render it innocuous.

Applications--

Dilute solutions of acids and bases can be used to remove a wide range of metal ions. Complexing and chelating agents can be used to form stable metal-chelate complexes. A wide range of hydrophobic, nonsoluble organics can be extracted using surfactants. Organics that can be treated using surfactants include PCBs, pesticides, and aromatic and polynuclear aromatic compounds.

Since effective extraction of contaminants requires that there be complete mixing of reagents with the waste constituents, extraction methods are best suited to slurries that can be easily mixed and to dewatered sediments that are sufficiently permeable to ensure contact of reagents with contaminants. Application of solvent extraction methods for sediments has not been demonstrated but there exists considerable research data that indicate that solvent extraction methods can be used for contaminated soils.

Limitations--

Solvent extraction methods are not suitable for treating fine-grained sediments that have been dewatered since it is difficult to ensure complete mixing of treatment reagents with waste constituents. Acids and chelating agents may not be effective in removing some metal complexes or metals that are strongly sorbed to the soil. Other limitations on the use of solvent extraction methods for treating sediments are not well known since these methods have not been applied to sediments.

Special Requirements/Considerations--

Carrying out solvent extraction in a dewatering lagoon poses the risk of contaminating groundwater supplies if a liner system is not properly installed and maintained. Use of acids or bases in extraction may result in the release of toxic gases. For example, acidification of certain wastes that contain sulfide could result in release of gases. Although weak acids such as acetic acid would generally be used for extracting metals, these reagents are corrosive and pose some risk to worker safety if not properly handled.

C.4.2.3 Neutralization

Description--

The neutralization process is described in Section C.3.4.

Applications--

Neutralization methods can be applied to any acidic or alkaline waste stream requiring a pH adjustment. In order to ensure complete mixing of neutralizing reagents with waste components, neutralization is best suited to slurries that can be easily mixed or to dewatered sediments that are sufficiently permeable to ensure complete contact of contaminants with neutralizing reagents.

Limitations--

Neutralization is not effective for fine-grained sediments that have been substantially dewatered since it would be difficult to ensure complete mixing of wastes with treatment reagents.

Special Requirements/Considerations--

Carrying out neutralization reactions in an earthen impoundment poses the risk of contaminating groundwater if a liner system is not properly installed and maintained. Reagents used in neutralization are corrosive and must be handled with appropriate precautions.

Neutralization of some wastes has the potential of producing air emissions. Acidification of streams containing certain salts, such as sulfides, will produce toxic gases. Adequate mixing should be provided to disperse the heat of reaction if wastes being treated are concentrated.

C.4.2.4 Chemical Dechlorination

Description--

Chemical dechlorination refers to a group of emerging technologies that can be used to strip chlorine atoms from highly chlorinated toxic compounds such as PCBs. One such process, developed by Acurex Corporation, uses a sodium reagent in a nitrogen atmosphere to decompose PCB. PCB- or pesticide-contaminated sediments must first be solvent washed to extract the PCBs before entering the reactor. The solvent is later reclaimed for reuse. This process has been tested on a laboratory scale for PCB-contaminated sediments. Portable units are available.

Several other companies, including Sunohio, Inc. and Goodyear Tire and Rubber Company, have developed similar processes.

Applications--

Chemical declorination processes are suitable for treating PCBs, dioxins, and chlorinated pesticides. Information on the process developed by Sunohio indicates that it can economically treat wastes containing up to 6,000 ppm PCBs. This process has been shown to reduce PCB concentration (in transformer oil) from 225 ppm to 1 ppm. (Stoddard et al. 1981).

Limitations--

The Sunohio and Acurex processes are not able to treat PCBs or other chlorinated compounds directly. The waste constituents must first be extracted using a solvent. These processes have not been demonstrated for treatment of sediments.

Special Requirements/Considerations--

The solvents used to reclaim PCBs or other chlorinated compounds prior to feeding them to the reactor can be reclaimed for reuse (NUS 1983). The process itself poses some risks since it involves reactions with metallic sodium reagents. Sodium can react violently with water, air, and other substances. However, these reactions can be prevented by proper process controls. Skilled operators are required to carry out chemical dechlorination.

C.4.2.5 Biological Treatment

Description--

The mechanism of biological treatment is described in Section C.3.2. However, in instances where contaminated sediments, rather than aqueous waste streams, are being treated, biodegradation would take place in an

impoundment basin or reaction tank. Oxygen would be supplied by aeration wells, diffusors, or in-line injection of oxygen or hydrogen peroxides. Nutrients would be added to promote biological growth.

Applications--

The applicability of biological treatment for various waste types is described in Section C.3.2. Because of the need to promote complete mixing of nutrients and aeration of soils, biological treatment would be best suited to slurries that can easily be mixed or to dewatered sediments that are sufficiently permeable to ensure contact of nutrients and oxygen with microorganisims.

Limitations--

Biological treatment is not suitable for waste streams containing high concentrations of metals and many chlorinated compounds.

It is also not suitable for treating fine-grained sediments that have been substantially dewatered, since it would be difficult to ensure complete oxygenation and mixing of nutrients.

Special Requirements/Considerations--

Carrying out biological treatment in an impoundment basin poses the risk of contaminating groundwater if a liner system is not properly installed and maintained. Biological treatment processes can be slow to initially effect treatment unless the microorganisms are adapted to the specific wastes. Neutralization may be required to adjust the pH to the range of 6 to 9 prior to biological treatment.

C.4.3 Summary

Techniques for treatment of solids and information pertinent to their evaluation and selection are summarized in Table C-5.

TABLE C-5. SUMMARY OF SOLIDS TREATMENT TECHNIQUES

Technique	Applications	Limitations	Secondary Impacts	Relative Cost
Cement-based Solidification	Physical incorporation of waste into the cement matrix in order to facilitate handling and/or minimize leaching.	Waste constituents, both organic and inorganic, are subject to leaching. A number of salts, and some clays and silt, will cause problems with the set, cure, and permanence of cement. Cause large increases in volume and weight.	Waste constituents will leach into soils and groundwater if there is no secondary contaminent.	Low to Medium
Silicate-Based Solidification	Chemical binding of heavy metals and physical incorporation of various other waste types (feasibility for other waste types must be determined on a case-by-case basis). Facilitates handling and/or minimizes leaching.	Applications for wastes other than heavy metals are not well demonstrated. Tendency for some leaching of waste constituents.	Waste constituents will leach into soils & groundwater if there is no secondary containment, although leaching is not as significant as with cement-based processes.	Low to Medium
Surface Encapsulation	Highly contaminated sediments.	Requires specialized equipment and specially trained equipment operations. Relatively costly.	No significant impacts.	High

(continued)

TABLE C-5. (continued)

Technique	Applications	Limitations	Secondary Impacts	Relative Cost
Chemical Oxidation/ Reduction	Oxidation of cyanides, phenols, polynuclear aromatic hydrocarbons, various pesticides. Reduction of chromium.	May result in more toxic or mobile degradation products. Not suitable for fine grained sediments that have been dewatered. Effectiveness is very waste- and site-specific. Not demonstrated for contaminated sediments.	Potential for groundwater contamination if reactions are carried out in an impoundment.	Medium to High
Solvent Extraction	Flushing of heavy metals using acids, bases or chelates. Flushing of hydrophobic organics using surfactants.	Not suitable for fine-grained sediments which have been dewatered. Effectiveness is very waste- and site-specific. Not demonstrated for contaminated sediments.	Potential for groundwater contamination if reactions are carried out in an impoundment.	Medium to High
Neutralization	Adjusting pH of acid or alkaline waste streams.	Not suitable for fine grained sediments that have been dewatered. Not demonstrated for contaminated sediments.	Potential for groundwater contamination if reactions are carried out in an impoundment.	Low to to Medium

(continued)

TABLE C-5. (continued)

Technique	Applications	Limitations	Secondary Impacts	Relative Cost
Chemicals Dechlorination	Degradation of difficult to degrade chlorinated contaminants such as PCBs.	Not fully demonstrated for contaminated sediment.	No significant impacts.	
Biological Treatment	Degradation of a wide range of organics present at non-inhibitory levels.	Not suitable for fine-grained sediments that have been dewatered. Start-up time may be slow. Not demonstrated for contaminated sediments.	Potential for groundwater contamination if reactions are carried out in an impoundment.	Low to High

APPENDIX D

CONTAMINATED MATERIAL DISPOSAL TECHNIQUES

Removal and treatment of contaminated bottom materials from lakes, streams, rivers, coastal waters, and estuaries can generate the following wastes that require ultimate disposal:

- Contaminated or treated sediments (Appendices B and C)
- Effluents from liquid waste treatment (Appendix C)
- Residues (solids and sludges) from aqueous waste treatment and incineration (Appendix C).

These wastes may be disposed of by various methods, but the selection of a disposal method must consider whether the waste is a hazardous waste under the Resource Conservation and Recovery Act (RCRA) or a regulated PCB-containing material under the Toxic Substances Control Act (TSCA). In general, the above three waste streams must be disposed of by strict standards if:

1. They are ignitable, corrosive, reactive, and/or are toxic according to a prescribed leaching test (see EP Toxicity in Appendix G, Glossary) under RCRA (40 CFR, Parts 261-20 to 261.24), and/or
2. They contain any concentration of a RCRA-listed substance, and/or
3. They contain PCBs in excess of 50 ppm.

Of the criteria in Item 1, only EP toxicity is likely to apply to contaminated sediments or to the effluents and residues generated by their treatment or incineration. Environmental physical and chemical conditions at the bottoms of water bodies would generally preclude sediments from exhibiting any ignitable, corrosive, or reactive properties that contaminants may have exhibited prior to entering the water body. The contaminants most likely to cause EP toxicity in contaminated sediments are the heavy metals: cadimum, chromium, lead, and mercury.

As suggested by Item 2 above, contaminated bottom materials or the effluents and residuals generated by their treatment could also fall under the definition of a RCRA hazardous waste if they are known to result from a cleanup of a spill of one or more of the materials listed under 40 CFR,

Part 261.30 to 261.33. It is important to note that any concentrations of "listed" substances in the cleanup materials results in their classification as RCRA hazardous wastes.

PCB concentrations in sediments, treatment effluents, or residuals are regulated under TSCA. TSCA regulations require that substances containing PCBs in concentrations exceeding 50 ppm be disposed at special PCB disposal facilities approved by EPA. Under TSCA, intentional dilution cannot be used to reduce to PCB concentrations below the threshold concentration of 50 ppm.

This appendix describes disposal options in separate sections for sediments, liquids, and residuals. Options are discussed primarily in terms of an overview of regulatory requirements and standards stipulated under the Resource Conservation and Recovery Act (RCRA), the Clean Water Act (CWA), the Marine Protection, Research, and Sanctuaries Act (MPRSA), and other Federal regulations. These regulations affect and, in most cases, dictate the available methods of disposal for such materials.

D.1 SEDIMENTS

Sediments that are removed in the course of a cleanup project can vary in composition and level of contamination. There are basically three methods of disposal: landfilling, land treatment, and open water disposal. However, open water disposal is not a legal option for hazardous or PCB-contaminated sediments. Moreover, PCB-contaminated sediments may not be placed in land treatment facilities; they can be placed only in EPA-approved landfills. Landfilling may be used for any type of non-PCB containing sediment disposal, but sediments containing hazardous wastes must be disposed of in specially permitted landfills or land treatment facilities, which are constructed and operated according to more rigid permit conditions than those facilities limited to acceptance of only nonhazardous sediments. Landfilling and land treatment of hazardous and nonhazardous sediments and open water disposal of nonhazardous sediments are discussed in the following sections.

D.1.1 Landfilling

D.1.1.1 Description

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. A RCRA hazardous waste landfill must be designed and operated according to the RCRA Landfill Facility Standards under 40 CFR Parts 264 and 265 or according to the state hazardous waste regulations in those states with authority to administer this part of the

RCRA regulations. Nonhazardous waste landfills must be designed and operated according to the regulations in the relevant state and/or local government. These state and local regulations are generally based on guidelines and criteria for solid waste management, issued under sections 1008(a) and 4004 of RCRA and under 40 CFR, Parts 241 and 257. Disposal regulations (particularly in California) for both nonhazardous and hazardous wastes are more stringent in certain states than Federal disposal regulations. Therefore, state regulations should be considered carefully when identifying and evaluating disposal alternatives.

The RCRA Hazardous and Solid Waste Amendments (HSWA) of 1984 require new hazardous waste landfills to have a double liner system, a leachate collection system, and a leachate removal system. The double liner system may consist of two synthetic liners and at least 5 feet of clay, or one synthetic liner and a clay layer that will not be penetrated by waste leachate for at least 30 years, even if the synthetic liner fails (USEPA 1984). Requirements for nonhazardous waste landfills are less stringent, but vary considerably between states. Generally, these requirements allow for consideration of geologic features (such as a natural clay layer) in the design of leachate control and groundwater protection systems.

Wastes can be transported to an existing permitted landfill, or a new, dedicated landfill can be constructed. Construction of a dedicated landfill should be considered in terms of the duration of the project, the costs of alternate disposal options, the degree of natural waste containment offered by the potential landfill site, local public awareness and sentiment, and the duration and complexity of the state permitting process. These are only a few of the factors that will affect the decision on costs and time involved in providing a dedicated nonhazardous landfill.

D.1.1.2 Applications

Hazardous waste landfills can receive both nonhazardous waste and hazardous wastes as defined under RCRA (see Section D.1.1.1 for definitions). Nonhazardous waste landfills can receive only nonhazardous wastes. Revisions to the RCRA regulations, under the authority of the Hazardous and Solid Waste Amendments of 1984 prohibited landfilling of bulk liquid wastes by 1985, and gradually prohibit landfilling of certain types of hazardous wastes over the next decade.

D.1.1.3 Limitations

There are almost no limitations for disposing of nonhazardous sediments in existing nonhazardous landfills. Some facilities may be restricted to municipal or industrial wastes. Other nonhazardous landfill facilities may have maximum daily disposal volumes or may limit the percentage of

liquids allowed in bulk wastes. The most severe limitation to the disposal of nonhazardous sediments in existing landfills is the transportation distances involved. Long transport distances may result in extremely high ultimate disposal costs.

Limitations concerning hazardous waste landfills include those listed above for nonhazardous waste landfills and several additional limitations. Since mid-1986, hazardous waste landfills have not been allowed to receive materials containing free liquid (liquid that can separate by gravity or compression from the bulk of the material). Individual landfills may have more stringent waste-acceptance restrictions. PCB-contaminated materials exceeding 50 ppm cannot be accepted at hazardous waste landfills that do not have EPA approval for PCBs.

It should also be noted that the option of constructing a dedicated landfill for disposal of contaminated sediments should be considered only under the most extreme circumstances, such as when hundreds of thousands of tons of wastes are involved. For example, the construction of one four-acre hazardous waste landfill would cost a minimum of $10 million, not including post-closure maintenance and permitting costs. The minimum time to obtain a permit for a hazardous waste landfill is about 2 1/2 years.

D.1.1.4 Special Requirements/Considerations

Special requirements and considerations differ significantly between different states and depend on whether wastes are being landfilled at a new landfill or at an existing landfill. For a new hazardous waste landfill, a RCRA permit is required and the facility must also be designed to meet requirements which are stricter than those applied to existing landfills (see previous section).

RCRA requires all owners and operators of hazardous waste land disposal facilities to establish a groundwater monitoring program. The groundwater monitoring program must be capable of determining the facility's impact on the quality of groundwater in the uppermost aquifer underlying the facility. Many states now require similar monitoring at nonhazardous waste disposal sites.

Since 1985, sludges and slurries meeting the definition of a hazardous waste have been required to be treated (see Section C.2) to remove any free liquid before landfilling. Other pretreatment requirements, such as neutralization and precipitation of metals, depend on specific landfill permit requirements and state regulations.

All hazardous wastes that are being transported for off-site disposal must be properly manifested in accordance with 40 CFR Parts 262 and 263. These same regulations also describe the requirements for labelling, placarding, and packaging wastes according to Department of Transportation (DOT) regulations.

D.1.2 Open Water Disposal

D.1.2.1 Description

Open water disposal involves placement of materials into ocean, estuary, river, or lake waters or wetlands, where the materials settle to the bottom of the water body. Materials are normally dumped or pumped from barges, scows, or hoppers into the water column. This type of disposal is regulated under the Marine Protection Research and Sanctuaries Act and the Clean Water Act.

D.1.2.2 Applications

The applicability of open water disposal for a particular dredged material must be determined on a case-by-case basis. In general, ocean disposal and disposal in inland waters is suitable only for noncontaminated sediments, and for sediments with only trace levels of contaminants that can be demonstrated to cause no harm to the receiving water body.

D.1.2.3 Limitations

Open water disposal of dredged materials is not applicable to contaminated sediments that will adversely impact the chemical, physical, or biological integrity of the receiving water body. Because of the stringency of testing requirements, the permitting process is costly and time-consuming, particularly for a permit for ocean disposal or disposal in a wetland area. Further, the presence of hazardous contaminants in dredged sediments could cause regulatory authorities to deny an openwater disposal permit.

D.1.2.4 Special Requirements/Considerations

Ocean disposal of dredged material is regulated by the Marine Protection, Research, and Sanctuaries Act of 1972. This act requires that a permit can be issued only after consideration of the environmental effects of the proposed operation, the need for ocean dumping, alternatives to ocean dumping, and the effect of the proposed action on aesthetic,

recreational, and economic values. Furthermore, bioassays and bioaccumulation studies must be conducted to determine whether contaminants will adversly affect biota. A detailed environmental assessment is also required (Peddicord 1980).

Disposal of dredged material in estuaries and inland waterways is regulated mainly by the Clean Water Act. The criteria are similar to those for ocean dumping in that issuance of a permit requires prior demonstration that dumping will not adversely impact water quality and biota. Testing requirements may typically include chemical comparison of the dredged material with the disposal site sediments and possibly benthic bioassay and bioaccumulation studies (Peddicord 1980).

D.1.3 Land Treatment/Disposal

D.1.3.1 Description

Land treatment of wastes and solids is generally a biological treatment technique used on both RCRA hazardous and nonhazardous organic wastes. Land treatment reduces the waste volume through evaporation and transforms contaminants into a less complex organic and inorganic mixture suitable for soil cultivation.

Land treatment may be used to dispose of dredged sediments or effluent from treatment facilities. The wastes are spread or sprayed over land in a controlled manner such that no runoff occurs, and all of the free liquids in the wastes either infiltrate the ground surface or evaporate. Land treatment is facilitated by microorganisms that are naturally occurring in the soil and degrade wastes. The land application area is diked to prevent erosion and runoff and to help keep the soil moist. Liquid or sludge is applied by spraying or spreading on the land surface or injection below the surface. Under proper conditions of aeration, moisture, and nutrient concentrations, and with correct application rates, bacteria degrade the wastes to carbon dioxide and water. The soil also has a limited capacity to immobilize organics by various chemical means (Morrison 1983). When only nonhazardous liquids are involved, this technique is sometimes called "spray irrigation".

Land treatment of hazardous wastes is stringently controlled by Federal requirements and by equally (or more) stringent state regulations in those states authorized to administer RCRA land disposal regulations. Land treatment of nonhazardous wastes is regulated by the individual states; Federal laws do not apply.

D.1.3.2 Applications

Land treatment of relatively contaminant-free waste is best used in arid climates to afford maximum evaporation. Biodegradable contaminants can be present in the waste since treatment is accomplished by bacteria within the soil.

Land treatment is best suited for wastes types that are amenable to biodegradation. Waste oil and grease and certain pesticides and solvents can be treated by land application. RCRA regulations (40 CFR Part 264) allow application of any hazardous wastes that can effectively be degraded, transformed, or immobilized. However, there are stringent requirements to assure complete degradation of specific constituents and protection of the underlying groundwater. There is no list of acceptable or unacceptable wastes and suitability must be evaluated on a case-by-case basis (Morrison 1983).

D.1.3.3 Limitations

Land treatment of hazardous wastes will probably not be permitted in areas with a high water table since the regulations require a minimum separation of three feet between the bottom of the treatment zone and the seasonal high water table. Land treatment is also not well suited to soils with high moisture content since this may impede oxygen transfer to soil microorganisms (Morrison 1983). Land treatment cannot be accomplished on frozen or snow-covered land and is, therefore, seasonally not appropriate in some climates. In addition to the above limitations, land treatment of hazardous and nonhazardous waste is subject to most of the same limitations discussed for landfills under Section D.1.1. However, it is generally more difficult to obtain a RCRA permit for a hazardous waste land treatment facility than for a landfill.

D.1.3.4 Special Requirements/Considerations

Land treatment of wastes from a hazardous waste spill cleanup must comply with the intent of RCRA regulations (40 CFR Part 264). The regulations require that the wastes be degraded, immobilized, or transformed in the "treatment zone." Groundwater in the unsaturated zone beneath the treatment zone must be monitored to ensure effectiveness of the method. The regulations also require a "treatment demonstration" prior to operation of a facility. The treatment demonstration will determine what wastes are allowable and under what conditions. These conditions are specified in a facility permit required prior to implementation.

D.2 LIQUIDS

Wastewater that is removed in the course of a cleanup project can vary in the presence and concentration of contaminants. Further, contaminated wastewater may or may not have been treated prior to disposal (see Section C.3). Three methods of wastewater disposal (direct discharge, land treatment, and deep well injection) are described in the following sections.

D.2.1 Direct Discharge

D.2.1.1 Description

Direct discharge is the discharge of any material into "waters of the United States," defined in 40 CFR, 122.3 as navigable waters, tributaries to navigable waters, lakes, rivers, and streams that are used for recreation, commercial fishing, and other interstate commerce.

The EPA regulates direct discharges through the National Pollutant Discharge Elimination System (NPDES). Some states have been given the authority to administer the NPDES program and may have more stringent requirements than the Federal program. In general, any party responsible for discharging from a point source must obtain a permit that specifies discharge limitations in terms of quantity of flow, concentrations of contaminants, and mass of contaminants. The contaminants chosen for each applicant vary according to general industry and site-specific criteria.

D.2.1.2 Applications

Direct discharge of liquid is generally applicable to effluents from treatment facilities and other waste streams that contain relatively low concentrations of contaminants. Larger, high-flow water bodies generally are able to receive higher discharge flows and contaminant concentrations because of dilution.

D.2.1.3 Limitations

NPDES permit requirements may necessitate wastewater treatment to lower contaminant concentrations prior to discharge. The NPDES permitting process is generally lengthy and may be extended by the uncertainty of the discharge compositions from hazardous materials cleanup projects.

D.2.1.4 Special Requirements/Considerations

A request for a permit must generally be submitted a minimum of 180 days prior to the anticipated date of discharge. The permit regulations require that extensive data be submitted as part of the application including information on flow rates, quantitative waste characterization, location of discharge, etc.

Furthermore, the applicant should expect monitoring to be a requirement under the permit, regardless of the concentrations of contaminants in the proposed discharge. The permit will also specify monitoring methods and frequencies and procedures for installing and maintaining monitoring equipment.

D.2.2 Deep Well Injection

D.2.2.1 Description

Deep well injection involves the subsurface placement of fluid through a well that has been permitted by a state or EPA permit-issuing authority. The well must be cased and cemented to prevent the movement of fluids into or between underground sources of drinking water. Furthermore, the well must be located so that the point of injection is at least one quarter of a mile above or beneath the lower-most formation containing groundwater. Other design criteria and standards that apply to deep well injection are described in 40 CFR Parts 144 through 146.

D.2.2.2 Applications

The permit conditions for each deep well injection facility specify the types of wastes that may be injected. Wastes accepted for deep well injection are usually inorganic with low organic content. The wastes must meet a relatively stringent suspended and settleable solids specification to prevent clogging of the injection zone (Wuslich 1982).

D.2.2.3 Limitations

The off-site disposal of hazardous liquid wastes at an existing deep well site would not present major limitations other than the need to manifest each shipment. Disposal of nonhazardous liquids by off-site deep well injection would probably not be cost-effective. On-site disposal of wastes by deep well injection will almost invariably be cost-prohibitive because of the extensive testing required to design and locate a well that can be demonstrated to have no adverse impact on drinking water and public health.

D.2.2.4 Special Requirements/Considerations

Monitoring programs are required with deep injection wells in order to detect migration of contaminants into drinking water aquifers. Injection wells must be equipped with continuous recording devices for monitoring injection pressure, flow rate, and volume. Waste streams to be injected must be pretreated using granular media filtration and possibly ultrafiltration to remove suspended solids greater than 1 micron in size. Persons intending to dispose of wastes by deep well injection must apply for and obtain a permit that complies with all applicable standards and criteria specified in 40 CFR Parts 144-146.

D.3 SLUDGE AND SOLID TREATMENT RESIDUALS

Treatment residuals, as defined in this appendix, are sludges and solid byproducts of treatment processes. Treatment residuals include but are not limited to spent sorbents, precipitation/coagulation sludges, filter media, scrubber sludges, and oil and grease. Three disposal methods (landfilling, incineration, and land treatment) are described in the following sections.

D.3.1 Landfilling

D.3.1.1 Description

The description of landfilling of sediments under Section D.1.1.1 also applies to treatment residuals.

D.3.1.2 Applications

The applications of landfilling for sediment disposal under Section D.1.1.2 also apply to treatment residuals. Treatment residuals that are most appropriate for landfilling are spent sorbents, filter media, "fixed" and solidified sludges, and other solid materials.

D.3.1.3 Limitations

The limitations of landfilling for sediment disposal under Section D.1.1.3 also apply to treatment residuals.

D.3.1.4 Special Requirements/Considerations

The special requirements and considerations of landfilling for sediment disposal under Section D.1.1.4 also apply to treatment residuals.

D.3.2 Incineration

D.3.2.1 Description

Incineration is the process of reducing the volume and/or toxicity of organic wastes by exposing them to high temperatures under controlled conditions. The main products of incineration include carbon dioxide, water, ash, and certain acids and oxides. The most commonly used incinerators for solid and liquid wastes are rotary kiln, multiple-hearth, fluidized bed, and high temperature fluid wall. Some incinerators are commercially available in mobile systems that can be transported to a cleanup project for on-site incineration of waste materials. Otherwise, off-site facilities must be used.

D.3.2.2 Applications

The BTU content of the waste is an important factor in determining suitability of a waste stream for incineration, and treatment residuals are likely to have low BTU contents. In the hazardous waste incineration industry, it is common to blend wastes with fuels to achieve an overall heating value of 8,000 BTU/lb or more (Oppelt 1981). A commercial hazardous waste facility may not accept a waste that has a BTU value unsuitable for blending or direct use.

Depending upon the type of incinerator, state and Federal regulations for incinerator facilities, and the facility's permit conditions, different maximum air emissions concentrations may be set for chlorine, sulfur, metals, and ash content. In addition, the facility must be able to achieve 99.99 percent destruction and removal efficiency for each principal organic hazardous constituent (POHC) in the permit. Each facility permit will specify POHCs to be used in monitoring the emission levels. More stringent destruction efficiencies are required to burn PCBs. In general, rotary kiln and high-temperature fluid wall incinerators are able to accept compounds with a higher heat of combustion than multiple hearth and fluidized bed incinerators (Stoddard 1981).

D.3.2.3 Limitations

Incineration is not applicable for destruction of inorganic wastes. Highly chlorinated waste, such as PCBs and dioxins, are not permitted at most facilities. Incineration is also not applicable for any waste type that will cause an existing facility to violate permit conditions.

D.3.2.4 Special Requirements/Considerations

Air pollution control equipment is generally required to remove particulates and certain gases from the exhaust gas stream. Wet scrubbers are generally used for this purpose, although electrostatic precipitators may be used for removal of particulates, and afterburners may be used for combustion of certain gases.

Incinerators generally require use of water to cool certain portions of the system. Auxiliary fuel may also be required particularly for low-BTU wastes.

Federal regulations require that an operator obtain a permit to incinerate hazardous wastes. The Federal regulations specify incinerator requirements, including test burns for new facilities, under 40 CFR Part 264.

State regulations may be more stringent than the Federal regulations.

D.3.3 Land Treatment/Disposal

D.3.3.1 Description

The description of land treatment and disposal of wastewater and other liquid effluents under Section D.1.1.1 also applies to treatment residuals.

D.3.3.2 Applications

The applications of land treatment and disposal of liquid and solid wastes under Section D.1.1.2 also applies to treatment residuals.

D.3.3.3 Limitations

The limitations of land treatment and disposal of liquid and solid wastes under Section D.1.1.3 also apply to treatment residuals.

D.3.3.4 Special Requirements/Considerations

The special requirements and considerations of land treatment and disposal of liquid and solid wastes under Section D.1.1.4 also apply to treatment residuals.

D.4 SUMMARY

Disposal methods and information pertinent to their evaluation and selection are summarized in Table D-1.

TABLE D-1. SUMMARY OF CONTAMINATED MATERIAL DISPOSAL TECHNIQUES

Technique	Applications	Limitations	Secondary Impacts	Relative Cost
Landfilling	Can receive hazardous and nonhazardous solids and some sludges.	Transportation costs may be extreme for hazardous materials. Free liquid cannot be accepted. PCB-contaminated materials are accepted at only a small number of approved landfills. Construction of a dedicated landfill is costly and time-consuming.	Potential for causing/contributing to leachate generation and groundwater contamination.	Low to High
Open Water Disposal	Sediments with low contaminant concentrations. Large volumes of sediments.	Permitting approval process is time consuming. Various studies may be needed to predict impacts. Not applicable to highly contaminated sediments.	Potential for causing a second environmental problem or spreading the initial problem. Potential water contamination via resuspension of contaminants. Potential contamination of fisheries.	Low to Medium
Land Treatment/ Disposal	Sediments, liquids, and sludges with low and/or biodegradable contaminant concentrations.	Not permitted in high water table areas, high rainfall areas, and cold climates.	Potential for causing leachate generation and groundwater and surface water contamination.	Low to High

(continued)

TABLE D-1. (continued)

Technique	Applications	Limitations	Secondary Impacts	Relative Cost
Land Treatment/ Disposal (continued)		Can be land intensive for long periods of time.		
Direct Discharge	Treated effluents with low flow rates relative to the receiving water body.	Liquid must meet strict permit requirements for concentrations of contaminants. Permitting process can be time-consuming.	Potential for causing contamination of surface water and sediments. Potential contamination of fisheries.	Low
Deep Well Injection	Highly contaminated liquids with low concentrations of suspended solids.	Transportation costs may be extreme for hazardous materials. Pretreatment may be required for suspended solids. Construction of on-site well is not practical.	Potential for causing groundwater contamination.	High
Incineration	Organic liquid, solid, and sludge wastes and contaminated sediments.	Does not apply to inorganic wastes. Facility must be permitted to accept contaminants of concern. Permitting for on-site incineration may be time-consuming and costly. Residuals must be treated or disposed.	Potential for causing air pollution.	Medium to High

APPENDIX E

IN SITU CONTAMINANT TREATMENT AND ISOLATION TECHNIQUES

In responding to a spill or a discharge of a sinking hazardous substance, it is sometimes physically or economically impractical to consider removing all of the contaminated material from its location in the watercourse. Response techniques that allow the spilled substance or the contaminated sediments to remain in place (or "in situ") may be applicable in such situations.

E.1 TREATMENT

In situ treatment methods involve the addition and mixing of chemical or biological reagents with contaminated bottom materials in place. The treatment promotes a physical, chemical, or biological reaction with the contaminants to form products that pose a reduced hazard. Treatment methods include sorption and chemical and biological processes. Each of these treatment methods is discussed in the following sections.

E.1.1 Sorption

E.1.1.1 Description

Sorption is the general term that refers to two processes: adsorption and absorption. In both processes, a sorbant material removes contaminants from a substance of concern (such as sediments) and incorporates the contaminants into its own structure. In adsorption, contaminants are drawn into small pore openings on the surface of the adsorbant material by physical and chemical attractive forces. In absorption, contaminants are "soaked up" by the absorbant, sometimes causing the absorbant to swell as the process takes place.

There are various types of sorbents and gels that can be added to contaminated sediments to induce the sorption process: activated carbon, polymer foams and fibers, resins, and gelling agents.

Activated Carbon--

Activated carbon is a highly porous carbon. It is so porous that a large percentage of the carbon atoms are surface atoms and are capable of adsorbing other materials. Activated carbon is made by controlled heating of a variety of materials, including wood, coal, and coconut shells. Three methods of applying activated carbon to contaminated bottom materials are carbon "pillows", direct carbon application, and permeable treatment barriers.

Carbon pillows are permeable filter bags filled with granules of activated carbon. Liquids can flow through the bag material, contact the carbon, and flow back through the bag material into the water column. Flotation units can be attached to the bags such that the bags are in a vertical position on the bottom of the water body and the contaminants are removed over an interval of depth (Pilie et al. 1975).

Granules of activated carbon can also be applied directly to contaminated bottom materials. Activated carbon is more capable than sediments of "holding" contaminants over time and, to the extent that contaminants are transferred from sediments to activated carbon, the contaminants are made less available to leaching into the water column or otherwise re-entering the environment. A three-phased equilibrium is established with the higher contaminant concentrations adsorbed to carbon, a lower concentration on the sediment, and the lowest concentration in water (Mackenthur et al. 1979). Laboratory studies have demonstrated the use of activated carbon in reducing levels of organics in the water column, but the feasibility of this has not been demonstrated on a large-scale application.

Permeable treatment barriers consist of two parallel wire mesh fences that are firmly anchored to the bottom. The spacing between the fences is filled with activated carbon in the form of carbon fibers, which resemble loosely packed steel wool. The fibers are weighted to sorb sinking spills. Carbon fibers developed for testing purposes have shown excellent adsorption potential in laboratory experiments (Pilie et al. 1975), but full-scale applications have not been demonstrated.

Polymer Foams and Fibers--

A wide range of polymeric foams and fibers has been developed in conjunction with hazardous oil spill recovery work. These products have been manufactured in a number of forms, including pillows, sheets, strips, booms, and pads. They are manufactured using various materials, including polyethylene, polypropylene, and polyurethane. Polymer foams and fibers can be used in the treatment or sinking spills by weighting the sorbents so that they sink to the bottom and contact the spill.

Resins--

Resins are synthetic sorbents with a porous structure that is similar to the molecular porosity of activated carbon (Bauer et al. 1976) and can

be applied to in situ treatment of bottom materials in the manner described for activated carbon, above.

Gelling--

Gelling agents may be used for in situ coagulation of contaminated sediments. One commercially available product is imbiber beads, which are made of polybutyl styrene. These beads have the capacity to absorb organic substances up to 27 times their volume. Water can initially pass through pads or pillows of the beads, which provide approximately 30 percent void space. Upon contact with an organic fluid, the beads expand and fill the void space, preventing further flow. Water is not absorbed and organic contaminants are permanently locked into the imbiber bead matrix. Gelling agents are available in blankets or packets, which are weighted so they can be deployed to the desired depth (EMCO undated).

E.1.1.2 Applications

Sorbents can be used only in relatively quiescent waters because of the logistics of placement and the risk of resuspending contaminants.

Activated carbon can effectively adsorb a broad range of organic and inorganic constituents. The adsorption efficiency depends on the type of carbon, the properties of the constituents (i.e., molecular size, polarity, solubility, and solution pH), and the contact time with the carbon.

Resins are less versatile than activated carbon. However, if sulfonated, resins sorb dissolved ionic contaminants more readily and are, therefore, better suited to sorption of metals and ionic organics than activated carbon. Resins also tend to sorb soluble species, whereas activated carbon favors sorption of nonsoluble compounds.

E.1.1.3 Limitations

In situ treatment techniques are generally not widely proven and accepted for treatment of contaminated bottom materials. Consultation with researchers and technical representatives may be needed to successfully implement the techniques.

The primary limitation of any sorption technique is that sorptive materials do not destroy or remove the contaminants and desorption (release of contaminants) over the long-term may occur. In addition, there are some limitations to the location in which some of the sorption methods can be applied. For example, carbon pillows are not effective in calm waters, as some nominal flow is needed to continuously bring contaminants into contact with the carbon. Permeable treatment barriers cannot be used in deep and

fast-flowing waters. High flow rates tend to wash away the wire mesh fence, whereas low flow rates limit the contact between the carbon and the contaminants.

E.1.1.4 Special Requirements/Considerations

Deployment and placement of sorbents can require support vessels with booms or cranes. Diver assistance may be necessary in deep-water applications. Manual labor and light equipment will be needed in shallow-water applications.

Costs of *in situ* sorption treatment can vary widely, ranging from low to high relative to other *in situ* techniques, depending on the contaminants, the setting, and the sorbent used.

E.1.2 Chemical and Biological Treatment

E.1.2.1 Description

Various chemical and biological treatment techniques can be used to treat *in situ* contaminated sediments and sinking spills or discharges. These techniques include precipitation, neutralization, oxidation, chemical dechlorination, and biological treatment. These techniques are most commonly used to reduce the concentrations of hazardous substances in industrial sludges and liquids. Chemical and biological treatment techniques involve mixing a treatment reagent with the contaminated sediments, allowing a reaction to take place that will modify the waste and render it less hazardous. Most chemical and biological treatment methods require other stream diversion or containment of the contaminated sediments in order to allow for proper mixing of the treatment reagent with the sediments and to ensure adequate time for the treatment reagent to be in contact with the sediments.

Precipitation--

Precipitation controls contaminants by converting high-solubility substances into low-solubility substances, thereby limiting their ability to contaminate the water column. The process involves stream diversion or containment of a spill, followed by spreading and mixing precipitating agents with the sediments. The result is a low-solubility solid substance (a "precipitate") that is a less hazardous substances. This process is amenable to inorganic contaminants. Sulfide precipitation reagents are the most promising because metal sulfide precipitates are the least soluble metal compounds that are likely to form over a broad pH range. Calcium sulfate, iron sulfate, or gypsum may also be used as precipitation agents. Solutions and slurries of precipitation agents can also be applied directly to sediments in calm waters using pumps and hoses.

Neutralization--

Neutralization involves stream diversion or containment of a spill, followed by spreading and mixing neutralizing agents with the sediments. This process is amenable to treating highly acidic and basic contaminants. The treatment reagents are weak acids and bases that react to form water and, in general, less hazardous substances. For example, calcium carbonate or sodium bicarbonate (bases) are used to neutralize acidic substances. Neutralizing agents can be applied to in situ sediments as slurries by using sand spreaders or a diffuser head, or by open pipe discharge. They can be applied as solids either by broadcast spreading or by use of hand shovels within the contained area.

Oxidation--

Oxidation involves the application of treatment reagents to oxidize spilled substances, thereby converting them to less hazardous substances. Containment of spills or contaminated sediments may be necessary prior to oxidation in order to prevent loss of oxidant and oxidation of non-target compounds outside the contaminated area. Contaminants amenable to oxidation include a wide range of organics. Highly chlorinated compounds and nitro-aromatics are not well suited to oxidation. Treatment reagents used for oxidation are oxygen and/or ozone, and hydrogen peroxide.

Chemical Dechlorination--

Chemical dechlorination entails the mixing of chemicals that react with chlorinated compounds, converting the chlorine component to chlorine salts and other nonhazardous compounds. The process requires stream diversion and sediment dewatering prior to mixing dechlorination agents with the sediments. Treatment agents used in this process are polythylene glycol or potassium hydroxide. Dechlorination is amenable to highly chlorinated organic contaminants, such as PCBs and dioxin.

Biological Treatment--

Biological treatment involves containment of contaminated materials followed by the addition of microorganisms to the materials. These microorganisms metabolize the contaminants, rendering them less hazardous. An oxygen source (for aerobic degradation) and nutrients must also be added to support the microorganisms. Biological treatment is used to degrade organic contaminants.

E.1.2.2 Applications

In general, in situ chemical and biological treatment methods may be most applicable to water bodies with low-velocity flows and currents.

Precipitation is applicable to inorganic contaminants that are in the ionic (dissolved) form, particularly metals.

Neutralization is applicable to highly acidic and basic contaminants. However, unless the spilled substance is otherwise hazardous or if the volume of the spill is large in relation to the size of the water body, natural dispersion and dilution can often rapidly return the pH of the water body to background.

Oxidation is applicable to most organic compounds, except highly chlorinated organics and nitro-aromatic compounds.

Chemical dechlorination is applicable to highly chlorinated organic compounds, such as PCBs and dioxin.

Biological treatment is applicable to organic contaminants, provided that, for aerobic treatment, sufficiently high concentrations of oxygen are naturally or artificially available to the active bacteria.

E.1.2.3 Limitations

In situ treatment techniques are generally not widely proven and accepted for treatment of contaminated bottom materials. Consultation with researchers and technical representatives may be needed to successfully implement the techniques.

Sulfide precipitation of inorganic contaminants (such as metals) is effective only under reducing conditions. In addition, sulfide precipitation has the potential to release toxic hydrogen sulfide gas.

The use of ferric sulfate as a neutralization agent under aerobic conditions may result in the formation of hydrous iron oxides. These oxides can scavange heavy metals from the water column and may coat the gills of bottom-feeding organisms.

Oxidation may be difficult to induce in compounds that are sorbed to sediments. Further, when oxidation does occur, it can result in degration products that are more mobile than the original contaminants.

Chemical dechlorination treatment systems have a limited tolerance to water. Therefore, this method cannot be used where in situ dewatering cannot be accomplished prior to treatment.

Partial degradation products of biological treatment processes may be more soluble or more toxic than the original contaminants. In addition, some microorganisms used for treatment may be pathogenic. Degradation by biological treatment may also proceed so slowly, especially at low temperatures, that its use alone may not be practical as a rapid spill response.

E.1.2.4 Special Requirements/Considerations

All *in situ* chemical and biological methods have the potential for secondary environmental impacts either as a result of the use of toxic treatment reagents or as a result of toxic products from reaction or degradation. Consequently, *in situ* treatment is generally limited to situations where the contaminated area can be contained during treatment or where stream flow can be diverted for the duration of treatment (see Appendix B).

For all *in situ* treatment methods, the treatment reagents should be well mixed with the contaminated material. Mixing can be accomplished in shallow waters with low-flow velocity by diverting the stream flow, spreading the reagents, and mixing the reagents using rubber-tired or crawler type rotor or trenching mixing equipment.

When stream diversion is not possible, *in situ* chemical injection and mixing methods may be used in cases of sinking liquids or slurries, and covering/capping methods may be used in cases of solids or sediments. The application methods must be conducted under carefully controlled conditions to minimize contamination of the water column. Because of the potential for secondary contamination and the difficulty of ensuring complete mixing of the reagent with the spill or contaminated sediments, chemical and biological treatment without stream diversion has limited application.

Costs of *in situ* chemical and biological treatment can vary widely, ranging from low to high relative to other *in situ* techniques, depending on the contaminants, the setting, and the chemical agent or biological organism used.

E.2 ISOLATION

Contaminated bottom materials can be physically isolated from the water column by a variety of methods that essentially confine the contaminants in place. The confinement can be short-term or long-term, depending on the needs of the situation. Available isolation methods include covering and capping and chemical fixation methods. These methods are discussed in the following sections.

E.2.1 Covering and Capping

E.2.1.1 Description

Covering is the application of a noncontaminated material over the surface of deposited contaminated materials. Covering is intended to

physically protect the contaminated material from erosion and transport and to limit interaction of the materials with the water column.

Capping is a special case of covering in which low-permeability materials are placed over contaminated materials so that the materials are essentially "sealed", preventing physical transport and contaminant migration by dissolution into the water column.

There are three basic types of cover and capping materials: inert materials, such as sand, silt, and clay; active materials, such as greensand, gypsum, and limestone; and synthetic liner materials.

Inert materials are placed over contaminated materials in granular form and are not intended to chemically alter the contaminants. Inert capping materials can be further divided into three classes: coarse-grained materials, fine-grained materials, and noncontaminated dredge spoils.

Active cover materials can be applied alone or with an inert material. The purpose of an active cover is to react with the contaminated materials to neutralize or otherwise detoxify the material, as well as to function as a cover. Potentially applicable active cover materials include:

- Limestone - neutralize acids
- Greensand - neutralize acids
- Oyster shells - neutralize acids
- Gypsum - precipitate metals
- Ferric sulfate - precipitate metals, neutralize bases
- Alum - neutralize bases
- Alumina - remove fluoride.

Activated carbon and ion exchange resins are also active cover materials in the sense that they adsorb contaminants. The use of these materials is discussed in Section E.1.1, Sorption.

The correct emplacement of active cover materials is critical. If placed outside the spill or contaminated area, active cover materials can be harmful to benthic organisms. Because of the potential hazard of these materials, they should be employed using a diffuser head or other system that generates little suspension.

Synthetic liners are low-permeability, flexible sheets that are customarily used to seal lagoons for seepage control or to cap waste disposal sites for infiltration control. Liners are made from a variety of materials, including polyethylene, polyvinyl-chloride, and hypalon. In applications involving contaminated bottom materials, a continuous liner can be placed

over the entire area of contamination. Large applications require splicing and sealing of sections, which cannot be accomplished under water.

There are basically three methods for placing granular (inert or active) cover materials:

- Point dumping
- Pump-down methods
- Submerged diffuser systems.

The amount of suspension and dispersion generated during capping and covering is largely a function of the method and equipment used for emplacing the material. Levels of suspension and dispersion are greatest with point dump methods and lowest with diffuser head applications. In point dump applications, cover material is dumped from the water surface, so the initial impact is largely determined by the range of particle sizes and the cohesiveness of the material (Hand et al. 1978).

In comparison with point dumping methods, pump-down methods are advantageous because they create substantially less suspension and resuspension of contaminated sediments. Pump-down is accomplished by means of pumping the cover material through a discharge pipe with an outlet located close to the desired area on the bottom of the water body.

The submerged diffuser system is one of the most effective methods for controlling the placement of cover material. The primary purpose of the diffuser head is to reduce the velocity and the turbulence associated with the discharged cover material. This is accomplished by routing the flow through a vertically oriented axial diffuser. The submerged diffuser provides increased control over the location of cover, decreased scouring of the bottom area, and less turbidity in the area of operation.

A variation on the diffuser system is the application of shotcrete (pneumatically applied concrete sprayed by hoses and nozzles). Close control of the nozzle can be maintained to place an effective cap or cover over submerged or exposed sediments.

The ability of bottom organisms to colonize a capped area without significant bioaccumulation of contaminants depends on the type of cover material, the similarity to natural surrounding sediments, the thickness of the cover, and the potential for leaching. The cap must be sufficiently thick to prevent burrowing. The majority of organisms will be found in the upper 0.3 to 0.5 feet of the strata with certain species expected to burrow to depths of one to two feet. Therefore, a cap thickness of two feet is considered adequate (Bokuniewicz 1981). Clay or silt caps are more susceptible to burrowing than sand caps, and this also should be considered when determining the thickness of the cap.

E.2.1.2 Applications

Covering and capping methods are best suited for use in waters where bottom currents and flow velocity are relatively low. Coarse-grained cover materials are best suited for applications where fine-grained materials would be transported or eroded by currents.

Covering and capping methods may be applied as a temporary remedial response or as a primary and long-term response action. They can also be used as a final step in the remedial process to isolate any residual contaminated material following the recovery and removal of contaminated material. Covering and capping methods can also be used in conjunction with other methods, such as containment dikes or trenches, to isolate and treat contaminated materials.

E.2.1.3 Limitations

Placement and long-term effectiveness of caps and covers may not be achievable in water bodies with high velocities or currents. Placement of covering and capping materials may cause suspension of the materials in the water column and resuspension of bottom materials by the turbulence of cap or cover placement.

Synthetic liner materials have been considered at a number of sites for containing contaminated sediments. Splicing of sections of conventional synthetic liners cannot be achieved under water, generally limiting the use of synthetic caps to relatively small surface areas. Also, many problems with the placement of the membrane on top of the sediment, the durability of the liner, and the compatability of the liner with the contaminated sediments prohibit this method from being of value as a long-term isolation technique.

E.2.1.4 Special Requirements/Considerations

Placement of cover and cap materials requires special equipment, including some combination of barges, scows, pumps, piping, and diffusers. Synthetic liners require specially fabricated equipment that is not readily available. In all but shallow water applications, diver assistance or closed-circuit television observation of the covering and capping progress may be needed to ensure that proper depth and continuity are achieved.

Costs of covering and capping techniques can vary widely, ranging from low to high relative to other in situ techniques, depending on the contaminants, the setting, and the cover or capping materials used.

E.2.2 Fixation

E.2.2.1 Description

Fixation involves the mixing of a substance (fixation agent) with contaminated material in order to embed the contaminated material in a stable, solid form. The process is most commonly used in solidifying industrial sludges in order to make contaminants less mobile in the environment. A number of materials are used as fixation agents, including cement, fly ash, quicklime, silicates, and bentonite.

There are basically two methods for applying fixation agents to contaminated bottom materials: in situ chemical injection and stream diversion followed by mixing.

In situ chemical injection methods involve the stabilization of contaminated sediments through the injection of grouting materials into the sediments. A method for grouting with clay-cement is the Deep Cement Mixing Method, which was developed in Japan. The system consists of a number of injection pipes mounted on a barge. The injection pipes are connected to mixing pipes that enter the sediments. Similar equipment is available for deep mixing with quicklime. The process is completed by lowering the operating mixing apparatus (mixing blades are located within the individual shafts) to the required depth and injecting a cement- or lime-based slurry into the sediments. The mixing blades are then reversed and the shafts are removed and relocated (Takenaka Doboku, Co., Inc. undated). Another barge-mounted injection and mixing apparatus continuously mixes the slurry with bottom materials and eliminates the need to continuously raise, relocate, and lower the mixing apparatus (Natori 1984).

Dewatered, exposed sediments can also be "fixed" by mixing cement, quicklime, or a grout with the contaminated sediments in order to promote stabilization. The stabilizing agent is applied to the surface and mixed with the contaminated sediments using rotor or trencher mixing equipment. Following completion of the sealing or stabilizing operation, the sediment bottom is restored to its natural grade and sediment composition in an effort to restore the habitat for bottom organisms.

E.2.2.2 Applications

Fixation can be applied in water bodies with relatively low-flow velocity and currents. Fixation may be applied in high-velocity streams by diverting stream flow around the area of concern. The applicability of fixation to the contaminant of concern is a matter of selecting the appropriate fixation agent.

E.2.2.3 Limitations

Permeability and chemical compatibility restrict the potential applications of many types of grouts. For example, clay-cement grout may not achieve a sufficiently low permeability to be acceptable in all cases. Quicklime is suitable only for the containment of inorganics. Neither clay nor cement are compatible with acids and bases. Compatibility and durability of bentonite must be determined on a case-by-case basis. The long-term permeability and durability of silica gel grouts is not well known.

E.2.2.4 Special Requirements/Considerations

Fixation of contaminated bottom materials can require the use of specialized equipment, such as mixing and injection equipment and support vessels. Diver support or closed-circuit television cameras may be needed to monitor the progress and continuity of the process.

Where stream diversion is used to expose bottom materials, cofferdams, diversion channels, and pumps may be needed to maintain stream flow. Tillers and bulldozers may also be needed for spreading and mixing fixation agents with the bottom materials.

Costs of in situ fixation can vary widely, ranging from low to high relative to other in situ techniques, depending on the contaminants, the setting, the accessibility of the bottom materials (e.g., shallow depth or stream diversion), and the fixation agent used.

E.3 SUMMARY

The in situ treatment and isolation techniques that are described in this appendix include sorption, chemical and biological treatment, cover and capping methods, and fixation. A summary of the characteristics and applications of each of these techniques is provided in Table E-1.

TABLE E-1. SUMMARY OF IN SITU TREATMENT AND ISOLATION TECHNIQUES

Technique	Applications	Limitations	Secondary Impacts	Type of Substance Treatable	Relative Cost
Sorption	In situ purification by adsorption of toxic substances in contaminated sediments. Long-term treatment of contaminated sediments. Adsorption of a broad range of organic and inorganic waste constituents. Carbon pillows used in waters with high flow rates in order to achieve needed adsorption kinetics. Permeable treatment barriers used in shallow water. Permeable treatment barriers used in narrow range of flow rates. Various waste compatibility limitations.	Technique not widely proven and accepted for treatment of contaminated bottom materials. Carbon pillows not effective in calm waters.	Desorption can occur over time because the contaminants are neither destroyed nor removed.	Resins best for sorption of metals and ionic organics. Activated carbon best for sorption of non-soluble compounds.	Low to High.

(continued)

TABLE E-1. (continued)

Technique	Applications	Limitations	Secondary Impacts	Type of Substance Treatable	Relative Cost
Chemical and Biological Treatment	Long-term treatment of contaminated sediments. In situ treatment of contaminated sediments or sinking spills. Chemical and biological treatment of a broad range of organic and inorganic wastes. Use in waters with low flow velocity and low volume for applications involving stream diversion.	Technique not widely proven and accepted for treatment of contaminated bottom materials. Various waste compatability limitations. Degradation products may be more toxic than original contaminants.	All chemical and biological treatment methods can contaminate the water column.	Precipitation of inorganic cationic and anionic wastes. Neutralization of acids and bases. Oxidation of a wide range of organics, except for highly chlorinated compounds and nitro-aromatics.	Low to High.
Cover and Capping Methods	Temporary or long-term isolation of contaminated sediments from streamflow. Final step in removal of contaminated sediments to isolate residual contaminants. Used in conjunction with containment methods to provide long-term isolation of contaminants.	Technique not widely proven and accepted for treatment of contaminated sediments. Active cover materials must remain in place long enough to react with and treat the contaminants.	Active cover materials can contaminate the water column. Natural grade and sediment composition are altered. Habitat for benthic organisms is destroyed. Must be restored for their survival.	Chemically compatible solids and semi-solids.	Low to High.

(continued)

TABLE E-1. (continued)

Technique	Applications	Limitations	Secondary Impacts	Type of Substance Treatable	Relative Cost
Cover and Capping Methods	Used in waters where bottom currents and flow velocity are relatively low so as not to erode the cover.	Synthetic membranes may be difficult or impossible to place.			
Fixation	Long-term treatment of contaminated sediments. In situ treatment used to immobilize contaminated sediments and prevent their interaction with the water column. Clay-cement grout used with low-permeability sediments. Chemical injection methods used in calm waters. Stream diversion methods used in shallow waters with low flow velocity.	Technique not widely proven and accepted for treatment of contaminated sediments. Type of sediment applicable can be limited by viscosity and particle size of fixation agent. Various waste compatability limitations.	Natural grade and sediment composition are altered by fixation. Habitat for benthic organisms is destroyed. It must be restored for their survival. Toxicity of some organic grouts is uncertain.	Waste compatibility factors must be evaluated on a site-specific basis.	Low to High.

APPENDIX F

DATA ON CHEMICALS THAT SINK

Most commercial and waste substances are a mixture of a variety of chemical compounds. A variety of physical, chemical, and toxilogical data are available for the individual chemicals, but not for the composite substances. Therefore, the properties of the individual chemicals are generally used to predict the behavior of a spilled substance.

The tendency of a substance to sink in water can be predicted from the substance's specific gravity, a measure of density relative to the density of water, and from its water solubility. The water solubility of a substance is the maximum mass of the substance that dissolves per unit mass of water, which can be expressed as parts per million (ppm). The solubility thus represents the concentration of the substance at saturation in water.

In addition to the specific gravity and the water solubility of a spilled substance, other physical, chemical, and toxicologic properties determine how it spreads in the environment, its ultimate fate, and the threat to humans and to the environment. The most important properties for predicting environmental transport, fate, and impact include the following:

- Specific gravity
- Water solubility
- Physical state
- Reactivity
- Toxicity
- Bioaccumulation
- Aquatic persistence.

The physical state of a chemical and its reactivity with water help to determine its potential threat to the sediments. Liquids tend to flow more readily and to dissolve more rapidly than solids. Chemicals that react exothermically will dissolve and disperse rapidly, creating a water body contamination problem, while averting contamination of sediments.

If the spilled chemical remains at the bottom of a water body, it can permeate the sediments and enter the food chain through ingestion by benthic organisms, decompose slowly to form water soluble products, or slowly dissolve or become suspended in the water body, producing toxic effects in aquatic and terrestrial flora and fauna. More seriously, the chemicals may produce toxic effects in humans who drink the water, eat the plants or animals, or come in contact with the water. Whether these events occur at all, and the extent to which they occur, is determined by the toxicity, bioaccumulation, and aquatic persistence of the spilled chemical. Therefore, the urgency of remediation in the event of a chemical spill to surface water is determined by the properties of the spilled chemical. Knowledge of these properties will also help in deciding what remedial actions are necessary and most likely to be effective.

To assist the on-scene coordinator in responding to spills of sinker chemicals, a database was developed using chemicals from the Chemical Hazard Response Information System (CHRIS) and chemicals regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or "Superfund". The chemical data are presented in Table F-4. The following sections describe the development of the database, including how the sinkers were identified and characterized.

F.1 BACKGROUND OF THE SINKERS LIST

The current list of 1,117 CHRIS chemicals and 90 additional chemicals denser than water not on the CHRIS List, but on the list of chemicals regulated under CERCLA, were combined to form an initial file of chemicals. A new file of 697 chemicals was drawn from the initial file that contained only those CHRIS and CERCLA chemicals with specific gravity greater than one ("Heavies"). The water solubilities of the chemicals in the Heavies file were then entered into the file, supplementing the CHRIS data from standard reference texts. Quantitative solubility data were entered whenever possible; otherwise, relative terms, such as slightly soluble, very soluble, etc., were used. Another new file, "Sinkers," was then extracted from the Heavies file, based on water solubility. Only Heavies with water solubility less than 100,000 parts per million in water (10 percent), or less than "very soluble" if the solubility information was qualitative, were entered into the Sinkers data file.

The Sinkers file was purged of nonhazardous chemicals (such as corn syrup); chemicals that can be transported under pressure as dense liquids, but are gases at ambient temperatures above 32°F (such as dichlorodifluoromethane); and chemicals that react exothermically with water to yield nonsinking chemicals, since they would dissipate before cleanup could take place. The resulting list of Sinkers, which includes 468 chemicals, is presented in Table F-4.

F.2 CONTENT OF THE SINKERS LIST

The following information was gathered on each of 468 sinking chemicals, within the limitation of the availability of data, and is presented on the Sinkers List in Table F-4:

- Chemical name
- CHRIS code
- Physical state
- Specific gravity
- Water solubility
- Toxicity
- Ignitability
- Reactivity
- Bioaccumulation
- Aquatic persistence
- Recovery and handling hazards
- Recommended response.

A significant number of data gaps exist in the information presented in the list because quantitative data are not readily available. Explanations of the abbreviations and symbols used on the list are provided in Table F-1. Criteria used for the ratings are provided in Tables F-2 and F-3. The information categories are explained in the following sections.

F.2.1 Chemical Name and CHRIS Code

The chemical names used on the Sinkers List are those used in the CHRIS or CERCLA Lists, except that Roman numerals are used to distinguish between oxidation states of transition metal compounds, such as cobalt acetate, as in current chemical nomenclature: cobalt (II) acetate, or cobalt (III) acetate. The CHRIS Code is provided for sinkers that were on the CHRIS List. It is a unique three-letter code for a particular compound.

TABLE F-1. KEY TO ABBREVIATIONS AND SYMBOLS

Physical State	Water Solubility
L - Liquid S - Solid	S - Soluble M - Moderately soluble SS - Slightly soluble I - Insoluble R - Reactive D - Decomposes Numerical values are in parts per million (ppm)

TABLE F-2. HAZARD RATING CRITERIA

Rating	Toxicity (LD_{50}*)	Ignitability	Reactivity with Water
N	>15 g/kg	Not ignitable	No reaction
L	5 to 15 g/kg	Flash point > 140°F (60°C)	Mild reaction; unlikely to be hazardous
M	0.5 to 5 g/kg	Flash point = 100 to 140°F (38 to 60°C)	Moderate reaction
H	50 to 500 mg/kg	Flash point < 100°F (38°C) and boiling point	More vigorous reaction; may be hazardous

* Lethal dose; see Glossary, Appendix G.

TABLE F-3. BIOACCUMULATION RATING CRITERIA

Rating	Octanol/Water Partition Coefficient* (K_{ow})	Bioconcentration Factor* (BCF)	Tendency to Adsorb to Sediment and Soil	Aquatic Persistence*
L (Low)	< 3	< 100	Adsorbs weakly	95% degradation in 6 months or less
M (Moderate)	≥ 3, < 5	≥ 100	Adsorbs moderately	95% degradation in 2 years or less
H (High)	≥ 5	≥ 1000	Adsorbs strongly	95% degradation in 10 years or less
E (Extreme)	-	-	-	< 95% degradation in 10 years or more

* See Glossary, Appendix G.
Source: Information adapted from Hand et al. 1978.

F.2.2 Physical State

The physical state is indicated as "S" for solids and "L" liquids. However, some sinkers can exist as either liquids or solids, depending on their temperature and purity. Phenol is such a material; its physical state is indicated as "S/L." Liquids flow more readily than solids and tend to pool in low points on the bottom of a water body. The rate at which a chemical will dissolve in water is affected by its physical state, but additional information about the chemical should be gathered at the spill site. For chemicals of similar solubility, one that is a liquid or a fine powder will dissolve more rapidly than one that has the form of large crystals, pellets, or chunks. Physical state must be considered together with the water solubility to predict whether a sinker can be removed before it dissolves.

F.2.3 Specific Gravity

The specific gravity of a sinker is greater than the specific gravity of water, causing it to sink in water. However, not all sinkers will sink in every situation. Sinkers with specific gravities only slightly greater than one will tend to disperse more readily than sinkers that are more dense. Of course, factors not related to the chemical, but to the environmental conditions, have a substantial effect. For instance, a rapidly moving river will suspend and disperse liquids or finely divided solids, even if they are denser than water.

F.2.4 Water Solubility

The solubility of a chemical is one of the most critical parameters predicting its behavior in the environment. As with the specific gravity, but to an even greater degree, the solubility of a sinker is dependent upon environmental factors. Warm bodies of water will dissolve much more of a chemical than cold ones. Salt water will not dissolve organic chemicals as completely as fresh water. Turbulent water bodies will cause a sinker to realize its solubility faster than quiescent water bodies. If the turbulence is caused by a river, then even slightly soluble sinkers can become completely dissolved and dissipated in a short time. If the turbulence is tidal, then the sinker will tend to reach saturation rapidly, but not be dissipated unless the spill size is small.

F.2.5 Toxicity

The threat posed by a spilled chemical to the nearby population and to the environment is critically dependent on its toxicity. The factors

already discussed earlier, physical state and solubility, affect the chemical's environmental transport to potential receptors, and its bioaccumulation and aquatic persistence, discussed below, also determine if and how the chemical will exert its toxicity on human and environmental receptors. However, a spilled chemical's toxicity can also be realized through absorption by workers attempting to remove the chemical.

F.2.6 Ignitability and Reactivity

The ignitability and reactivity of a sinker are mainly a threat to the workers performing removal operations. If the substance can ignite and burn once removed from the water, or if it reacts with water or equipment to generate pressure or toxic products, it must be handled more carefully.

F.2.7 Bioaccumulation and Aquatic Persistence

The characteristics of bioaccumulation and aquatic persistence govern the environmental transport and toxic effects of spilled chemicals. If a chemical bioaccumulates, that is, tends to remain in organisms rather than being excreted, it is more likely to cause a toxic effect in the organism. Even if a bioaccumulative chemical does not reach toxic levels in a lower organism that absorbs it, it may accumulate to higher concentrations in animals higher in the food chain, such as people. Then it can produce adverse health effects. The aquatic persistence is a measure of the chemical stability of a chemical in a wet environment. Aquatic persistence indicates whether the chemical will last long enough to be transported in the surface water to reach an environmental receptor, bioaccumulate, and/or produce toxic effects. Since the toxicity of a chemical is concentration-dependent, low aquatic persistence has the same effect on toxicity as does dilution or dispersion--it reduces the probability of a toxic effect. Bioaccumulation has the opposite effect of dilution--it increases the probability of a toxic effect on some environmental receptor.

F.2.8 Recovery and Handling Hazards

Personal protective equipment, appropriate to the hazard and necessary for safe handling of sinkers during removal, is recommended in this column. This column also contains additional toxicity information and warnings of any other handling hazards. The absence of an entry in this column does not mean that the chemical poses no hazards; all chemicals on the list are hazardous and appropriate protective clothing should be worn by response personnel handling these chemicals.

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Allyl Trichlorosilane	ATC	L	1.215	R							
Aluminum Fluoride	ALF	S	2.550	5590	M	N	N		E	Goggles and mask to protect against particulate material. Aqueous solution is toxic.	Because of toxicity, removal preferred. Burial second-best alternative.
Aminoethyl Ethanolamine	AEA	L	1.028	M	M	L	N				
Amitrole		S	1.157	48							
Ammonium Lactate	ALT	S	1.200	S		L	N				
Ammonium Lauryl Sulfate	ALS	L	1.030	M		L	N				
Ammonium Oxalate	OAX	S	1.500	25,400	H	L	N			Highly toxic via oral & inhalation routes. Powerful irritant corrosive to tissue.	
Ammonium Pentaborate	APB	S	1.580	70,300		N	N			Highly toxic affects CNS. Poisoning causes depression of circulation, vomiting, shock and coma. Absorbed by skin only through wounds, open skin.	
Ammonium Persulfate	APE	S	1.980	58,200	M	L	N			Moderately toxic via oral route.	
Ammonium Picrate		S	1.719	1100							
Ammonium Stearate	AMR	S	1.010	M		L	N				
Ammonium Vanadate		S	2.326	6,060							
Amyltrichlorosilane, n-	ATS	L	1.137	R							
Aniline	ANL	L	1.022	37,000	H	L	N	L	M	Wear organic vapor respirator, goggles, rubber gloves and boots. Contact w/ strong acids will cause violent splattering. Will attack some forms of plastics, rubber and coatings.	Toxic, should be removed.

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Anisoyl Chloride	ASC	L	1.260	R							
Anthracene	ATH	S	1.240	I		L	N	M	L	Mildly irritating. A recognized carcinogen of skin.	
Antimony		S	6.684								
Antimony Pentachloride	APC	L	2.354	D							
Antimony Pentafluoride	APF	L	2.340	S	M	N	E			Moderately toxic via oral route. When moisture is present causes severe corrosion of metals (except steel). May cause fire in contact with combustible material.	
Antimony Potassium Tartrate	APT	S	2.600	83,000	H	N	N			Highly toxic via oral route. Can cause salivation, nausea, diarrhea, skin rash. Large dose causes severe liver damage.	
Antimony Tribromide	ATB	S	4.148	D							
Antimony Trioxide	ATX	S	5.200	I		N	N				
Arochlor 1254		L	1.50								
Arsenic		S	5.727								
Arsenic Disulfide	ARD	S	3.500	I		N	M			Wear chemical protective suit w/ self contained breathing unit, goggles, rubber gloves. Inhalation irritates or ulcerates respiratory passages.	Should be removed and treated chemically and physically.
Arsenic Trichloride	ASI	S	2.156	D	H	N	M			Wear goggles, self-contained breathing unit, rubber gloves. Inhalation causes irritation to nose, throat. Severe irritant to eyes & skin.	Isolate and remove or disperse and flush.

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Arsenic Trioxide	ATO	S	3.700	37,000	E	M	M			Avoid contact w/ solid & dust. Irritant to eyes, nose & throat. Wear respirator, gloves, goggles, full protective suit.	Isolate and remove.
Arsenic Trisulfide	ART	S	3.430	0.5		M	M			Avoid contact w/ dust or solid. Irrtant to skin may cause ulceration. Wear chemical protective suit w/ self contained breathing unit, goggles, gloves.	Isolate and remove.
Asbestos		S	2.55								
Asphalt Blending Stocks: Roofers Flux	ARF	S	1.110	I		L	N		H	Protective clothing and goggles should be worn when handling hot material. May foul dredging equipment..	Should be buried or removed.
Atrazine	ATZ	S	1.200	I	M	M	N	L	L		
Azinphosmethyl	AZM	S	1.400	30	E	M	N			Highly toxic via dermal and oral routes.	
Barium		S	3.51								
Barium Carbonate	BRC	S	4.300	20	H	M	N		H	Solution is toxic.	Will react w/ sulfate to form inert insoluble barium sulfate. If not reacted w/ sulfate, material should be removed.
Barium Nitrate	BNT	S	3.240	87,000		M	N				
Barium Peroxide	BPO	S	4.960	I		M	L			Toxic if ingested. Avoid breathing dust in handling. Corrodes metal slowly. If mixed with combustible material, can ignite spontaneously.	
Benz (a) anthracene		S	1.274	.011							

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Benzal Chloride		L	1.295								
Benzaldehyde	BZD	L	1.046	3,000	M	L	N	L	L	Local contact may cause contact dermatitis. Goggles and protective clothing should be worn.	Toxic, should be removed. Due to high degradation rate, material may not remain sufficiently long to dredge. Dispersion may be only recourse.
Benzene Hexachloride	BHC	S	1.891	10	H	N	N		H	Wear goggles & self contained breathing apparatus.	Toxic, should be removed.
Benzene Phosphorous Thiodichloride	BPT	L	1.378	R						Poisonous if inhaled.	
Benzene Phosphorus Dichloride	BPD	L	1.140	R						Poisonous if inhaled.	
Benzenesulfonyl Chloride			1.384	I	M						
Benzenethiol			1.077								
Benzidene		S	1.250	400							
Benzo (a) Pyrene		S	1.351	.012							
Benzoic Acid	BZA	S	1.316	3,400	M	L	N	L	L	Eye protection and protective clothing should be worn.	Moderately toxic, should be removed, if possible. Dispersal may be acceptable.
Benzonitrile	BZN	L	1.010	I		L	N	L		When heated emits highly toxic cyanide fumes. Will attack some plastics.	
Benzophenone	BZP	S	1.085	I			N	M		Will attack some plastics.	
Benzoquinone		S	1.318	15,000							
Benzotrichloride		L	1.3723	5.9							
Benzoyl Chloride	BZC	L	1.211	3,300		L	L		L	Reacts w/ water to produce hydrochloric acid. Protective clothing, goggles, gloves, & full face respirator required. Will corrode dredge equipment.	Toxic, should be removed, if possible. Otherwise neutralize w/ lime and disperse.

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignita-bility	Reactivity	Bioaccum-ulation	Aquatic Persis-tence	Recovery & Handling Hazards	Recommended Response
Benzyl Alcohol	BAL	L	1.050	30,000	M	L	N	L		Will attack some plastics.	
Benzyl Bromide	BBR	L	1.441	I		L	L	L		Intensely irritating to skin, eyes and mucous membranes.	
Benzyl Chloride	BCL	L	1.100	33	M	L	L	L		Highly irritating to respiratory tract. Moderately irritating via oral route.	
Benzyl Chloroformate	BCF	L	1.220	R		L	L			Irritating to skin, eyes, and mucous membranes. Wear protective suit w/ self contained breathing unit & gloves.	Should be removed.
Benzyl n-Butyl Phthalate	BBP	L	1.120	I	M	L	N				
Benzyltrimethylammonium Chloride	BMA	L	1.070	M		L	L				
Beryllium Oxide	BEO	S	3.000	0.2		N	N		L	Dust mask, protective clothing and goggles required.	Toxic, should be removed.
Beryllium, Metallic	BEM	S	1.850	I	E	N	N			Avoid contact w/ solid & dust. Wear goggles & self contained breathing unit. Dust extremely toxic if inhaled.	Isolate and remove.
Bis (2-Chloroethoxy) Methane			1.2339	81,000							
Bismuth Oxychloride	BOC	S	7.700	I		N	N				
Bisphenol A	BPA	S	1.195	600	H	L	N	M		Protective clothing and respirator required.	Toxic, should be removed.
Bisphenol A Diglycidyl Ether	BDE	L	1.160	I	E	L	N				
Boiler Compound - Liquid	BCP	L	1.480	M		N	N				
Boron Tribromide	BIB	L	2.645	D							

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Boron Trichloride	BRT	G	1.350	D		N	H			Irritant to eyes, nose, throat. Inhalation causes edema & severe irritation to respiratory tract. Wear goggles, self-contained breathing unit. Attacks elastomers & synthetic rubbers. In presence of moisture, highly corrosive to most metals.	Disperse and flush or isolate & remove.
Bromine	BRX	I	3.120	35,800		N			E	Highly corrosive causes fire in contact w/ combustibles. Reacts violently w/ aluminum. Full protective clothing required. Epoxy or Teflon-lined equipment should be used to avoid corrosion damage.	Toxic, may be flushed away because of high solubility or may be removed.
Bromine Pentafluoride	BPX	L	2.480	D							
Bromine Trifluoride	BIF	L	2.810	D							
Bromoacetone		L	1.634	.01							
Bromobenzene	BBZ	L	1.490	41,000		M	N			An irritant to eyes and mucous membranes. A deadly poison.	
Brucine	BRU	S	>1	I	E	L	N				
Butanediol, 1,4-	BDO	L	1.017	M	H	L	N				
Butenediol, 1,4-	BUD	L	1.070	M		L	N				
Butylphenol, p-tert-	BTB	S	1.037	I	M	L	N				
Butyltrichlorosilane	BCS	L	1.160	R							
Cadmium		S	8.642	20							
Cadmium Fluoborate	CFB	S	1.600	M		N	N				
Cadmium Oxide	COP	S	6.950	I							
Calcium Arsenate	CCA	S	3.620	130	E	N	N			Highly irritating via oral and inhalation routes.	

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Calcium Carbide	CCB	S	2.220	D						Reacts with water to form acetylene gas, which is flammable. By-product is calcium hydroxide, which is alkaline.	Should be removed as soon as possible.
Calcium Cyanide	CCN	S	1.853	100	E	N	M			Releases very poisonous hydrogen cyanide gas slowly on contact with water or rapidly w/ acids.	
Calcium Fluoride	CAF	S	3.180	16		N	N		E	Protection against inhaling particulates required. Presence is dangerous to aquatic organisims & local water supplies.	Remove or bury.
Calcium Hydroxide	CAH	S	2.240	1,850	L	N	N		H	Goggles and dust-proof mask required. Solution is corrosive (strongly alkaline).	Remove, bury or disperse.
Calcium Hypochlorite	CHY	S	2.350	D							
Calcium Oxide	CAO	S	3.300	1,310		N	N		H	Generates heat when on contact w/ water. Goggles, gloves, and respirator should be worn. Solution is corrosive (strongly alkaline).	Will react completely do form calcium hydroxide which should be removed, buried or dispersed.
Calcium Peroxide	CCP	S	2.920	I		L	L				
Calcium Phosphate	CAL	S	2.500	3,000		N	N				
Calcium Phosphide	CPP	S	2.510	D							
Calcium Resinate	CRE	S	1.130	I		L	N				
Calcium, Metallic	CAM	S	1.550	D							
Captan	CPT	S	1.740	D							

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignita-bility	Reactivity	Bioaccum-ulation	Aquatic Persis-tence	Recovery & Handling Hazards	Recommended Response
Carbaryl	CBY	S	1.230	I	H	N	N	L	M	Avoid contact w/ solid or solutions. Absorbed via all routes, causes blurred vision, headache, stomachache, vomiting.	Toxic, should be removed.
Carbolic Oil		S	1.040	84,160		L	N	L	M	May explode if mixed w/ air. Air mask, rubber gloves, protective clothing, and full face shield required.	Toxic, should be removed.
Carbon Disulfide	CBB	L	1.260	2,200		H	N			Toxic by oral intake, inhalation or prolonged skin contact.	
Carbon Tetrachloride	CBT	L	1.590	800	M	N	N	L	H	Face mask, protective clothing should be worn. Exposure to high concentrations can cause unconsciousness & can be fatal.	Toxic, should be removed.
Caustic Soda Solution	CSS	L	1.500	42,000	E	N	N			A severe hazard. Solid or concentrated solution destroys tissue on contact. Corrosive to aluminum, zinc, and tin.	
Chloral		L	1.5121	14,740							
Chlordane	CDN	L	1.600	.009	H	L	N	M	E	Readily absorbed through the skin and highly toxic.	
Chlorine Trifluoride	CTF	G	1.850	D						Poisonous if inhaled.	
Chloro-o-toluidine, 4-	CTD	S	1.101	I	H	L	N				
Chloroacetophenone	CRA	S	1.320	I	H	L	M	L		A powerful irritant via oral and inhalation routes.	
Chloroacetyl Chloride	CAC	L	1.420	R						Reacts slowly with metals causing mild corrosion.	
Chloroaniline, a-		S	1.430	17,000							

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Chlorobenzene	CRB	L	1.110	490	M	M	M	L	M	Heavy vapor can travel considerable distance to flame. Protective clothing, full face respirator, goggles required.	Toxic, should be removed.
Chlorobutyronitrile, 4-	CBN	L	1.220	I			N			May attack some forms of plastic.	
Chlorodibromomethane		L	2.451								
Chloroform	CRF	L	1.490	8,000	M	N	N	L	H	Goggles, full face mask or self-contained breathing unit required depending on concentrations encountered. Moderately toxic via oral & inhalation routes.	Toxic, should be removed.
Chlorohydrin (crude)	CHD	L	1.180	60,000	H	H	L			High toxicity via oral and inhalation routes.	
Chloromethyl Methyl Ether	CME	L	1.070	D	M		M			High toxicity via inhalation routes, moderately toxic via oral route. Reacts with surface moisture to evolve HCl which is corrosive to metal.	
Chloronitrobenzene, o-	CPN	S	1.368	I							
Chlorophenol, p-	CPL	S	1.310	27,100		L	N	M			
Chloropicrin		L	1.640	1,800	H	N	N			Pronounced irritant to all body surfaces. Causes skin irritation, bronchitis, pulmonry edema. Short exposure may cause fatal lung damage.	
Chloropropionic Acid, 2-		L	1.259	M	M	L	N			Moderately toxic via oral route.	
Chlorosulfonic Acid	CSA	L	1.350	D							

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Chlorotoluene, m-		L	1.072		I		M	N	M		
Chlorotoluene, o-		L	1.082		I		L	N			
Chlorotoluene, p-		L	1.070		I		L	N			
Chromic Sulfate	CHS	S	3.012		I						
Chromium		S	7.20		20						
Chromous Chloride	CRC	S	2.878		S	M				Moderately toxic via oral route. Can have corrosive action on skin and mucous membranes.	
Chromyl Chloride	CMC	L	1.960		D						
Chrysene		S	1.274		.002						
Cobalt (II) Acetate	CBA	S	1.710		S	E	N	N			
Cobalt (II) Flouride	COF	S	4.46		15,000						
Cobalt (II) Formate	CFM	S	2.129		50,300						
Copper (I) Bromide	CBD	S	4.98		I		N	N			
Copper (I) Cyanide	CCY	S	2.920		I		N	N			
Copper (I) Iodide	CID	S	5.620		S		N	N			
Copper (II) Acetate	COP	S	1.900		72,000	M	N	N		Moderately toxic via oral and inhalation routes.	
Copper (II) Acetoarsenite	CAA	S	1.101		30,000	E	N	N		Highly toxic via oral and inhalation routes.	
Copper (II) Arsenite	CPA	S	1.101		I		N	N			
Copper (II) Fluoborate	CPF	L	1.540		M		N	N		May corrode some metals.	
Copper (II) Naphthenate	CNN	S	1.980		I	H	N	N		Highly toxic via oral and inhalation routes.	
Copper (II) Oxalate	COL	S	1.001		25.3		N	N			
Coumaphos	COU	S	1.474		I	E	L	N		Moderately toxic via dermal routes.	

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Creosote, Coal Tar	CCT	L	1.070		I	H	L	N		Moderately toxic via oral and inhalation routes. A recognized carcinogen of skin, forearm, scrotum, face, neck and penis.	
Cresol, m-		L	1.034	5,000	H	L	N	L	H		
Cresol, o-		L	1.027	25,000	H	L	N	L	H		
Cresol, p-		L	1.018	18,000	H	L	N	L	H		
Cresols	CRS	L	1.050	22,000		L	N				
Cresyl Glycidyl Ether	CGE	L	1.090		I		L	N		May attack some forms of plastic.	
Cumene Hydroperoxide	CMH	L	1.030		I	H	L	E		Known skin sensitizer. Toxic by inhalation, skin absorption and ingestion.	
Cupriethylenediamine Solution	CES	L	1.101		M		N	N		An irritant and corrosive substance. Dissolves cotton, wood, and other cellulose materials. Corrosive to copper, aluminum, tin and zinc.	
Cyanoacetic Acid	CYA	L	1.101		S	H	L	N		Skin irritant. Vapor can be absorbed via skin and respiratory tract. Upon heating, acetonitrile forms, of which high concentrations are rapidly fatal.	
Cyclohexanone Peroxide	CHP	L	1.050		I		L	N		Irritant to skin, eyes and mucous membranes.	
Cyclohexenyltrichlorosilane	CHT	L	1.230		R						
DDD	DDD	S	1.476		I	H		N	H	Highly toxic via oral route. Moderately toxic via dermal routes.	

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignita-bility	Reactivity	Bioaccum-ulation	Aquatic Persis-tence	Recovery & Handling Hazards	Recommended Response
DDT	DDT	S	1.560	I	H	L	N	M	H	Protective clothing required. Absorbed readily through skin if in solution. High toxicity via oral and dermal routes.	Toxic, should be removed.
Dalapon	DLP	L	1.390	M	M		L			Moderately irritant to skin, eyes and mucous membranes and via oral and inhalation routes. Very corrosive to aluminum and copper alloys.	
Demeton	DTN	L	1.100	I	H	M	N			Highly toxic insecticide, via oral and dermal routes. May attack some forms of plastics.	
Di-(o-Chlorobenzoyl)Peroxide		S	1.101								
Diallate		S	1.188	14							
Diazinon	DZN	L	1.117	40	M	H	N	L	L	High toxicity via oral and dermal routes.	
Dibenzo [a,h] anthracene		S	1.0695								
Dibenzyl Ether		L	1.0428	I	M	L	N			Moderate irritant. Moderately toxic via oral route. Vapors narcotic in high concentrations.	
Dibutyl Phthalate	DPA	L	1.049	I	M	L	N		M	High toxicity via oral routes. Protect eyes.	Somewhat toxic, should probably be removed, but is a possible candidate for containment and burial.
Dichlorobenzene, m-		L	1.282	I							
Dichlorobenzene, o-	DBO	L	1.360	25		L	N	M	H		

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Dichlorobenzene, p-	DBP	S	1.458	80	M	L	N	M	M		
Dichlorobromomethane		S	1.980								
Dichlorobutene		L	1.112	2,000	H		L			High toxicity via oral and inhalation routes. Corrodes metal when wet.	
Dichloroethane, 1,1-		L	1.270	500	M	H	N	L	L	Moderately toxic via oral route.	
Dichloroethyl Ether, 2,2-		L	1.220	10,700	H	M	N			Toxic by inhalation or oral intake: strong eye, skin & respiratory irritant. Absorbed by skin. Decomposes when heated to toxic, irritating products.	
Dichloroethylene, 1,2-	DEL	L	1.282	6,300	M	H	M				
Dichloroisopropyl Ether			1.103								
Dichloromethane	DCM	L	1.322	13,800	M	N	L	L	M	Organic vapor mask, eye protection, & protective clothing required. Vapor in high concentrations may cause narcosis and death.	Toxic, should be removed, but due to high solubility, dispersal may be only recourse.
Dichlorophenol, 2,4-	DCP	S	1.400	4,600	M	L	N	M	M	Use of respirator, rubber gloves and goggles required. Moderately toxic via oral route.	Toxic, should be removed.
Dichlorophenoxyacetic Acid, 2,4-	DCA	S	1.563	700	H	L	N	L	L	An herbicide. High toxicity via oral route. Moderately toxic via dermal routes. Can cause nausea, vomiting and CNS depression.	
Dichlorophenylarsine			1.8358								

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignita-bility	Reactivity	Bioaccum-ulation	Aquatic Persis-tence	Recovery & Handling Hazards	Recommended Response
Dichloropropane, 1,1-		L	1.132	2,700	L		N	L	H	Flashback along vapor trail may occur. Rubber gloves & boots, goggles & protective clothing required.	Toxic, should be removed.
Dichloropropane, 1,2-	DPP	L	1.158	2,700	M	H	N	L	H	Flashback along vapor trail may occur. Rubber gloves & boots, goggles & protective clothing required.	Toxic, should be removed.
Dichloropropane, 1,3-		L	1.188	SS		H	N	L	H	Flashback along vapor trail may occur. Rubber gloves & boots, goggles & protective clothing required.	Toxic, should be removed.
Dichloropropene, 1,3-	DPR	L	1.200	I	H	H	N	L	H	Toxic by inhalation or oral intake. Strong eye, skin & respiratory irritant. Decomposes when heated to form toxic and irritating products. Full face organic vapor mask required.	Toxic, should be removed.
Dichloropropene, 2,3-		L	1.217	I	H		N	L	H	Toxic by inhalation or oral intake. Strong eye, skin & respiratory irritant. Decomposes when heated to form toxic & irritating products. Toxic gases produced in fire. Full face organic vapor mask required.	Toxic, should be removed.
Dichloropropene, Dichloropropane Mixture	DMX	L	>1	SS							
Dichlorotetrafluoroethane		G	1.455								
Dieldrin	DED	S	1.750	.25	E	N	N	L		An insecticide. Readily absorbed through skin and other portals. Acts as CNS stimulant.	
Diethanolamine	DEA	L	1.095	M	M	H	N	L		Moderately toxic via oral route.	

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Diethyl Phthalate	DPH	L	1.120	I	L	L	N			An irritant to mucous membranes and a narcotic in high concentrations. May attack some forms of plastics.	
Diethyl Sulfate		L	1.177	I	H	L	L			Toxic by inhalation, skin contact or oral intake. When heated to decomposition, emits highly toxic fumes of sulfur oxides.	
Diethylarsine			1.1338								
Diethylene Glycol	DEG	L	1.118	M		L	N				
Diethyleneglycol Monomethyl Ether		L	1.025	M		L	N				
Diethylzinc	DEZ	L	1.207	R							
Difluorophosphoric Acid, Anhydrous	DFA	L	1.583	R							
Dihydrosafrole			1.0695								
Diisobutyl Phthalate		L	1.049								
Diisopropyl Fluorophosphate		L	1.055								
Dimethoate		S	1.277								
Dimethyl Phthalate		L	1.19	I	M	L	N			Moderately toxic via oral routes.	
Dimethyl Sulfate	DSF	L	1.330	2,800	H	L	L		H	Extremely irritating, causes severe burns. Hazard to eyes. Toxic by inhalation, skin contct or oral intake. Goggles, rubber clothing required. Corrodes metal when wet.	
Dimethyl Sulfoxide	DMS	L	1.101	S							
Dimethyl Terephthalate	DMT	S	1.200	I		L	N				
Dimethylcarbamoyl Chloride		L	1.168								

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignita-bility	Reactivity	Bioaccum-ulation	Aquatic Persis-tence	Recovery & Handling Hazards	Recommended Response
Dimethyldichlorosilane	DMD	L	1.070	R							
Dimethylzinc	DMZ	L	1.390	R							
Dinitroaniline, 2,4-	DNT	S	1.615	I	H	L	N		H	Toxic if inhaled, ingested or in contact w/skin. Self-contained breathing apparatus, goggles, rubber gloves, impermeable clothing required. May require special handling. Consult American Aniline Products or Martin Marietta Corp.	Toxic, should be removed.
Dinitrobenzene		S	1.600	1,800				L		High toxicity via oral route.	
Dinitrobenzene, m-	DNB	S	1.580	5,000		L	N	L			
Dinitrobenzene, o-		L	1.600	I				L	I		
Dinitrocresols	DNC	S	1.101	I	E	L	N			Highly irritant to skin, eyes & mucous membranes. Can cause brain damage & injury to liver & kidneys when absorbed via inhalation, ingestion, or skin.	
Dinitrophenol, 2,4-	DNP	S	1.680	I	E		N	L	H	High toxicity orally, moderately toxic dermally. Phytotoxic. May explode if heated when confined. Wear breathing apparatus, impermeable clothing. May require special handling. Consult American Aniline Products or Martin Marietta Corp.	Toxic, should be removed.

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Dinitrotoluene, 2,4-	DTT	S	1.379	24,500	H	L	H	L		Can cause anemia, methemoglobinemia & cyanosis. Highly toxic by skin absorption, ingestion or inhalation. Can cause liver injury.	
Dinitrotoluene, 2,5-			1,282								
Dinitrotoluene, 3,4-			1,259	I	H			L		Can cause anemia, methemoglobinemia & cyanosis. Highly toxic by skin absorption, ingestion or inhalation. Can cause liver injury.	
Dinoseb			1.2647	52							
Dioctyl Sodium Sulfosuccinate (solid or liquid)		S/L	1.100	1,500	M	M	M			Moderately toxic via oral route.	
Diphenyl Ether	DPE	S/L	1.070	I	M	L	M	M		Moderately toxic via oral and inhalation routes, mild irritant. Prolonged exposure damages liver, spleen, kidneys & thyroids, and upsets GI tract.	
Diphenylamine		S/L	1.068	I	M	L	M	M		Moderately toxic via oral route. Can cause anoxemia and depression of the central nervous system.	
Diphenyldichlorosilane		L	1.220	R							
Diphenylmethane Diisocyanate	DPM	S	1.200	I		L	L		M	Slow reaction w/ water, forms carbon dioxide. Respirator, gloves, goggles, and protective clothing recommended.	Toxic material and reaction products, should be removed.

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignita-bility	Reactivity	Bioaccum-ulation	Aquatic Persis-tence	Recovery & Handling Hazards	Recommended Response
Dipropylene Glycol	DPG	L	1.023	M	M	L	N			Low toxicity via oral route. Moderately irritant to skin, eyes, mucous membranes. Can cause CNS stimulation followed by depression if ingested.	
Dodecyl Sulfate, Diethanolamine Salt	DSD	S	1.010								
Dodecyl Sulfate, Magnesium Salt	DSM	S	1.040	M		N	N				
Dodecyl Sulfate, Triethanolamine Salt	DST	S	1.101	M		N	N				
Dodecylbenzene Sulfonic Acid			1.081	C							
Dodecylbenzenesulfonic Acid, Triethanolamine Salt	DBS	L	1.200			N	N				
Dodecyltrichlorisilane	DTC	L	1.030	R							
Dowtherm	DTH	L	1.060	13.8	E	L	N		M	Wear eye protection.	Somewhat toxic and aesthetically objectionable, should be removed.
Endrin	EDR	S	1.650	0.16	E	L	N			Toxic by skin contact, inhalation, ingestion causes dizziness, weakness of legs, nausea, abdominal pains. Absorbed by skin from solutions > 2.5%. Extremely toxic via oral & dermal routes.	
Epichlorohydrin	EPC	L	1.180	60,000	H	H	L	L	N	High toxicity orally, moderately toxic dermally. Produces sterilty, respiratory paralysis, kidney damage, irritation to eyes, lungs, skin.	Toxic, should be removed. However due to reactivity & solubility, dispersal may be most practical response to a water spill.
Esters, 2,4,5-T			1.200								

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignita-bility	Reactivity	Bioaccum-ulation	Aquatic Persis-tence	Recovery & Handling Hazards	Recommended Response
Esters, 2,4-D			1.163	I							
Ethion			1.22	2	E					An insecticide. Very high toxicity orally. High toxicity via dermal routes.	
Ethoxy Triglycol	ETG	L	1.020	M	L	L	M			Low toxicity via oral and dermal routes.	
Ethoxylated Nonylphenol	ENP	S/L	1.030	M							
Ethyl Chloroacetate	ECA	L	1.150	I	L	M				Moderately irritating via oral and inhalation routes.	
Ethyl Chloroformate	ECF	L	1.135	R							
Ethyl Guthion			1.284	I							
Ethyl Lactate	ELT	L	1.030	M	M	M	M			Moderately toxic via oral route.	
Ethyl Phosphonothioic Dichloride, Anhydrous	EPD	L	1.350	R							
Ethyl Phosphorodichloridate	EPP	L	1.350	R							
Ethylaluminum Dichloride	EAD	S	1.227	R							
Ethylaluminum Sesquichloride	EAS	L	1.089	R							
Ethyldichlorosilane	ECS	L	1.092	D							
Ethylene Chlorohydrin	ECH	L	1.197	M	H	M	M	L		High toxicity via dermal, oral and inhalation routes. Vapor irritates mucous membranes, causes drowsiness, vomiting later dyspnea, headache, cyanosis, heart pain. Fatal amounts can be absorbed through skin.	

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignita-bility	Reactivity	Bioaccum-ulation	Aquatic Persis-tence	Recovery & Handling Hazards	Recommended Response
Ethylene Cyanohydrin		L	1.047	M	L		L			When heated or on contact with acid, emits highly toxic cyanide products. Can react vigorously w/ oxidizing material. Moderately toxic via oral & dermal routes.	
Ethylene Dibromide	EDB	L	2.180	2,700	H	M	N		H	Wear cannister-type mask, neoprene gloves/goggles. Vapor toxic by inhalation, skin contact, ingestion. Irritating to eyes, skin & respiratory tract.	Toxic, should be removed.
Ethylene Dichloride	EDC	L	1.253	8,000	M	H	L	L	H	Flashes back along vapor trail. Protective clothing, goggles & gas mask or self-contained breathing unit required. Toxic by inhalation, skin, orally.	Toxic, should be removed.
Ethylphenyl Dichlorosilane	EPS	L	1.159	R							
Ethyltrichlorosilane	ETS	L	1.240	R							
Ferric Fluoride	FFX	S	4.09	910	M					Highly toxic & irritating. If ingested can cause vomiting, asthma, severe bone changes. Highly irritating to eyes, skin & mucous membranes.	
Ferric Sulfate	FSF	S	3.100	SS	L	N	N			A mild irritant, low toxicity via oral route.	
Ferrous Fluoborate	FFB	L	1.101	M		N	N				
Ferrous Oxalate	FOX	S	2.300	0.022	H	N	N			Highly toxic via oral & inhalation routes. A powerful irritant. Corrosive to tissue.	

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Ferrous Sulfate	FRS	S	1.900	15.65	M	N	N			Moderately toxic via oral route.	
Fluoranthene		S	1.252	.265							
Fluorene		S	1.203	1.98							
Fluosilicic Acid	FSL	L	1.300	SM		N	N			Highly irritant to skin, eyes, mucous membranes and via inhalation route.	
Fluosulfonic Acid	FSA	L	1.730	SR	H	M	N				
Formic Acid	FMA	L	1.220	M	M	M	N	L		Acutely irritating, highly toxic if inhaled for brief periods. Very caustic to skin, producing superficial blisters, burns on contact.	
Fumaric Acid	FUM	S	1.635	7,000	H	L	N			Probably low toxicity via oral route.	
Furfural	FFA	L	1.159	90,000	H	M	L		H	Moderately irrtating to skin, eyes & mucous membranes. Liquid is dangerous to eyes. Vapor is absorbed by skin, mucous membranes, and is CNS poison. Protect exposed skin & eyes.	Toxic, should be removed, however high solubility may result in dispersion.
Furfuryl Alcohol	FAL	L	1.130	M	H	L	L			Highly toxic via oral, inhalation & dermal routes. Moderately irritating to skin, eyes & mucous membranes.	
Gallic Acid	GLA	S	1.700	11,500	M	L	N			Moderately toxic via oral route. Mildly irritating.	
Glycerine	GCR	L	1.261	M	H	L	N			Moderately toxic via oral route. In form of mist is a respiratory tract irritant.	

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Glycidyl Methacrylate	GCM	L	1.073	I	M	L	N		M	Polyethylene coated apron, gloves & goggles should be worn. Heat, peroxides, and caustics cause polymerization. May clog equipment, may float.	Toxic, should be removed.
Guthion		S	1.44	33							
Heptachlor	HTC	S	1.660	0.02	E	N	N	M		Highly toxic via oral & dermal routes. Prolonged exposure causes liver damage.	
Hexachlorobenzene		S	1.5691	.006							
Hexachlorobutadiene		L	1.682	.005							
Hexachlorocyclopentadiene	HCC	L	1.710	0.0805	H	N	L	M		Highly toxic via oral & dermal routes. Reacts slowly with water to form HCl. In presence of moisture, will corrode iron, releasing flammable & explosive hydrogen gas.	
Hexachloroethane		S	2.091	50							
Hexaethyl Tetraphosphate		L	1.4273								
Hexylene Glycol	HXG	L	1.008	M	M	L	N			Moderately toxic via oral route. Irritating to skin, eyes, and mucous membranes.	
Hydroquinone	HDQ	S	1.330	70,000	H	L	N	L		Highly toxic orally. Active allergen & strong irritant. Vapors must be avoided. Causes dermatitis.	
Hydroxyethyl Acrylate, 2-	HAI	L	1.100	M	M	L	N				
Hydroxypropyl Acrylate	HPA	L	1.060	M		L	N				
Hydroxypropyl Methacrylate	HPM	L	1.060	M		L	N				
Isophthalic Acid	IPL	S	1.540	SS	M	L	N	L		A mild irritant. Moderately toxic via oral route.	

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignita-bility	Reactivity	Bioaccum-ulation	Aquatic Persis-tence	Recovery & Handling Hazards	Recommended Response
Isopropyl Percarbonate	IPC	S	1.080	I	M	L	M			Should not be allowed to remain in contact w/ skin. Inhalation of vapor or ingestion should be avoided.	
Isosafrole		S	1.1224								
Latex, Liquid Synthetic	LLS	L	1.057	M		L	M				
Lead		S	11.344	.001							
Lead Acetate	LAC	S	2.550	100	H	N	N			Toxic by inhalation, ingestion and skin contact. Do not handle with bare hands.	
Lead Arsenate	LAR	S	5.790	I	H	N	N		E	Poisonous if swallowed. Respirator to prevent inhalation of particulates is required, protective clothing necessary.	Soluble under acid conditions. Removal is best course followed by burial with a basic material to prevent dissolution and to isolate.
Lead Fluoborate		L	1.750	M	H					Highly toxic via oral route.	
Lead Fluoride	LFR	S	8.240	64,000	M	N	N			Moderately toxic via oral route.	
Lead Iodide	LID	S	6.160	64,000		N	N				
Lead Phosphate		S	7.15	.014							
Lead Subacetate		S	3.25	44,300							
Lead Tetraacetate	LTT	S	2.200	R-D							
Lead Thiocyanate	LTC	S	3.820	5,000		N	N			Products of decomposition by heat in presence of air include highly toxic carbon disulfide and sulfur dioxide.	

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Lindane		S	1.87	10							
Magnesium		S	1.740	I		L	M			Dust is a slight irritant.	
Malathion		L	1.234	145	M	L	N	L	L	Extremely toxic to aquatic fauna. Moderately toxic via oral & dermal routes. Affects CNS causes allergic sensitization.	Toxic, should be removed.
Maleic Hydrazide	MLH	S	1.600	6,000	M	L	N			Moderately toxic via oral route.	
Malononitrite		S	1.191	100							
Mercuric Ammonium Chloride	MCC	S	5.700	1,400	H	N	N			Highly toxic, causes skin burns and other forms of irritation. Absorbed through the skin.	
Mercuric Chloride	MRC	S	5.400	54,000	E	N	N			A deadly poison. Highly toxic via all routes. Causes skin burns & other forms of irritation. Absorbed by skin.	
Mercuric Iodide	MID	S	6.300	7,000	E	N	N			Highly toxic via oral route. Causes skin burns & other forms of irritation. Absorbed by skin.	
Mercuric Sulfide	MRS	S	8.000	0.01	H	L	N			Highly toxic via all routes. Causes skin burns and other forms of irritation. Absorbed by skin.	
Mercurous Chloride	MRR	S	7.150	2	H	N	N			Highly toxic via oral route. Causes skin burns & other forms of irritation. Absorbed by skin.	

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Mercurous Nitrate	MRN	S	4.780	I-D	H	L	L			Highly toxic via oral route. Causes skin burns & other forms of irritation. Absorbed by skin. Solution may corrode most metals. Solid in contact with wood or paper may cause fire.	
Mercury Fulminate		S	4.42							Highly explosive.	
Methacrylic Acid		L	1.015	S							
Methanearsonic Acid, Sodium Salts (liquid)		S	1.500								
Methomyl			1.2946	10,000							
Methoxychlor	MOC	S	1.410	I	M	L	N	M		An insecticide. An irritant and allergen. Moderately toxic via oral & dermal routes. Prolonged exposure may cause kidney injury.	
Methyl Chlorocarbonate		L	1.223								
Methyl Chloroformate		L	1.220	R							
Methyl Ethyl Ketone Peroxide		L	1.170								
Methyl Iodide		L	2.279	20,000							
Methyl Naphthalene		S	1.020	I							
Methyl Parathion	MPT	L/S	1.360	50							
Methylcholanthrene		S	1.28								
Methylcyclopentadienylmanganese Tricarbonyl	MCT	L	1.390	70	E	L	N			Highly toxic via oral & inhalation routes. Moderately toxic via dermal routes. Exposure to dust or fumes can cause respiratory infections.	
Methyldichlorosilane	MCS	L	1.110								

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Methylene Bromide		L	2.4970	11,930							
Methylphosphonothioic Dichloride, Anhydrous	MPD	L	1.420	R							
Methylpyrrolidone, 1-	MPY	L	1.030	M	L	L	L			Contact of liquid or vapors with skin, eyes or mucous membranes should be avoided.	
Methyltrichlorosilane		L	1.270	R							
Mevinphos			1.25								
Molybdic Trioxide	MTO	S	4.690	1,000	H	N	N			Highly toxic via oral & inhalation routes. Also an irritant. Suitable precautions should be taken against inhaling the substance.	
Monochloroacetic Acid	MCA	S	1.580	M	H	L	N			High irritant to skin, eyes and mucous membranes. Highly toxic via oral route.	
Monoethanolamine	MEA	L	1.016	S	M	L	N	L		Moderately toxic via oral and dermal routes.	
Motor Fuel Antiknock Compounds (Lead Alkyls)	MFA	L	1.600	0.1-100	H		N		H	Air supplied respirator, gloves, goggles required. Vapors very toxic. Fatal lead poisoning may occur following ingestion, inhalation, skin absorption.	Toxic, should be removed.
N-Aminoethanolamine		L	1.028								
N-Nitroso-N-Methylurethane			1.133								
N-Nitrosodimethylamine			1.0048							Carcinogen, no exposure or bodily contact should be permitted.	
N-Nitrosodiphenylamine		S	1.23	I							
N-Nitrosopiperidine			1.0631	77,000							

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Naphthalene, Molten	NTM	S	1.145	3,000	M	L	H	M	H	Organic vapor respirator, goggles, and protective clothing should be worn. May foul dredging equipment. Irritates eyes, skin, respiratory tract. Molten naphthalene spatters & foams in contact w/ water.	Toxic, especially to aquatic life, should be removed.
Naphthylamine, 1-	NAO	S	1.120	1,700	H	L	N	L		Toxic when absorbed by lungs, gastro-intestinal tract & skin. May produce tumors or bladder cancer if long exposure occurs.	
Naram		S	1.140	M							
Nickel		S	8.90								
Nickel Ammonium Sulfate	NAS	S	1.920	85,000		N	N			Airborne nickel dust is carcinogenic if inhaled. Can cause dermatitis.	
Nickel Carbonyl	NKC	L	1.322	180	E	H	N			Extremely toxic by inhalation and ingestion. A few breaths could be fatal.	
Nickel Cyanide	NCN	S	2.400	60		N	N			Highly toxic.	
Nickel Fluoborate	NFB	L	1.500	M		N	N			Highly toxic via oral and inhalation routes.	
Nickel Formate	NFM	S	2.150	31,500		N				Can cause dermatitis. Should not be inhaled if in dust form.	
Nitralin	NTL	S	1.001	I		L	N				
Nitroaniline, 2-	NTA	S	1.440	500	H	L	N			Highly toxic by skin contact or inhalation of vapors.	
Nitroaniline, 4-	NAL	S	1.440	I	M	L	N	L			

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Nitrobenzene	NTB	L	1.204	1,900	M	L	N	L		Rapidly absorbed through skin. Organic vapor respirator, protective clothing necessary. Moderately toxic via oral & dermal routes. Causes cyanosis.	Toxic, should be removed.
Nitroethane	NTE	L	1.050	45,000	M	H	N	L		Somewhat toxic by inhalation and ingestion. Decomposition products are highly toxic. May attack some forms of plastic.	
Nitroglycerine		L	1.5931	1,800						Highly explosive.	
Nitrophenol, 2-	NTP	S	1.490	1,500	H	L	N	L		Highly toxic upon ingestion, inhalation,or absorption through skin. Emits highly toxic oxides of nitrogen upon thermal decomposition.	
Nitrophenol, 3-		S	1.263	20,000	H			L		Highly toxic via oral route.	
Nitrophenol, 4-	NPH	S	1.480	16,000	H	L	N	L		Highly toxic via oral route.	
Nitrotoluene, m-		L	1.153	498	M	L		L		Moderately toxic via oral and dermal routes.	
Nitrotoluene, o-		L	1.153	650	M	L		L		Moderately toxic via oral & dermal routes.	
Nitrotoluene, p-		S	1.113	40	M	L		L		Moderately toxic via ingestion, inhalation, or absorption through skin. Yields toxic oxides of nitrogen when burned.	
Octamethyl Pyrophosphoramide		L	1.09	100							
Octyl Epoxytallate	OET	L	1.002	I		L	N				
Oil, Misc: Road	ORD	L	1.100	I		L	N				
Paraformaldehyde	PFA	S	1.460								

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignita-bility	Reactivity	Bioaccum-ulation	Aquatic Persis-tence	Recovery & Handling Hazards	Recommended Response
Parathion	PTO	L	1.269	20	E	H	L	M		Very toxic. Can be fatal by skin contact, inhalation, or ingestion. When handled, a supply of atropine should be available.	
Pentaborane	PTB	L	1.6796								
Pentachlorobenzene		S	1.8342	.135							
Pentachloroethane		L	1.6796	I	M			L		Moderately toxic via oral route. Highly toxic via inhalation route.	
Pentachloronitrobenzene		S	1.718	.02							
Pentachlorophenol	PCP	S	1.980	1,000	H	N	N	H	H	Respirator & protective clothing should be worn. Highly toxic. Irritant to eyes, skin. Dermatitis occurs.	Toxic, should be removed.
Pentaerythritol	PET	S	1.390	62,000	L	L	N			Low toxicity. A nuisance dust.	
Peracetic Acid	PAA	L	1.153	M	M	M	N			Will produce severe acid burns to skin & eyes. Prolonged inhalation of vapor may be harmful. Corrosive to most metals including aluminum. may cause fire in contact with organic materials (i.e. wood, straw).	
Perchloroethylene		L	1.6227	2,000	L	N	N			Incoordination occurs at vapor exposures of 300-1000 ppm. Dizziness, drowsiness, loss of consciousness & death can occur at higher exposures.	

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Perchloromethyl Mercaptan	PCM	L	1.706								
Phenol	PHN	S/L	1.058	84,000	M	L	M	L		Highly toxic via oral, dermal routes. Death has resulted from absorption through a skin area of 64 sq in. Causes severe tissue burns.	
Phenyldichlorosreine, Liquid		L	1.657	I	H		L			Highly toxic via inhalation, dermal, and oral routes. Corrodes metal.	
Phorate *	PDL		1.156	50							
Phosdrin	PHD		78.03	M	E	L	L			An eye & skin irritant. Wear protective clothing. Highly toxic via oral, inhalation & dermal routes. Will attack some plastics.	
	PHD										
Phosphorus Pentasulfide	PPP	S	2.030	R							
Phosphorus, Black	PPB	S	2.70	I							
Phosphorus, Red	PPR	S	2.200	I		L	M		H	Heat may cause reversion to highly toxic & spontaneously flammable yellow phosphorus. Dust mask, rubber gloves required. Reacts violently with oxidizing agent in the presence of air & water releasing phosphorous acids, phosphine gas (flammable).	Toxic, remove.

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Phosphorus, White	PPW	S	1.820	.0003	H	E	M		H	Highly toxic via oral, dermal & inhalation routes. Ignites spontaneously in air. Heavy rubber gloves & face shield should be worn. Requires specialized handling by manufacturers (FMC Corp & Monsanto).	Toxic, should be removed.
Phthalic Anhydride	PAN	S	1.530	6,200	M	L	L	L	L	Moderately toxic protective clothing, organic vapor respirator recommended. Dust & vapor irritate eyes, upper respiratory tract, & moist skin.	Moderately toxic, should be removed, if possible. Dispersal may be acceptable.
Polychlorinated Biphenyls	PCB	L	1.550	I	M	L	M		E	Gloves & protective clothing recommended. Moderately toxic via dermal & oral routes. A strong irritant toxic to liver. Toxic, nondegradable & highly bioaccumulating.	Absolutely should be removed.
Polymethylene Polyphenyl Isocyanate	PPI	L	1.200	I		L	M				
Polypropylene Glycol	PGC	L	1.012	I	M	L	M			Highly toxic via oral route.	
Potassium Chlorate	PCR	S	2.340	75,000	M		M			Moderately toxic via oral route. Contact with combustibles may cause fire.	
Potassium Permanganate	PTP	S	2.700	60,000	M	M	M			Skin & eye irritant. Moderately toxic via oral route. A strong irritant because of oxidizing properties. Attacks rubber and most fibers.	
Potassium Peroxide	POP	S	1.001	R							

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Propionic Anhydride	PAH	L	1.010	I	M	L	L	L		Eye, skin & respiratory irritant. Moderately toxic via oral route.	
Propylene Glycol	PPG	L	1.040	S		L	N			No toxicity via oral route.	
Pyrene		S	1.271								
Quinoline	QNL	L	1.095	6,000	H	L	N	L		Highly toxic via oral & dermal routes. May produce retinitis. May attack some forms of plastics.	
Safrole		L	1.100	.0001							
Salicylaldehyde			1.167	SS				L			
Salicylic Acid	SLA	S	1.440	SS	M	L	N	L		Moderately toxic via oral route.	
Selenium		S	4.81								
Selenium Dioxide	SLD	S	3.950								
Selenium Trioxide	STO	S	3.600								
Silver Acetate	SVA	S	3.260	10,200		N	N			Absorption by cuts in skin can produce permanent pigmentation of the skin.	
Silver Carbonate	SVC	S	6.100			N	N			Absorption by skin can cause permanent pigmentation of the skin.	
Silver Cyanide		S	3.95	0.23							
Silver Fluoride	SVF	S	5.820								
Silver Iodate	SVI	S	5.330			N	N			Absorption by skin can cause permanent discoloration of skin.	
Silver Oxide	SVD	S	7.140		M	N	N			Moderately toxic via oral route.	

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Silver Sulfate	SVS	S	5.450							Absorption by skin can cause permanent discoloration of skin.	
Silvex			1.2085	140							
Sodium Borate	SDB	S	2.367		M	N	N			Moderately toxic via oral route.	
Sodium Oxalate	SOX	S	2.270		H	N	N			Highly toxic via oral route.	
Sodium Phosphate	SPP	S	2.150	88,000							
Sodium Silicate		L	1.400	S	M	N	N			Moderately toxic via oral route. Very caustic, irritant to skin & mucous membranes.	
Sodium Silicofluoride	SFR	S	2.680		H	N	N			Highly toxic via oral route.	
Strontium Sulfide		S	3.70								
Sulfolane	SFL	S	1.260	M	M	L	N			Moderately toxic via oral & dermal routes.	
Sulfur		S	1.800	I	L	L	N		M	Low toxicity inhalation can cause irritation of mucous membranes. Safety goggles, respirator should be used.	Should be removed or buried due to potential production of toxic gases or acid.
Tetrachloroethane	TEC	L	1.602	2,820	H	N	N	L		Highly toxic to liver via oral & inhalation routes moderately toxic via dermal route. Strong irritant of eyes & upper respiratory tract. May attack some forms of plastics.	
Tetrachloroethane, 1,1,2,2-		L	1.595		L	N	N				
Tetrachloroethylene	TTR	L	1.630	165	M	N	N		H	Moderately toxic via inhalation, oral & dermal routes. Injures eyes. Can cause dermatitis. Wear goggles, protective clothing, & respirator.	Toxic, should be removed.

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Tetraethyl Dithiopyrophosphate	TED	L	1.190	25	E	N	L			Corrosive to most metals in the presence of moisture.	
Tetraethyl Lead	TEL	L	1.633	I	H	L	N		H	Highly toxic via oral, inhalation & dermal routes. Dissolves rubber. Causes intoxication by inhalation & absorption by skin.	Toxic, should be removed.
Tetraethyl Pyrophosphate	TEP		1.180	M	E	N	L			Very high toxicity by all routes. Action similar to parathion. Reacts slowly with water to form phosphoric acid, corrosive to aluminum, slowly corrosive to copper, brass, zinc, tin.	
Tetrafluoroethylene	TFE	G	1.519	I	M	L	N			Moderately toxic can act as an asphyxiant.	
Tetramethyl Lead	TML	L	1.999	500	H	M	N	L		High toxicity by inhalation and skin absorption. Wear air line mask, goggles, rubber boots, neoprene gloves.	Toxic, should be removed.
Tetranitromethane		L	1.6380								
Thallic Oxide		S	9.65								
Thallium		S	11.85								
Thallium (I) Carbonate		S	7.11	4,030							
Thallium (I) Chloride		S	7.004	2,900							
Thallium (I) Nitrate (v)		S	5.556	3,910							
Thallium (I) Selenide			9.05								
Thiophenol			1.0766								
Thiophosgene	TPG		1.513	I	M		H			Highly irritant to skin, eyes, mucous membranes. Corrodes metals in presence of moisture.	

(continued)

Table F-4., (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Thiourea		S	1.405	90,909							
Thiram	THR	S	1.430	I	M	L	M			Moderately toxic by dermal route. Mild allergen and irritant.	
Toluene-2,4-diisocyanate	TDI	S	1.220	I	H	L	L			Strong irritant and sensitizer. Vapors cause serious lung injury if inhaled.	
Toxaphene	TXP	S	1.600	3	M		M		H	Absorbed by skin highly toxic orally. Respirator, rubber gloves, and goggles or face shield required.	Toxic, should be removed.
Trichloro-s-triazinetrione		S	1.001	12,000	M						
Trichlorobenzene, 1,2,4-		L	1.454	I	M	L				Moderately toxic via oral route.	
Trichloroethane, 1,1,1-	TCE	L	1.310	I	M	M		L	M	Incoordination & impaired judgement at vapor exposures of 500-1000 ppm. Dizziness, drowsiness, loss of consciousness & death at increasing exposures.	Toxic, should be removed.
Trichloroethane, 1,1,2-		L	1.441	4,400	M			L	M	Reacts slowly w/ water forming hydrochloric acid. Respirator and protective clothing required. Corrodes dredge equipment.	Toxic, should be removed.
Trichloroethylene	TCL	L	1.460	1,100	M	H	M	L	H	Incoordination & impaired judgement occur at vapor exposures of 500-1000 ppm. Dizziness, drowsiness, loss of consciousness & death at higher exposures.	Toxic, should be removed.

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Trichlorofluoromethane	TCF	L	1.490	1,100	L	H	N	L	N	Mild irritant. Low toxicity via inhalation route. Air line respirator, rubber gloves & goggles required.	Slightly toxic should be brought to surface and allowed to evaporate in safe area.
Trichloromethanesulfonyl Chloride		S	1.700								
Trichlorophenol	TPH	S	1.700	<1,000	M	M	M	M	M	Moderately toxic via oral route. Dust is an irritant. Protective clothing & mask for toxic dust should be worn.	Toxic, should be removed.
Trichlorophenoxyacetic Acid, 2,4,5-	TCA	S	1.803	240	H	L	N			Highly toxic via oral route. Slowly absorbed by skin.	
Trichlorosilane	TCS	L	1.344	R							
Tricresyl Phosphate (< 1% Ortho-Isomer)	TCP	L	1.160								
Triethanolamine	TEA	L	1.130	M	L	L	M			Moderately irritating to eyes & skin.	
Triethylene Glycol	TEG	L	1.125	M	N	L	M				
Trifluorochloroethylene	TFC	G	1.307	I	M	N	M			Moderately toxic via inhalation route.	
Trifluralin	TFR	S	1.294	<10	M	L	M	M		An herbicide. Moderately toxic via oral route.	
Tripropylene Glycol	TGC	L	1.022	M	M	L	M			Moderately toxic via oral route. Moderate irritant to skin, eyes, mucous membranes. May attack some forms of plastics.	
Uranyl Acetate	URA	S	2.890								
Uranyl Nitrate	UAN	S	2.810								
Uranyl Sulfate	URS	S	3.280								
Vanadium Oxytrichloride	VOT	L	1.830	R-D							

(continued)

Table F-4. (continued)

Chemical Name	CHRIS Code	Phys. State	Specific Gravity	Water Solubility	Toxicity	Ignitability	Reactivity	Bioaccumulation	Aquatic Persistence	Recovery & Handling Hazards	Recommended Response
Vanadium Pentoxide	VOX	S	3.360		E	M				Dust is highly toxic via oral & inhalation routes.	
Vanadyl Sulfate	VSF	S	2.500		E	M	M				
Vinylidene chloride	VCI	L	1.210	I							
Vinyltrichlorosilane	VTS	L	1.260	R							
Warfarin		S	>1							Moderately to highly toxic via oral route.	
Xylenol	XYL	L	1.010	2,000	M						
Zinc Arsenate	ZNA	S	3.310			M	M			Moderately toxic orally.	
Zinc Borate	ZBO	S	2.700		M	M	M				
Zinc Bromide	ZBR	S	4.220								
Zinc Chromate	ZCR	S	3.430			M	M				
Zinc Dialkyldithiophosphate	ZDP	S	1.600	I		L	M				
Zinc Dialkyldithiophosphate (liquid)		L	1.190	I		L	M				
Zinc Fluroborate		L	1.450	M						Highly toxic via oral route.	
Zinc Phosphide	ZFB	S	4.550		E	M	M				
Zinc Potassium Chromate	ZPC	S	2.100								
Zirconium Acetate	ZCA	S	1.370	M		M	M				
Zirconium Sulfate	ZSF	S	3.000								

APPENDIX G

GLOSSARY

Absorption: The soaking up of one substance by another, particularly a liquid by a solid.

Adsorbate: A solid, liquid, or gas that is adsorbed as molecules, atoms, or ions to the surface of a solid.

Adsorption: The attraction of molecules, atoms, or ions or compounds to the surface of a solid.

Aerobic: Having molecular oxygen as part of the environment or growing in the presence of molecular oxygen.

Alternative: A collection of techniques that are used to accomplish all objectives of a response.

Anion: A negatively charged atom or group of atoms.

Aquatic persistance: Chemical stability of a substance over time in a water body.

Aromatics: A class of organic compounds characterized by one or more cyclic rings that contain double bonds. Benzene is a prominent compound of this class.

Backwash: An upward flow of water through a filter bed that cleans the filter after it is exhausted.

Benthic organisms: Plant and animal life whose habitat is the bottom of a sea, lake, or river.

Bentonite: A highly plastic clay, consisting of the minerals montmorillonite and beidellite, that swells extensively when wetted.

Berm: A narrow shelf or flat area that breaks the continuity of a slope.

Bioaccumulation: The result of chemical intake by an organism when the rate of intake is greater than the rate of excretion, resulting in and increase in tissue concentration relative to the exposure concentration.

Bioaccumulation factor: The ratio of the concentration of a substance in the tissue of an organism to the concentration of the substance in the environment surrounding the organism.

Biomagnification: The increase in chemical concentration in tissues of organisms through the food chain; a progressive increase in bioaccumulation through the food chain.

Biota: Animal and plant life, especially of a particular region.

BOD (Biochemical oxygen demand): A measure of the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions.

Bottom materials: Any materials that are on the bottom of a water body, including sediments, vegetation, and contaminating substances.

Carbonate: A compound that contains the carbonate ($(CO_3)^{-2}$) ion.

Cation: A positively charged atom or group of atoms.

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act (Superfund), Federal law under which uncontrolled hazardous waste sites and spills of hazardous materials are remediated.

CFR: Code of Federal Regulations; publication of regulations promulgated under Federal laws.

Chemical equilibrium: A condition in which a chemical reaction is occuring at equal rates in its forward and reverse directions, so that concentrations of the reacting substances do not change with time.

CHRIS: Chemical Hazards Response Information System; a U.S. Coast Guard information system pertaining to water transport of hazardous chemicals that consists of the following components: the Condensed Guide to Chemical Hazards (handbook), the Hazardous Chemical Data Manual, the Hazard-Assessment Handbook, the Response Methods Handbook, Data Bases for Regional Contingency Plans, and the Hazard-Assessment Computer System (HACS).

Coarse-grained material: Granular material (such as soil or sediments) in which sands and gravels predominate; in general, material larger than 74 microns (200 mesh).

COD (Chemical oxygen demand): A measure of the amount of oxygen required to convert organic compounds to carbon dioxide and water by a strong oxidizing agent.

Cohesive soil: A soil that has considerable compressive strength when it is unconfined and air-dried and exhibits significant cohesion (clumping) when it is wetted; opposite of free-flowing material.

Colloidal particles: Particles that are so small (1 to 100 millimicrons) that surface charges produce an appreciable influence on the behavior of the particles.

Contaminated: Having been exposed to, and retained all or a portion of, a harmful substance.

CWA: Clean Water Act; Federal law for restoring and maintaining the quality of surface waters.

Dewatering: Removal of water from a substance or an area by means of gravity, pumps, drains, or filters.

DOT: U.S. Department of Transportation.

Dredge bucket: That part of a mechanical dredge that dislodges and collects sediments.

Dredge head: That part of a hydraulic or pneumatic dredge that dislodges and collects sediments.

Embankment: A man-made deposit of soil, rock, or other material used to form an impoundment.

Endangered species: Biota that are in danger of extinction, especially those species that are officially so declared by the U.S. Department of Interior and/or state agencies.

Environmental setting: The total natural background of a location, including hydrology, geology, climatology, and biology.

EP Toxicity: Extraction Procedure (EP) test used by EPA as a determination of toxicity; the degree of leaching of contaminants from a substance is measured under conditions that simulate a waste landfill.

Estuary: Part of a flowing water body where its current is met and influenced by tides.

Exothermic: Releasing heat as a by-product of a chemical reaction.

Exposure: The subjecting of a receptor to a contaminating substance.

Fauna: Animal life, especially of a particular region.

FDA: Food and Drug Administration of U.S. Department of Health and Human Services.

Filter cake: A concentrated solid or semisolid material that is separated from a liquid by filtration.

Fine-grained material: Granular material (such as soil or sediments) in which silts and clays predominate; in general, material smaller than 74 microns (200 mesh).

Flocculant: A reagent added to a dispersion of solids in a liquid to bring together fine particles to form aggregates, or flocs.

Flocculate: To aggregate or clump small particles into larger masses.

Flora: Plant life, especially of a particular region.

Free-flowing material: Generally granular material (such as soil or sediments) that can be poured or dumped with minimal clumping; opposite of cohesive material.

Grain size: The effective diameter of a particle measured by sedimentation, sieving, micrometry, or a combination of these methods.

HACS: Hazard Assessment Computer System; a system for obtaining rapid hazard evaluations from U.S. Coast Guard headquarters; part of CHRIS.

Habitat: The area in which a biological population normally lives or occurs.

Halogen: Any element of the halogen family of chemical elements (e.g. chlorine, bromine, fluorine).

HSWA: Hazardous and Solid Waste Amendments to RCRA.

Hydrostatic pressure: The pressure at a point in a fluid at rest caused by the weight of the fluid above the point.

Hydroxide: Compound containing the OH^- group; the hydroxides of metals are bases and those of non-metals are usually acids.

IARC: International Agency for Research on Cancer of the World Health Organization.

Immediate response: An action or multiple actions that are implemented with minimal planning and consideration of alternatives to control a rapidly worsening situation or to minimize the impacts of a severe situation.

Impact: The effect or result of a receptor being exposed to a contaminating substance.

<u>In situ</u>: In its original place, as opposed to being moved or relocated.

Ions: Atoms, groups of atoms, or compounds, that are electrically charged as a result of an imbalance between protons and electrons.

Leach: The transfer of liquid, solid, or dissolved compounds from a solid matrix to a liquid as a result of passing of the liquid through the interconnected pores of a pile or cell of the solid matrix.

Leachate: The liquid that is produced as a result of leaching; generally considered to be contaminated.

LD_{50} (or lethal dose): The concentration of substance that is fatal to 50 percent of the population that is exposed.

Micron: One-millionth of a meter; 25,400 microns equal one inch.

Mesh: A size of screen or particles passed through a screen in terms of the number of openings occuring per linear inch; 200 mesh is equivalent to 200 microns.

MPRSA: Marine Protection, Research, and Sanctuaries Act; Federal law under which dumping of materials into ocean waters is regulated.

NAS: National Academy of Sciences.

NCP: National Contingency Plan; Federal plan for implementing CERCLA.

NIOSH: National Institute for Occupational Health and Safety of the U.S. Department of Health and Human Services.

NOAA: National Oceanic and Atmospheric Administration of the U.S. Department of Commerce.

NPDES: National Pollutant Discharge Elimination System; a program for controlling point discharges to surface waters; administered by USEPA under the Clean Water Act.

Objectives (or response objectives): Goals that are established for minimizing, eliminating, or reversing the impacts of a release of a contaminating substance.

Octanol-water partition coefficient: A measure of the affinity of a substance for octanol (a liquid that behaves chemically similar to animal fat tissue) relative to water.

On-site: On the same or contiguous geographical area.

Organic matter: Substances comprised mainly of carbon and originating in animal or plant life or in laboratory synthesis.

OSC (On-scene coordinator): Person that is responsible for responses to spills of hazardous substances.

OSHA: Occupational Safety and Health Administration of the U.S. Department of Labor.

Oxidation: A chemical reaction in which a compound or radical loses electrons.

Packed bed: A fixed layer of granular material arranged in a vessel to promote intimate contact between gases, vapors, liquids, solids, or various combinations.

Partition: The tendency of a substance to exhibit an affinity for one material over another (such as sediments over water).

PCBs (Polychlorinated biphenyls): A toxic and highly persistent class of compounds that were originally used as insulating fluids in electrical equipment.

Persistence: Chemical stability of a substance over time.

pH: A measure of the hydrogen ion concentration of a substance, which controls the direction, speed, and extent of chemical and biochemical reactions.

Publicly owned treatment works (or POTW): In general, a central system for collecting and treating municipal wastewater.

Quiescent waters: Areas of a water body that have relatively little wave action, current, and flow velocity.

RCRA: Resource Conservation and Recovery Act; Federal law under which solid and hazardous wastes are regulated.

Receptors: Persons, plants, animals, or objects that are subjected to a contaminating substance.

Release: A substance that has entered the environment through a leak, discharge, or other failure of a containment or confinement system.

Remote sensing: A class of techniques for monitoring a situation that does not involve physically entering the substances being monitored; examples are sonar and x-ray fluorescence.

Residual (or byproduct): A material that is produced without intent during the processing or treatment of other materials.

Response (or response action): An action or multiple actions that are taken to minimize the impacts of a release of contaminating materials to the environment.

Resuspension: The causing of bottom materials to become suspended in the water column, usually by agititation.

Scour: The clearing and digging action of flowing water, especially the downward erosion caused by stream water in sweeping away mud and silt from the outside bank of a channel.

Scrubber: A device for removal of entrained liquid droplets, dust, or an undesired gas component from a gas stream.

SDWA: Safe Drinking Water Act; Federal law under which standards and criteria are established to protect drinking water.

Sediments: Material that has settled to the bottom of a water body, consisting primarily of eroded and transported soil and organic matter.

Sediment-water partition coefficient: A measure of the affinity of a substance for sediments relative to water.

Sensitive species (or indicator species): Biota that exhibit an usually rapid or extreme reaction to a changed environmental condition; such reactions can provide a qualitative measure of contamination patterns.

Sinker: A chemical substance that is heavier than water and has low solubility in water.

Slurry: A mixture of solids and liquid, generally of a consistency that can be pumped.

Soil permeability: The quality of a soil horizon that enables water or air to move through it. The permeability of a soil may be limited by the presence of one low-permeability horizon, even though others are highly permeable.

Solute: The substance dissolved in a solvent.

Sorbent: A substance that can take up and hold a contaminating substance; includes absorbents and adsorbents.

Specific gravity: The ratio of the density of a material to the density of water at a specific temperature.

Spill: Release of a substance from a container, generally of short duration.

Standards and criteria: Regulatory or advisory numerical limits for concentrations of contaminating substances; generally apply to drinking water and discharges of waste streams to surface water.

Suspended solids: A mixture of fine, nonsettling particles in a liquid.

Technique: A process, method, or technology that is used to accomplish a response.

Toxicity: The characteristic of being poisonous or harmful to plant or animal life; the relative degree of severity of this characteristic.

Transformation rate: The rate at which the properties of a chemical change to pose a lesser or greater hazard.

TSCA: Toxic Substances Control Act; Federal law under which selected chemicals are regulated (including PCBs).

Turbidity: Cloudiness of a liquid caused by suspension of solid particles; a measure of the suspended solids in a liquid.

Underdrain: A subsurface drain pipe or gravel drainage layer into which water flows.

USCG: United States Coast Guard of the U.S. Department of Transportation

USEPA: United States Environmental Protection Agency.

USGS: United States Geologic Survey of the U.S. Department of Interior.

Water column: That part of a water body that is water, as opposed to the bottom, banks, vegetation, etc.

APPENDIX H

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APPENDIX I

BLANK WORKSHEETS FOR DOCUMENTATION AND DECISIONMAKING

Blank copies of the following worksheets that are presented in the body of this handbook are provided in this appendix:

- Discharge Summary Worksheet
- Spilled Substance Data Worksheet
- Water Body Data Collection Worksheet
- Environmental Setting Worksheet
- Exposure and Impact Data Worksheet
- Worksheet and Screening Response Categories
- Worksheet and Screening Response Techniques
- Worksheet and Development of Response Alternatives
- Alternatives Evaluation Worksheet.

It is recommended that additional, separate copies be made for use in field response situations.

DISCHARGE SUMMARY WORKSHEET

Site _____

Time of Observation _____ Date _____

Type of Water Body _____

CIRCUMSTANCES OF DISCHARGE

Location _____

Source _____

Cause _____

Status (Circle One): Discrete Intermittent Continuous

Time Elapsed Since Discharge Began _____

Quantity of Material Released _____ Rate of Release _____

Duration of Release (if intermittent) _____

Substances Released	Quantity

Form of Release (Circle One):
Powder Crystal/Pellets Chunks Semi-Solid Liquid

EXTENT OF CONTAMINATION

Sediments	Water Body

OBSERVATIONS _____

SPILLED SUBSTANCE DATA WORKSHEET

Information Factor	Substance A _____	Information Source	Substance B _____	Information Source
1. Specific Gravity				
2. Physical State				
3. Particle Size				
4. Water Solubility				
5. Water Reactivity				
6. Chemical Reactivity				
7. Ignitability				
8. Surface Tension				

(continued)

SPILLED SUBSTANCE DATA WORKSHEET (continued)

	Information Factor	Substance A _____	Information Source	Substance B _____	Information Source
9.	Octanol-water partition coefficient				
10.	Sediment-water partition coefficient				
11.	Bioaccumulation				
12.	Aquatic persistence				
13.	Transformation rate constants o Hydrolysis o Oxidation o Biotransformation				
14.	Toxicity o Aquatic species o Mammals o Human o Food chain				

WATER BODY DATA COLLECTION WORKSHEET

Information Requirements	Site-Specific Data	Information Source
WATER BODY:		
Depth of Water Body		
Minimum		
Maximum		
Average		
Width of Water Body		
Minimum		
Maximum		
Average		
Water Current Direction		
Surface		
Subsurface		
Water Current Velocity		
Surface		
Subsurface		
Tidal Cycle		
Time of high tide		
Time of low tide		
Velocity of tide		
Amplitude of tide		
Wave Height		

(continued)

WATER BODY DATA COLLECTION WORKSHEET (continued)

Information Requirements	Site-Specific Data	Information Source
SEDIMENTS:		
Depth to Contaminated Sediments		
Sediment Type		
Sediment Grain Size		
Sediment Organic Carbon Content		
WATER:		
Suspended Particulate Concentration		
Water Temperature Profile		
Salinity Profile		
SEASONAL CONSIDERATIONS:		
Seasonal Conditions and Impacts Drought Snow melt Storm flood		

SKETCH WATER BODY/CHANNEL CONFIGURATION (CROSS-SECTION)

ENVIRONMENTAL SETTING WORKSHEET

Site Information	Information Sources

DISTINCTIVE HABITATS (Check and list if near spill area)

____ 1. Breeding Grounds, Nesting, or Roosting Sites

____ 2. Wildlife/Refuges

____ 3. Endangered Species Habitats

____ 4. Marshes or Swamps (e.g., mangrove)

____ 5. Subtidal Seagrass Systems

____ 6. Harvesting Beds

____ 7. Coral Reefs

____ 8. Soft Bottom Benthos

____ 9. Unused Natural Ecosystem (ecologically or aesthetically important)

____ 10. Other

(continued)

ENVIRONMENTAL SETTING WORKSHEET (continued)

Site Information	Information Sources

ENDANGERED SPECIES (List)

_____
_____
_____
_____

SENSITIVE SPECIES (Check if applicable and list)

____ 1. Aquatic (Fish/Shellfish) _____

____ 2. Birds _____

____ 3. Reptiles/Amphibians _____

____ 4. Mammals _____

____ 5. Plants _____

SENSITIVE WATER BODY USAGE (Check if applicable)

Type of Use	Distance Downstream From Spill

CONSUMPTIVE WATER USE

____ 1. Drinking Water Supply
____ 2. Industrial Water Supply
____ 3. Irrigation
____ 4. Fire Water Supply

RECREATIONAL USE

____ 1. State/National Park
____ 2. Swimming
____ 3. Boating
____ 4. Fishing
____ 5. Other _____

(continued)

ENVIRONMENTAL SETTING WORKSHEET (continued)

Site Information	Information Sources

COMMERCIAL USE (Check if applicable and list)

____ 1. Shellfish _____

____ 2. Finfish _____

____ 3. Resort area or other waterfront property _____

____ 4. Marinas _____

____ 5. Harbor/Docks _____

____ 6. Transportation (shipping lanes) _____

POTENTIAL RECEPTORS (Check if applicable and identify)

____ 1. Fish _____

____ 2. Shellfish _____

____ 3. Aquatic Plants _____

____ 4. Reptiles/Amphibians _____

____ 5. Other aquatic or benthic receptors _____

____ 6. Birds _____

____ 7. Mammals _____

____ 8. Humans _____

Adapted from Byroad, Twedell, and LeBoff, 1981.

EXPOSURE AND IMPACT DATA WORKSHEET

RESOURCE/ RECEPTOR	TYPE OF EXPOSURE	EXPOSURE LEVEL CURRENT ( )	TIME 1 ( )	TIME 2 ( )	TIME 3 ( )	REGULATORY STANDARD OR OTHER EXPOSURE CRITERIA	COMMENT ON POTENTIAL FOR HARM

WORKSHEET FOR SCREENING RESPONSE CATEGORIES

I. Select the site scenario that characterizes the existing site conditions (check one or both):

____ Contaminants are relatively stationary.

____ Contaminants are mobile.

II. As identified in Table 4-1, Column B, the preferred response category, or "train" of categories, is as follows:

(1) _____ (3) _____

(2) _____ (4) _____

III. Applicability of the preferred response category:

IIIa. Is containment necessary for implementation of removal (circle one)?

Yes (go to IIIb) No (go to IIIc)

IIIb. Is containment applicable (circle one)?

Yes (go to IIIc) No (go to IVa & d)

IIIc. Is immediate and total removal physically applicable (circle one)?

Yes (go to IIId) No (go to IVa, b & c)

IIId. Does removed material require treatment? (circle one)?

Yes (go to IIIe) No (go to IIIf)

IIIe. Is treatment applicable (circle one)?

Yes (go to IIIf) No (go to IVd)

(continued)

IIIf. Is disposal of removed material or treatment residuals necessary (circle one)?

Yes (go to IIIg) No (go to IIIh)

IIIg. Is disposal applicable (circle one)?

Yes (go to IIIh) No (go to IVa & d)

IIIh. The preferred response category is applicable at the site. The reasons for its applicability are as follows:

_____

_____

IV. Other Response Categories:

IVa. Summarize the reasons why the preferred response category is not applicable at the site.

_____

_____

IVb. Is immediate partial removal applicable (circle one)?

Yes (go to IVb1) No (go t IVc)

IVb1. Does partially removed material require treatment? (circle one)?

Yes (go to IVb2) No (go to IVb3)

IVb2. Is treatment applicable (circle one)?

Yes (go to IVb3) No (go to IVd)

IVb3. Is disposal necessary (circle one)?

Yes (go to IVb4) No (go to V)

IVb4. Is disposal applicable (circle one)?

Yes (go to V) No (go to IVd)

(continued)

IVc. Can removal be temporarily delayed (circle one)?

Yes (go to IIId) No (go to IVd)

IVd. Is in situ response applicable (circle one)?

Yes (go to V) No (go to IVe)

IVe. "No action" should be considered.

(go to V)

V. Based on existing site conditions, the following other response categories are applicable at the site:

- o Partial removal (accompanied by treatment and/or disposal)
- o Removal implementation delay
- o In situ treatment/isolation
- o No action possible
  (go to VI)

VI. Summary:

VIa. The following response categories are applicable at the site:

- o Containment
- o Removal
- o Treatment
- o Disposal
- o In situ treatment/isolation
- o No action

VIb. Comments:

_____

_____

_____

_____

WORKSHEET FOR SCREENING RESPONSE TECHNIQUES

Identify those categories and Response Techniques that are applicable under existing site conditions.

Containment Techniques	Comments Regarding Applicability/Inapplicability
Containment curtains	
Trenches and pits	
Dikes and berms	
Cofferdams	
Temporary cover material	
Pneumatic barriers	
Floating breakwater	
Removal Techniques	
Mechanical dredges	
- Dipper dredges	
- Bucket ladder dredges	
- Clamshell dredges	
- Draglines	
- Conventional earth excavation equipment	
Hydraulic dredges	
- Plain suction dredge	
- Cutterhead dredge	
- Dustpan dredge	
- Hopper dredge	
- Portable hydraulic dredge	
- Hand-held hydraulic dredge	
Pneumatic dredges	
- Airlift dredge	
- Pneuma dredge	
- Oozer dredge	

(continued)

Treatment Techniques for Removed Material

Sediment/water separation
- Settling basins
- Hydraulic classifiers
- Spiral classifiers
- Cyclones
- Filters

Sediment dewatering
- High-rate gravity settlers
- Centrifuges
- Belt press filters
- Vacuum filters
- Pressure filters

Water treatment
- Adsorption
- Ultrafiltration
- Reverse osmosis
- Ion exchange
- Biological treatment
- Precipitation
- Wet air oxidation
- Ozonation
- Ultraviolet radiation
- Discharge to publicly owned treatment works

Sediment treatment
- Contaminant immobilization
- Contaminant treatment

Disposal Techniques

Sediments
- Land disposal
- Open water disposal

Water
- Discharge to surface water
- Land application
- Deep well injection

Treatment residuals
- Land disposal
- Incineration
- Land application
- Deep well injection

(continued)

In Situ Treatment and Isolation Techniques

Treatment _____
- Sorption _____
- Chemical treatment _____
- Biological treatment _____

Isolation _____
- Capping _____
- Covering _____
- Fixation _____

WORKSHEET FOR DEVELOPMENT OF RESPONSE ALTERNATIVES

Alternative	Containment	Removal	Treatment	Disposal	In Situ
A					
B					
C • • • • • etc.					

ALTERNATIVES EVALUATION WORKSHEET

Alternative (See Alternatives Development Worksheet)	Performance	Reliability	Implement-ability	Environ-mental and Public Health Impacts	Safety	Cost	Other Concerns/ Comments

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