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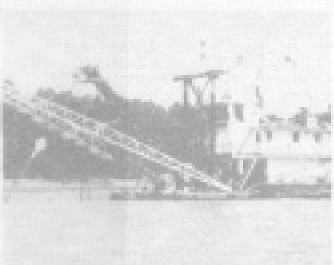

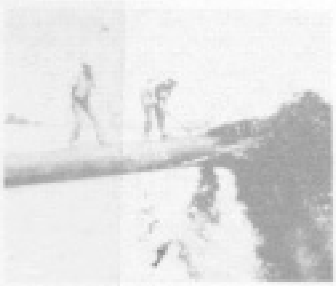

DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM

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MANAGEMENT STRATEGY FOR DISPOSAL OF DREDGED MATERIAL: CONTAMINANT TESTING AND CONTROLS

by

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The diversity of disposal alternatives and techniques for management of contaminated dredged material requires the development of an overall long-term management strategy for disposal. The selection of an appropriate strategy is dependent on nature of the dredged material, nature and level of contamination, available dredging alternatives, project size, and site-specific physical and chemical conditions, all of which influence the potential for

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environmental impacts. Technical feasibility, economics, and other socioeconomic factors must also be considered in the decisionmaking process. The management strategy presented mainly considers the nature and degree of contamination, potential environmental impacts, and related technical factors. The technical strategy is based on findings of research conducted by the US Army Corps of Engineers, the US Environmental Protection Agency, and others over the past 10 years and experiences gained while actively managing dredged material disposal. Approaches for evaluating potential for contaminant-related problems and the applicability of various disposal alternatives are discussed. Detailed procedures for conducting tests or for design and implementation of management strategies are not presented, but are the topics of other papers to follow.

A technically feasible and environmentally sound strategy for the disposal of dredged material is presented, and it is recommended that this strategy be implemented for future dredged material disposal operations.

EXECUTIVE SUMMARY

The US Army Corps of Engineers (CE) dredges approximately 290 million cu m of material annually for maintenance of the Nation's navigation system. Over 90 percent of the total volume is considered acceptable for a wide range of disposal alternatives. However, the potential presence of contaminants in some sediments has generated concern that disposal of dredged material may adversely affect water quality and aquatic, wetland, or terrestrial organisms. These concerns have led to the regulation of dredged material for environmental protection under Section 404 of the Clean Water Act and Section 103 of the Ocean Dumping Act.

The diversity of disposal alternatives and techniques for management of contaminated dredged material requires the development of an overall long-term management strategy for disposal. The selection of an appropriate strategy is partially dependent on the nature of the dredged material, nature and level of contamination, the physicochemical nature of the disposal site environment, available dredging alternatives, project size, and site-specific physical and chemical conditions, all of which influence the potential for environmental impacts. Technical feasibility, economics, and other socioeconomic factors must also be considered in the decisionmaking process. The technical management strategy presented mainly considers the nature and degree of contamination, physicochemical conditions at disposal sites, potential environmental impacts, and related technical factors. The steps for managing dredged material disposal consist of the following:

- a. Evaluate contamination potential.
- b. Consider potential disposal alternatives.
- c. Identify potential problems.
- d. Apply appropriate testing protocols.
- e. Assess the need for disposal restrictions.
- f. Select an implementation plan.
- g. Identify available control options.
- h. Evaluate design considerations.
- i. Select appropriate control measures.

The initial screening for potential contamination is the initial evaluation outlined in the testing requirements for Section 404 of the Clean Water Act. The evaluation consists of examining available historical data and

information on pollutant discharges and spills at the dredging site to determine whether there is a reason to suspect the presence of significant concentrations of contaminants.

If the dredged material is clean and/or environmental impacts are within acceptable limits, conventional open-water or confined disposal methods may be used. If impacts resulting from conventional disposal techniques would not be within acceptable limits, contaminated material may be disposed by either open-water or confined methods with appropriate restrictions.

Each disposal alternative may pose problems for managing contaminated dredged material. Based on the initial evaluation, site-specific conditions, dredging methods, and anticipated site use, the potential contaminant problems can be identified. For open-water disposal, contaminant problems may be either water column or benthic related. Confined disposal contaminant problems may be either water quality related (effluent, surface runoff, or leachate) or contaminant uptake related (plants or animals).

The magnitude and potential impacts of specific contaminants must be evaluated using appropriate testing protocols. Such protocols, designed for evaluation of dredged material, consider the unique nature of dredged material and the physicochemical environment of each disposal alternative.

The results of all testing are compiled and evaluated to determine the potential for environmental harm from contamination, to examine the interrelationships of the problems and potential solutions, and to determine what restrictions on open-water or confined disposal are appropriate. If impacts as evaluated using the testing protocols are acceptable, conventional open-water or confined disposal may again be considered.

Specific environmental problems identified using the testing protocols must be addressed by implementation plans appropriate for the level of potential contamination. Restrictions may also be required for open-water or confined disposal that could eliminate certain options from consideration.

Several options may be available for the selected implementation strategy. Options for controlling water column and benthic impacts include bottom discharge via submerged diffusers, treatment, contained aquatic disposal, and subaqueous capping using clean sediments. Options for controlling confined disposal impacts include treatment, long-term storage, and reuse.

The degree of contaminant control finally selected may range anywhere between disposal in open water with no special restrictions to a completely controlled confinement. Many of the technologies identified are either commonly used in CE dredging activities or are presently being evaluated as part of the CE's ongoing research and operations programs.

PREFACE

The lead responsibility for the development of specific ecological criteria and guidelines for use in regulating the transport and disposal of dredged and fill material was legislatively assigned to the US Environmental Protection Agency (USEPA) in consultation or conjunction with the Corps of Engineers (CE). The enactment of Public Laws 92-532 (the Marine Protection, Research, and Sanctuaries Act of 1972) and 92-500 (the Federal Water Pollution Control Act Amendments of 1972), concerned with the transport and disposal of dredged and fill material, required the CE to participate in developing guidelines and criteria for regulating dredged and fill material disposal. Major research efforts in this area included the CE Dredged Material Research Program which was completed in 1978, the ongoing CE Dredging Operations Technical Support (DOTS) Program, the Long-term Effects of Dredging Operations (LEDO) Program, the CE/USEPA Field Verification Program (FVP), and portions of the Improvements in Operations and Maintenance Techniques (IOMT) Program. All of the programs have been assigned to the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The ongoing programs are under the general management of the Environmental Effects of Dredging Programs (EEDP) of WES's Environmental Laboratory (EL). Results of these programs and experience gained through management of dredged material serve as the basis for the strategy outlined in this document.

This document was prepared through the DOTS Program at the request of the Dredging Division, Water Resources Support Center (WRSC-D), CE. Mr. David P. Mathis, WRSC-D, was project monitor.

This study was conducted at WES from July 1983 to August 1984 by personnel of the Environmental Engineering Division (EED) and Ecosystem Research and Simulation Division (ERSD): Mr. Norman R. Francingues, Jr., and Dr. Michael R. Palermo, EED; and Drs. Charles R. Lee and Richard K. Peddicord, ERSD. Mr. Charles C. Calhoun, Jr., Manager, EEDP, EL, (at the time the study was conducted) provided general coordination for the study.

The study was under the general supervision of Dr. Raymond L. Montgomery, Special Assistant, EED; Dr. Robert M. Engler, Senior Scientist, ERSD, (current PM, EEDP); the late Mr. Andrew J. Green, Chief, EED; Mr. Donald L. Robey, Chief, ERSD; and Dr. John Harrison, Chief, EL.

During the preparation of this report, COL Tilford C. Creel, CE, and COL Robert C. Lee, CE, were Commanders and Directors of WES and Mr. F. R. Brown was Technical Director. At the time of publication, COL Allen F. Grum, CE, was Director and Dr. Robert W. Whalin was Technical Director.

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MANAGEMENT STRATEGY FOR DISPOSAL OF DREDGED MATERIAL: CONTAMINANT TESTING AND CONTROLS

PART I: INTRODUCTION

Background

1. Navigable waterways of the United States have played a vital role in the Nation's economic growth through the years. The Corps of Engineers (CE), in fulfilling its mission to maintain, improve, and extend these waterways, is responsible for the dredging and disposal of large volumes of sediment each year. Dredging is a process by which sediments are removed from the bottom of streams, rivers, lakes, and coastal waters; transported via ship, barge, or pipeline; and discharged to land or water. Annual quantities of dredged material average about 290 million cu m in maintenance dredging operations and about 78 million cu m in new work dredging operations with the total annual cost now exceeding $250 million.

2. Over 90 percent of the total volume of dredged material is considered acceptable for a wide range of disposal alternatives. However, the potential presence of contamination has generated concern that dredged material disposal may adversely affect water quality and aquatic or terrestrial organisms. Since many of the waterways are located in industrial and urban areas, sediments may be contaminated with wastes from these sources. In addition, sediments may be contaminated with chemicals from agricultural practices.

3. The 404(b)(1) guidelines at 40 CFR Part 230 and ocean dumping criteria at 40 CFR Part 220 implement the environmental protection provisions of the Clean Water Act (CWA) and the Ocean Dumping Act (ODA), respectively. These guidelines and criteria provide general regulatory guidance and objectives, but not a specific technical framework for evaluating or managing the small percentage of contaminated sediment that must be dredged. Further, neither the guidelines nor criteria could adequately address the multitude of technical factors that must be considered when removing and disposing of contaminated sediments. One essential factor or management consideration in any dredging project is the potential impact of a decision to not dredge contaminated sediments. This decision could not only be influenced by economic

considerations, but also by environmental concerns/benefits resulting from removing the contaminated sediments.

4. Since the nature and level of contamination in sediment vary greatly on a project-to-project basis, the appropriate method of disposal may involve any of several available disposal alternatives. Also, control measures to manage specific problems associated with the presence or mobility of contaminants may be required as a part of any given disposal alternative. Further, many states, in an effort to more fully manage their natural resources, are looking to the Corps of Engineers to aid them via a long-term approach to dealing with the operation and management and new work dredging volumes. An overall long-term management strategy for disposal of dredged material is therefore required. Such a strategy must provide a framework for decision-making to select the best possible disposal alternatives and to identify appropriate control measures to offset problems associated with the presence of contaminants.

Purpose and Scope

5. The intended use of this document is to assist the regulator in complying with the criteria and guidelines of the CWA and the ODA for disposing of contaminated dredged material. The specific purpose of this document is to present a technically and environmentally sound technical management strategy for contaminant testing and controls for disposal of dredged material. The strategy is based on findings of research conducted by the CE, the US Environmental Protection Agency (USEPA), and others over the past 10 years and on experience in actively managing dredged material disposal. Approaches for evaluating potential for contaminant-related problems, testing protocols, and applicability of various disposal alternatives are discussed. Detailed procedures for conducting tests or for design and implementation of technical management strategies are not presented but are appropriately referenced. The technical management strategy is currently being applied at various CE field projects. It will be further developed and refined based on the field experience gained in the demonstration studies. This technical management strategy would become part of any long-term management strategy designed to address not only the alternatives for contaminated sediment but also the alternatives for clean sediment disposal including beneficial uses such as habitat creation and

engineering functions, while meeting some of the objectives of the state resource agencies in managing their natural resources (e.g., avoiding certain critical habitats; recognition of critical, biologically sensitive time periods; etc.).

6. The dredged material disposal management strategy developed for the Corps' dredging program must be broad enough to handle a wide range of dredged material characteristics, dredging techniques, and disposal alternatives. The long-term management strategy must consider the nature of the sediment to be dredged, potential environmental impacts of dredged material disposal, nature and degree of contamination, dredging equipment, project size, site-specific conditions, technical feasibility, economics, and other socioeconomic factors. This report presents a technical management strategy that considers most of these factors (Figure 1). The two major features of the technical management strategy are consideration of disposal alternatives and steps required for selection and implementation of appropriate disposal management strategies. The steps identified are as follows:

a. Conduct an initial evaluation to assess contamination potential.
b. Select a potential disposal alternative.
c. Identify potential problems associated with that alternative.
d. Apply appropriate testing protocols.
e. Assess the need for disposal restrictions.
f. Select an implementation plan.
g. Identify available control options.
h. Evaluate design considerations for technical and economic feasibility.
i. Select appropriate control measures.

Conduct an Initial Evaluation

7. The initial screening for contamination is the initial evaluation outlined in the testing requirements for Section 404 of the Clean Water Act (USEPA 1980). The evaluation is designed to determine if there is reason to believe that the sediment contains any contaminant at a significant concentration (above background levels). Considerations include but are not limited to:

a. Potential routes by which contaminants could reasonably have been introduced to the sediments.

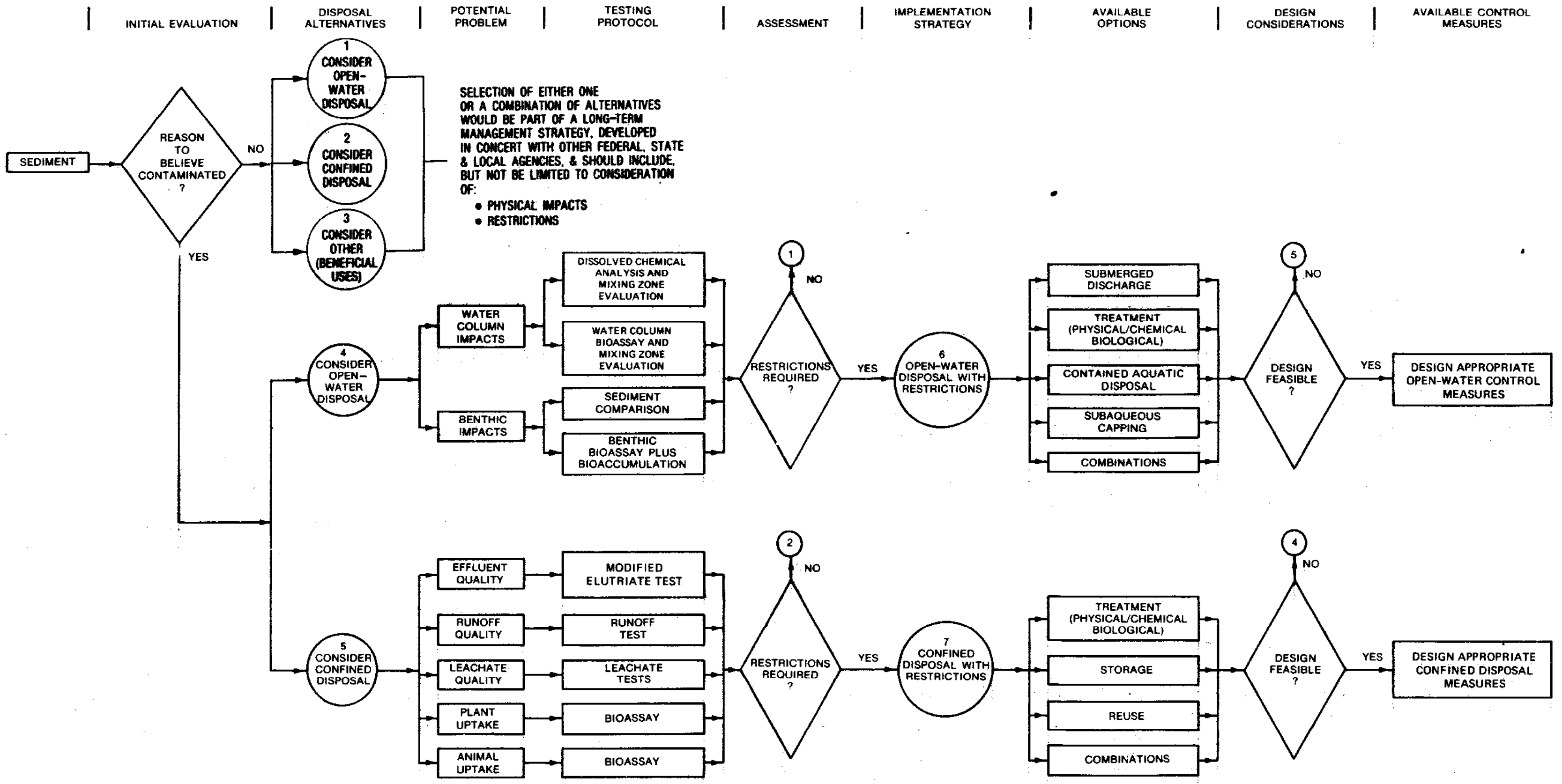

Figure 1. Management strategy flowchart

b. Data from previous bulk sediment analysis and other tests of the material or other similar material in the vicinity, provided the comparisons are still appropriate.

c. Probability of contamination from agricultural and urban surface runoff.

d. Spills of contaminants in the area to be dredged.

e. Industrial and municipal waste discharges.

8. If there is available information indicating contaminants are not present above background levels, restrictions are not required. In this case any disposal alternative may be selected though the possibility of other environmental impacts such as effects of turbidity, salinity, suspended solids, temperature changes, and low dissolved oxygen concentrations must be considered in the final selection. Three disposal alternatives are shown in the flowchart (Figure 1) for acceptable materials or so-called "clean" sediments: [1]* open water (aquatic), [2] confined (intertidal, nearshore and upland), and [3] others, which include marsh or wetland development and other beneficial uses. The final selection is based on environmental considerations, available dredging alternatives, site-specific conditions, technical feasibility, economics, and other socioeconomic considerations.

9. If there is reason to believe that contaminants are present, the sediment must be evaluated in relation to the physicochemical conditions that would be present at the disposal site to examine the potential for environmental impacts. Either open-water [4] or confined disposal [5] could be initially considered and appropriately evaluated or both alternatives could be evaluated concurrently. The selection of the disposal alternative to be considered is dependent on the potential problems posed by contaminants, available dredging equipment, site-specific conditions, technical feasibility, economics, and socioeconomic considerations.

Select a Potential Disposal Alternative

10. The technical management strategy has divided the dredged material disposal alternatives into the following seven categories:

---

* Numbers in brackets refer to the respective disposal alternative as numbered in Figure 1. Also, open water disposal is used to describe only aquatic environments, whereas confined disposal operations can be classified for intertidal, nearshore and upland environments.

a. Open-water disposal [1].

b. Confined disposal [2].

c. Other (beneficial uses, etc.) [3].

d. Open-water disposal (contaminated sediments) [4].

e. Open-water disposal with restrictions [5].

f. Confined disposal (contaminated sediments) [6].

g. Confined disposal with restrictions [7].

Open-water disposal [4]

11. Consideration of open-water disposal [4] for a contaminated sediment requires an evaluation of the potential impacts on the water column and the benthic environment. Other special disposal problems such as effects on health of disposal personnel would be a rare occurrence but should also be considered. Water column impacts can be evaluated by chemical analysis of dissolved contaminants for which water quality criteria exist. The effects of mixing and dilution should be considered during assessment of the test results. If the water quality is expected to be significantly impaired or the water quality criteria to be exceeded, a water column bioassay can be used to determine the potential for adverse consequences.

12. Potential benthic impacts are first evaluated by comparing contaminant concentrations of the sediments in both the dredging and disposal sites. If the concentrations of contaminants in the dredging site sediment are lower than or similar to the concentrations in the disposal site sediment, it can be concluded that disposal will not have unacceptable adverse impacts on the benthic environment. If contaminant concentrations are greater, a bioassay/bioaccumulation test should be performed to determine the bioavailability of the contaminants. If the initial evaluation for contaminants and initial sediment characterization indicates a potential for special dredging problems (e.g., noxious emissions), appropriate tests must be performed.

13. If the impacts are acceptable, the dredged material can be disposed in open water without restrictions [1]. If unacceptable, options for open-water disposal with restrictions [6] must be evaluated.

Open-water disposal
with restrictions [6]

14. Four options are available for implementing open-water disposal with restrictions [6]. These options include submerging the discharge; treating the material by physical, chemical, or biological methods; containing or

immobilizing the dredged material subaqueously; and capping the dredged material subaqueously. Each option may be used separately or in combination with other options. The design considerations for these options must be examined to evaluate the technical feasibility of the disposal alternative based on effectiveness, availability, compatibility, cost, and scheduling. If the design is feasible, the appropriate open-water control measures and technologies can be chosen and implemented. If the design is not feasible, confined disposal [5] should then be considered.

Confined disposal [5]

15. Consideration of confined disposal [5] for a contaminated sediment requires evaluation of the following potential problems: effluent quality, surface runoff quality, leachate production and quality, and contaminant uptake by plants and animals. Impacts of effluent, runoff, and leachate quality must be evaluated by chemical analysis of contaminants released in modified elutriate, runoff, and leachate tests, respectively. If the contaminant levels exceed applicable criteria after considering mixing and dilution effects, bioassays are performed to determine the potential toxicity. Plant and animal uptake must be evaluated by appropriate bioassay and bioaccumulation tests. If the initial evaluation and sediment characterization indicates a potential for special dredging or disposal problems (e.g., noxious emissions), appropriate tests must be performed. If the impacts are acceptable, the dredged material can be disposed in confined areas without restrictions [2]. If unacceptable, options for confined disposal with restrictions [7] must be evaluated.

Confined disposal with restrictions [7]

16. Three basic options are available for implementing confined disposal with restrictions. These options include long-term storage, physical/chemical/biological treatment, and reuse. Combinations of the options exist for this strategy. The selection of the appropriate option is dependent mainly on the nature and level of contamination, site-specific conditions, economics, and socioeconomic considerations. The design considerations for these options must be examined to evaluate the technical feasibility of the disposal alternative based on effectiveness, availability, compatibility, cost, and scheduling. If the design is feasible, the appropriate confined disposal control measures and technologies can be chosen and implemented. If the design is not feasible, open-water disposal [4] should be considered.

Identify Potential Problems

17. Each disposal alternative may pose potential problems for managing contaminated dredged material. Potential contaminant problems can be identified after the initial evaluation and consideration of site-specific conditions, dredging methods, and anticipated site use. For open-water disposal, contaminant problems may be either water quality related (water column) or sediment related (benthic environment). For confined disposal, potential contaminant problems may be either water quality related (effluent, surface runoff, or leachate) or contaminant uptake related (plants or animals).

Apply Appropriate Testing Protocols

18. The magnitude and potential impacts of specific contaminant problems must be evaluated using appropriate testing protocols. Such protocols, designed for evaluation of dredged material, consider the unique nature of dredged material and the physicochemical conditions of each disposal alternative under consideration. The testing of the sediment to be dredged depends on which of the two questions in Figure 2 is being addressed. Testing intended to answer the question, "Where should sediment be placed to minimize contaminant mobility?", is site selection testing and addresses the situation where there are no limitations on available disposal sites, i.e., open-water disposal sites are available as well as upland or nearshore confined sites. The emphasis is on selecting the most appropriate disposal environment for the dredged material. Testing intended to answer the second question, "Is the available disposal site acceptable for dredged material?", is acceptability testing and addresses the situation where there are limitations on available disposal sites. Therefore, the sediment is tested to determine the acceptability of a given disposal site for the disposal of the sediment. For example, if the only disposal sites available are confined sites, then testing should focus on confined disposal and not on open-water disposal. Ultimately, the testing should be tailored to the available disposal site.

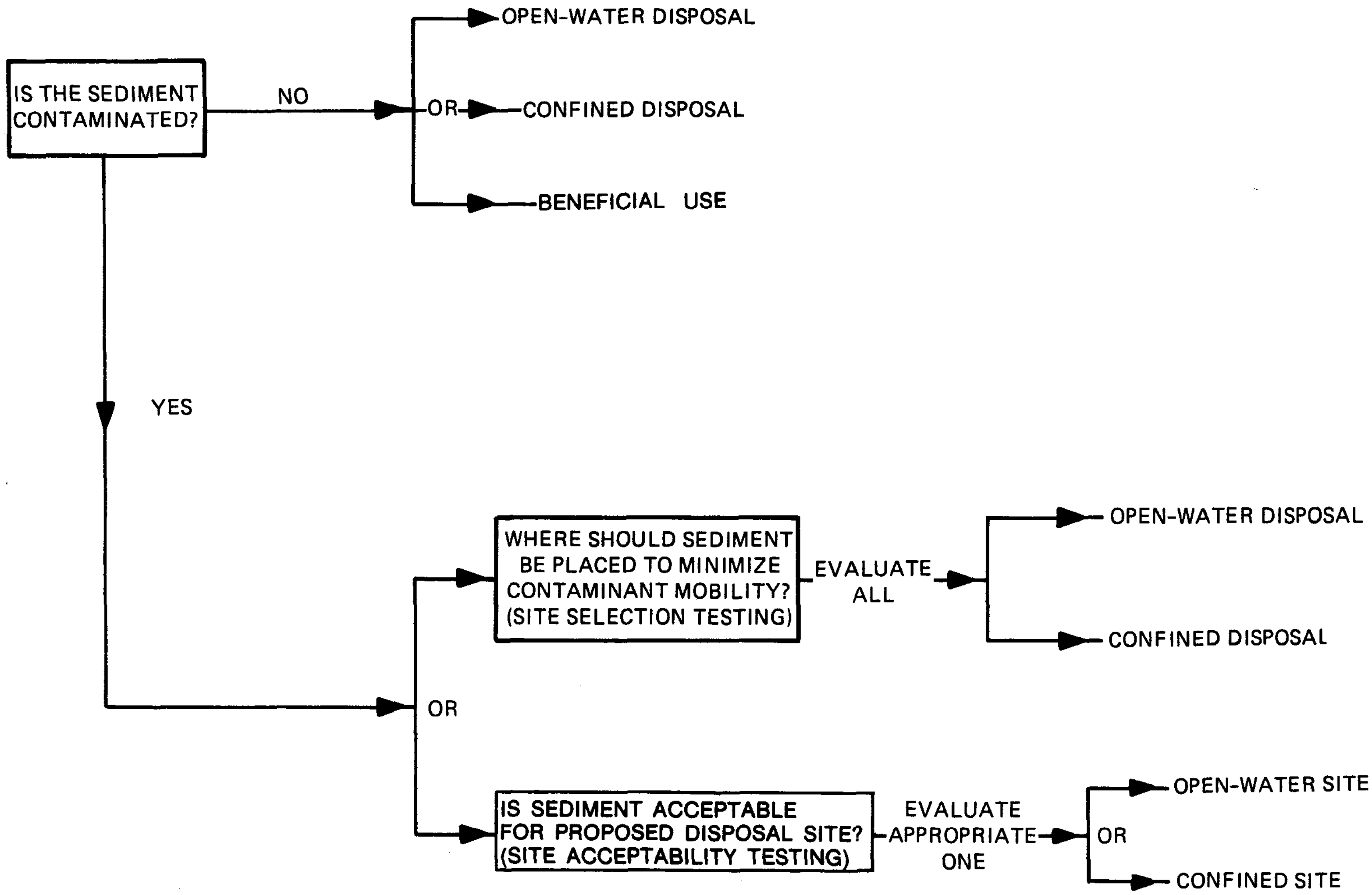

Figure 2. Initial questions to be addressed for testing of contaminated sediments

Assess Need for Disposal Restrictions

19. The results of all testing are compiled and evaluated to determine the potential for environmental harm from contamination, examine the interrelationships of the problems and potential solutions, and determine what restrictions on open-water (aquatic) disposal or confined disposal (intertidal, nearshore, upland) are appropriate. If impacts as evaluated by the testing protocols are acceptable, conventional open-water or confined disposal may again be considered.

Select an Implementation Plan

20. Specific environmental problems identified by the testing protocols must be considered in the development of an implementation plan appropriate for dredged material and appropriate for the level of potential contamination.

Identify Available Control Options

21. Several options may be available for the selected implementation strategy. Options for controlling water column and benthic impacts include bottom discharge via submerged diffusers, treatment, confined aquatic disposal, and subaqueous capping using cleaner sediments. Options for controlling confined disposal impacts include treatment, storage, and reuse.

Evaluate Design Considerations

22. Design considerations should be based on environmental and human health protection, technical feasibility, economics, proven reliability and performance considerations, and other engineering and operational factors.

Select Appropriate Control Measures

23. The degree of contaminant control finally selected may range anywhere between disposal in open water with no special restrictions to a completely controlled confinement. Many of the technologies identified are either commonly used in CE dredging activities or are presently being evaluated as part of the CE's ongoing research and operations programs.

PART III: POTENTIAL PROBLEMS AND TESTING PROTOCOLS

General

24. The properties of a dredged material affect the fate of any contaminants present, and the short- and long-term physical and chemical environment of the dredged material at the disposal site influences the environmental consequences of contaminants (Gambrell, Khalid, and Patrick 1978). These factors should be considered in evaluating the environmental risk of a proposed disposal method for contaminated sediment. The processes involved with release or immobilization of most sediment-associated contaminants are regulated to a large extent by the physicochemical nature of the disposal environment and the related bacteriological activity associated with the dredged material at the disposal site. Where the physicochemical nature of a contaminated sediment is altered by disposal, chemical and biological processes important in determining environmental consequences of potentially toxic materials may be affected.

25. Physicochemical (oxidation-reduction, pH, and salinity) conditions of dredged material at a disposal site influence the mobility and bioavailability of most contaminants (Gambrell, Khalid, and Patrick 1978). Typical maintenance dredged sediments are anoxic (reducing) and near neutral in pH. Depending on the disposal methods selected and the properties of the dredged sediments, changes in the physicochemical conditions at the disposal site may result in substantial mobilization of certain contaminants. Understanding the interaction between contaminants, dredged material properties, and physical, chemical, and biological conditions at a proposed disposal site will permit selection of disposal methods that will minimize potential contaminant release in many cases.

26. The major disposal alternatives are open water (aquatic) and confined (nearshore, intertidal, or upland). A number of variations exist for each of the major alternatives, each having a significant influence on the fate of contaminants at disposal sites. In this document the term open-water or aquatic disposal is used in a general sense to refer to all disposal conditions in which fine-grained material remains water-saturated, anoxic, reduced and near neutral in pH. In contrast, when a fine-grained sediment is taken out of the water and allowed to dry, it becomes oxic and the pH may drop

considerably. In this document all disposal options in which a fine-grained sediment has these characteristics are referred to generally as confined disposal, even though such conditions can occur on the surface of dredged material islands, the above-tide portions of fills, etc. Nearshore and intertidal confined disposal sites could have a combination of anoxic, reduced conditions below tide elevation and oxic conditions in the dredged material placed above tidal elevation. Environmentally sound disposal of dredged material can be achieved using any of the major alternatives if appropriate management practices are employed.

Open Water

27. When dredged material is placed in an open-water environment, there is a potential for release of contaminants into the water column. In addition, there is a potential for physical effects on benthic organisms and for long-term bioaccumulation of contaminants from the dredged material.

Water column

28. Potential problem. The fraction of a chemical constituent that is potentially available for release to the water column when sediments are disturbed (dredged and disposed through the water column) is approximated by the interstitial water concentrations and the loosely bound (easily exchangeable) fraction in the sediment.

29. Although the vast majority of heavy metals, nutrients, and petroleum and chlorinated hydrocarbons are usually associated with the fine-grained and organic components of the sediment (Burks and Engler 1978), there has been little evidence of biologically significant release of these constituents from typical dredged material to the water column during or after dredging or disposal operations. Levels of manganese, iron, ammonium nitrogen, orthophosphate, and reactive silica in the water column may be increased somewhat over background conditions for a matter of minutes during open-water disposal operations; however, there are generally no persistent, well-defined plumes of dissolved metals or nutrients observed at levels significantly greater than background concentrations.

30. Test protocol. Water column impacts can best be evaluated by chemical analyses of dissolved contaminants for which water quality criteria exist. The standard elutriate test (USEPA/CE 1977) is used for this purpose. Results

must be considered in light of mixing and dilution. If the criteria are exceeded after consideration of mixing, a bioassay can be used to determine the potential consequences of exceeding the criteria for a short time.

Benthic

31. Potential problem. The CE's Dredged Material Research Program (DMRP) results conclusively indicated that most subaqueous disposal in low-energy aquatic environments where stable mounding will occur will favor containment of contaminated materials. Dredging and disposal do not introduce new contaminants to the aquatic environment, but simply redistribute the sediments, which are the natural depository of contaminants introduced from other sources. The potential for accumulation of a contaminant in the tissues of an organism (bioaccumulation) may be affected by several factors such as duration of exposure, salinity, water hardness, exposure concentration, temperature, chemical form of the contaminant, and the particular organism under study. The relative importance of these factors varies. Elevated concentrations of contaminants in the ambient medium or associated sediments are not always indicative of high levels of contaminants in tissues of benthic invertebrates. The diversity of results among species, contaminants, types of exposure, and salinity regimes strongly suggests that bulk analysis of sediments for contaminant content alone cannot be used as a reliable index of availability and potential ecological impact of dredged material, but only as an indicator of the presence of contaminants and total contaminant content.

32. Test protocol. Potential benthic impacts can be evaluated by comparing contaminant concentrations in the sediments of both the dredging and disposal sites. If the concentrations are higher in the dredged material than in the disposal site sediment, a bioassay/bioaccumulation test can be used to determine the environmental consequences of the contaminant levels.

Confined

33. Material that is deemed unsuitable for open-water disposal may be placed in confined disposal sites, normally incorporating a dike to enclose an area for containment of the dredged material. Dredged material is usually placed in confined sites hydraulically by pipeline dredge or by hopper dredge or scow pumpout. In some instances material may be mechanically placed into the sites by clamshell.

34. Confined disposal areas are used to retain dredged material solids while allowing the carrier water to be released from the containment area. The two objectives inherent in the design and operation of a containment are to: (a) provide adequate storage capacity to meet dredging requirements, and (b) attain the highest possible efficiency in retaining solids during the dredging operation in order to maintain effluent quality. These considerations are basically interrelated and depend upon effective design, operation, and management of the containment area (Palermo, Montgomery, and Poindexter 1978).

35. Confined disposal of contaminated sediments must be planned to contain dredged material within the site and restrict contaminant mobility out of the site in order to control or minimize potential environmental impacts. There are six possible mechanisms for transport of contaminants from confined disposal sites that should be considered:

a. Release of contaminants in the effluent during disposal operations.

b. Surface runoff of contaminants in either dissolved or suspended particulate form following disposal.

c. Leaching into ground water.

d. Plant uptake directly from sediments, followed by indirect animal uptake from feeding on vegetation.

e. Animal uptake directly from sediments.

f. Gaseous or volatile emissions during and after placement of dredged material.

The environmental impact of confined disposal of contaminated dredged material may be more severe than open-water discharge (Jones and Lee 1978; Gambrell, Khalid, and Patrick 1978).

Effluent quality

36. Potential problem. Water quality effects of confined disposal effluents (water discharged during active disposal operations) have been identified as one of the greatest deficiencies in knowledge of the environmental impact of dredged material disposal (Jones and Lee 1978). Dredged material placed in a confined disposal area undergoes sedimentation, while clarified supernatant waters are discharged from the site as effluent during active dredging operations. The effluent may contain levels of both dissolved contaminants and particulate-associated contaminants. A large portion of the total contaminant level is particulate associated.

37. Test protocol. The standard elutriate test has been used to evaluate effluent water quality, but this test does not reflect the conditions existing in confined disposal sites that influence contaminant release. A modified elutriate test procedure, developed under the Long-Term Effects of Dredging Operations (LEDO) Program (Palermo, In press), can be used to predict both the dissolved and particulate-associated concentrations of contaminants in confined disposal area effluents (water discharged during active disposal operations). The laboratory test simulates contaminant release under confined disposal conditions and reflects sedimentation behavior of dredged material, retention time of the containment, and chemical environment in ponded water during active disposal.

38. The modified elutriate test procedure defines both dissolved contaminant concentrations and particulate-associated concentrations under quiescent settling conditions and accounts for geochemical changes occurring in the disposal area during active disposal operations. Column settling tests, similar to those used for design of disposal areas for effective settling (Palermo, Montgomery, and Poindexter 1978; Palermo, In press), are used to estimate the sedimentation performance for a given operational condition, i.e. ponded area, depth, and inflow rate. Using results from both of these analyses, the total contaminant concentration in the effluent may be calculated. The acceptability of the proposed confined disposal operation can be evaluated by comparing the predicted contaminant concentrations with applicable water quality standards while considering an appropriate mixing zone. In some cases appropriate water column bioassays would be required if water quality criteria are exceeded or do not exist.

Surface runoff quality

39. Potential problem. After dredged material has been placed in a confined disposal site and the dewatering process has been initiated, contaminant mobility in rainfall-induced runoff is considered in the overall environmental impact of the dredged material being placed in a confined disposal site. The quality of the runoff water can vary depending on the physicochemical process and the contaminants present in the dredged material. Drying and oxidation will promote microbiological activity, which breaks down the organic component of the dredged material and oxidizes sulfide compounds to more soluble sulfate compounds. Concurrently, reduced iron compounds will become oxidized and iron oxides will be formed that can act as metal scavengers to adsorb soluble

metals and render them less soluble. The pH of the dredged material will be affected by the amount of acid-forming compounds present as well as the amount of basic compounds that can buffer acid formation. Generally, large amounts of sulfur, organic matter, and pyrite material will generate acid conditions. Basic components of dredged material such as calcium carbonate will tend to neutralize acidity produced. The resulting pH of the dredged material will depend on the relative amounts of acid formed and the basic compounds present.

40. Runoff water quality will depend on the results of the above processes as the dredged material dries out. For example, should there be more acid formation than the amount of bases present to neutralize the acid, then the dredged material will become acidic in pH. Excessive amounts of pyrite when oxidized can reduce pH values from an initial pH 7 down to pH 3. Under these conditions surface runoff water quality can be acid and could contain elevated concentrations of trace metals.

41. Test protocol. An appropriate test for evaluating surface runoff water quality must consider the effects of the drying process to adequately estimate and predict runoff water quality. At present there is no single simplified laboratory test to predict runoff water quality. A laboratory test using a rainfall simulator has been developed (Westerdahl and Skogerboe 1981) and is being used to predict surface runoff water quality from dredged material as part of the CE/USEPA Field Verification (FVP) Program (Lee and Skogerboe 1983a, 1983b). This test protocol involves taking a sediment sample from a waterway and placing it in a soil-bed lysimeter in its original wet reduced state. The sediment is allowed to dry out. At intervals during the drying process, rainfall events are applied to the lysimeter, and surface runoff water samples are collected and analyzed for selected water quality parameters. Rainfall simulations are repeated on the soil-bed lysimeter until the sediment has completely dried out. Results of the tests can be used to predict the surface runoff water quality that can be expected in a confined disposal site when the dredged material dries out. From these results control measures can be formulated to treat surface runoff water if required to minimize the environmental impact to surrounding areas.

Leachate quality

42. Potential problem. Subsurface drainage from confined disposal sites in an upland environment may reach adjacent aquifers. Fine-grained dredged material tends to form its own disposal-area liner as particles settle with

percolation drainage water, but the settlement process may require some time for self-sealing to develop. Since most contaminants potentially present in dredged material are closely adsorbed to particles, only the dissolved fraction will be present in leachates. A potential for leachate impacts exists when a dredged material is placed in a confined site adjacent to freshwater aquifers. The site-specific nature of subsurface conditions is the major factor in determining possible impact (Chen et al. 1978).

43. Test protocol. At present, there is no routinely applied laboratory testing protocol capable of predicting leachate quality from confined disposal facilities. However, development of a predictive protocol for leachate quality is the objective of current research studies on Indiana Harbor sediments. The protocol in its current state of development involves both experimental leaching tests and procedures for extrapolating the laboratory leach data to the field situation using mathematical modeling. Aerobic and anaerobic sequential batch leaching tests are being conducted on the sediment. Sequential batch leaching tests are batch tests where the sediment is challenged by fresh leaching solution over time instead of being continually exposed to the same solution. These tests will allow identification of the critical factors influencing contaminant mobility and quantification of release rates under varying environmental conditions that may be encountered in a confined disposal facility. The batch leaching tests will provide the desorption coefficients needed to model mass transfer of contaminants from the solid (particulate) phase to the aqueous phase. Anaerobic and aerobic divided-flow permeameter leaching tests are also being used to simulate field leaching processes. Permeameter testing is used to verify the mass transfer equation and the generality of the desorption coefficients determined in the batch leaching tests. A one-dimensional, convective-dispersive mass transfer equation with a source term for contaminant leaching will be used to model leachate quality in the confined disposal facility and to estimate contaminant flux at the dredged material/site bottom interface.

Plant uptake

44. Potential problem. After dredged material has been placed in either an intertidal, wetland, or upland environment, plants can invade and colonize the site. In most cases, fine-grained dredged material contains large amounts of nitrogen and phosphorus, which tend to promote vigorous growth of plants on dredged material placed in confined disposal sites at elevations that range

from wetland to upland terrestrial environments. In many cases, the dredged material had been placed in confined disposal sites because contaminants were present in the dredged material. There is potential for movement of contaminants from the dredged material into plants and then eventually into the food chain.

45. Test protocol. An appropriate test for evaluating plant uptake of contaminants from dredged material must consider the ultimate environment in which the dredged material is placed and the physicochemical processes governing the availability of contaminants for plant uptake.

46. There is a test protocol that was developed under the LEDO Program based on the results of the DMRP. This procedure has been applied to testing a number of contaminated dredged materials and has given appropriate results and information to predict the potential for plant uptake of contaminants from dredged material (Folsom and Lee 1981, 1983; Lee, Folsom, and Engler 1982; Folsom, Lee, and Preston 1981). The procedure is presently being field verified under the FVP.

47. The procedure requires taking a sample of sediment from a waterway and placing it either in a flooded wetland environment or an upland terrestrial environment in the laboratory. An index plant, *Cyperus esculentus*, is then grown in the sediment under conditions of both wetland and upland environments. Plant growth, phytotoxicity, and bioaccumulation of contaminants are monitored during the growth period. Plants are harvested and analyzed for contaminants. The test results indicate the potential for plants to become contaminated when grown on the dredged material in either a wetland or upland terrestrial environment. From the test results, appropriate management strategies can be formulated as to where to place a dredged material to minimize plant uptake.

48. There is another laboratory test being developed under the LEDO Program that utilizes an organic extractant of dredged material to predict plant uptake of certain trace metals such as zinc, cadmium, nickel, chromium, lead, and copper (Lee, Folsom, Bates 1983). This test procedure attempts to simulate the capacity of a plant root to extract metals from a dredged material. Field verification of this test protocol is being conducted under the FVP.

Animal uptake

49. Potential problem. Animals have also been known to invade and colonize confined (intertidal, wetland and upland) dredged material disposal

sites. In some cases, prolific wildlife habitats have become established on these sites. Concern has developed recently on the potential for animals inhabiting either wetland or upland terrestrial confined disposal sites to become contaminated and contribute to the contamination of food chains associated with the site.

50. Test protocol. An appropriate test for evaluating animal uptake of contaminants from dredged material must consider the ultimate environment in which the dredged material is placed and the physicochemical processes governing the biological availability of contaminants for animal uptake.

51. There is a test protocol being tested under the FVP that utilizes an earthworm as an index species to indicate toxicity and bioaccumulation of contaminants from dredged material. In this procedure, an earthworm is placed in sediment maintained in moist and semimoist, air-dried environments. The toxicity and bioaccumulation of contaminants are monitored over a 28-day period (Simmers, Rhett, and Lee 1983).

Other impacts

52. Potential impacts could arise from flammable or noxious emissions released from the dredged material during dredging and disposal operations. Standard safety precautions will eliminate adverse human health effects and are normally required under contract specifications.

Summary

53. The DMRP and subsequent research conducted by the CE, USEPA, and others have supplied much needed information on evaluation of the physical and chemical impacts of contaminated dredged material disposal. Appropriate testing protocols to address specific contaminant problems are available or are now under development.

PART IV: DESCRIPTION AND APPLICABILITY OF DREDGING AND DISPOSAL ALTERNATIVES

54. Disposal alternatives are divided into general classes: open water, confined, open-water disposal with restrictions, and confined disposal with restrictions. Disposal alternatives with restrictions are used whenever results of the testing protocols indicate that they are needed. Conventional disposal alternatives are well documented in DMRP reports (Herner and Company 1978) and are described only briefly in this section. The preference of open-water disposal over confined disposal, or vice versa, is dependent on many factors other than contaminants as discussed earlier. The effects of the presence of contaminants on the applicability and selection of a disposal alternative and implementation strategy and option will also be presented in this section.

Open Water

55. This disposal alternative involves conventional open-water disposal techniques. This alternative would be selected if the initial evaluation and testing protocols as discussed earlier indicated that water column and benthic effects are acceptable.

Placement techniques

56. Dredged material can be placed in open-water sites by direct pipeline discharge, hopper dredge discharge, or dumping from scows. For conventional open-water disposal, no special placement techniques are used and the material is normally discharged at a selected point within a designated disposal site.

Site designation

57. Ocean open-water disposal sites are designated using a set procedure (USEPA 1977). Criteria for site designation include storage capacity requirements and chemical/biological considerations. Procedures for site selection are under review with the objective of improving the efficiency of the overall site designation process.

Site capacity

58. The capacity of open-water disposal sites is determined by the volume of accumulated material that can be placed without exceeding the

designated site boundaries or exceeding water-depth constraints. Capacity also may be determined by the assimulative ability of the waters within the designated site boundaries, i.e., their ability to reduce concentrations of suspended material and associated contaminants to an acceptable level. Procedures for evaluation of open-water disposal site capacity to include descent and spread of discharges, dispersion, erosion and resuspension from mounds, and consolidation of mounds are currently under study by the CE.

Dispersion and mixing

59. The open-water environment is physically dynamic and materials placed in open water will be dispersed, mixed, and diluted to some degree. Therefore, all evaluative procedures must be interpreted in light of the mixing expected at the disposal site. Any of several methods or models (Holliday, Johnson, and Thomas 1978) may be used to estimate the maximum concentration of the liquid and suspended particulate phases found at the disposal site after initial mixing.

Confined Disposal

Design

60. Conventional confined disposal consists of placing or pumping the dredged material into a diked containment area where the material settles and consolidates. The area should be designed to provide good sedimentation and sufficient volume for storage (Palermo, Montgomery, and Poindexter 1978). The supernatant water is normally discharged over a weir which is designed to maintain good effluent quality by minimizing resuspension of settled material. If the suspended solids or associated turbidity of the effluent exceeds applicable water quality standards, a chemical clarification system may be used for additional solids removal. The system generally consists of a polymer feed system, a weir and discharge culvert for mixing polymer with the primary containment area effluent, and a small secondary containment area for collection of the treated material (Schroeder 1983).

Management

61. Following completion of the disposal operation, the site should be managed to promote consolidation and drying (Haliburton 1978). The containment area can then be used for additional disposal, mined for productive use of the material, or returned to the sponsor for other uses (Montgomery et al. 1978).

Open-Water Disposal with Restrictions

62. In cases where testing protocols indicate that water column or benthic effects will be unacceptable when conventional open-water disposal techniques are used, open-water disposal with restrictions may be considered. This alternative involves the use of dredging or disposal techniques that will reduce water column and benthic effects. Such techniques include use of subaqueous discharge points, diffusers, subaqueous confinement of material, or capping of contaminated material with clean material. The same basic considerations for conventional open-water disposal site designation, site capacity, and dispersion and mixing also apply to open-water disposal with restrictions.

Submerged discharge

63. The use of a submerged point of discharge reduces the area of exposure in the water column and the amount of material suspended in the water column and susceptible to dispersion. The use of submerged diffusers also reduces the exit velocities for hydraulic placement, allowing more precise placement and reducing both resuspension and spread of the discharged material. Considerations in evaluating feasibility of a submerged discharge and/or use of a diffuser include water depth, bottom topography, currents, type of dredge, and site capacity. The DMRP (Barnard 1978) developed a conceptual design for a submerged diffuser that has been successfully demonstrated by European dredging interests and is now being considered for more detailed study in the United States under the DOTS Program.

Contained aquatic disposal

64. The use of subaqueous depressions or borrow pits or the construction of subaqueous dikes can provide containment of material reaching the bottom during open-water disposal. Such techniques reduce the areal extent of a given disposal operation, thereby reducing both physical benthic effects and the potential for release of contaminants. Considerations in evaluating feasibility of subaqueous containment include type of dredge, water depth, bottom topography, bottom sediment type, and site capacity. Contained aquatic disposal has been used in Europe and to a limited extent by the CE's Seattle District. Precise placement of material and use of submerged points of discharge increase the effectiveness of contained aquatic disposal.

Capping

65. Capping is the placement of a clean material over material considered contaminated. Considerations in evaluation of the feasibility of capping include water depth, bottom topography, currents, dredged material and capping material characteristics, and site capacity. Both the Europeans and the Japanese have successfully used capping techniques to isolate contaminated material in the open-water disposal environment. Capping is also currently used by the New York District and the New England Division as a means of offsetting the potential harm of open-water disposal of contaminated or otherwise unacceptable sediments. The London Dumping Convention has accepted capping, subject to careful monitoring and research, as a physical means of rapidly rendering harmless contaminated material dumped in the ocean. The physical means are essentially to seal or sequester the unacceptable material from the aquatic environment by a covering of acceptable material.

66. The efficiency of capping in preventing the movement of contaminants through this seal and the degradation of the biological community by leakage, erosion of the cover (cap), or bioturbation are being addressed by research under the LEDO Program. The engineering aspects of cap design and placement are also being addressed under this Program. It is possible that techniques and equipment can be developed that will provide a capped dredged material disposal area as secure from potential environmental harm as confined disposal areas. The capping technique for disposal of dredged material has potential for relieving some pressure on acquiring sites for confined disposal areas in localities where land is rapidly becoming unavailable.

Chemical/physical/biological treatment

67. Treatment of discharges into open water may be considered to reduce certain impacts. For example, the Japanese have used an effective in-line dredged material treatment scheme for highly contaminated harbor sediments (Barnard and Hand 1978). However, this strategy has not been widely applied and its effectiveness has not been demonstrated for solution of the problem of contaminant release during open-water disposal.

Confined Disposal with Restrictions

68. Conventional confined disposal methods, described previously, can be modified to accommodate disposal of contaminated sediments in new, existing,

and reusable disposal areas. The design or modification of these areas must consider the problems associated with contaminants and their effects on conventional design. Many of the following design considerations apply to all of the implementation options.

Site selection and design

69. Site location is an important consideration since it can mitigate many contaminant mobilization problems. Proper site selection may reduce surface runon and therefore contaminated runoff and contaminant release by flooding. Ground-water contamination problems can be offset through selection of a site with natural clay foundation instead of a sandy area and through avoidance of aquifer recharge areas (Gambrell, Khalid, and Patrick 1978).

70. Careful attention to basic design as discussed previously will aid in implementing many of the controls outlined. Retention time can be increased to improve suspended solids removal and therefore contaminant removal. Additional ponding depth can also improve sedimentation. Decreasing the weir loading rate and improving the weir design to reduce leakage and control the discharge rate can also reduce the suspended solids and contaminant concentration of the effluent.

71. Dewatering should be examined carefully before selecting a method since dewatering promotes oxidation of the material and thereby increases the mobility of certain contaminants (Gambrell, Khalid, and Patrick 1978). Care must also be taken to reduce loss of contaminated sediment by erosion during drainage and storm events.

Restrictions

72. Conventional confined disposal methods, described previously, may be modified to accommodate disposal of slightly to highly contaminated sediments. Many of the restrictions on confined disposal that may be required are common to the available options. Among these restrictions are:

- a. Effluent quality controls during dredging operations.
- b. Runoff water quality controls after dredging operations.
- c. Leachate controls during and after dredging operations.
- d. Control of contaminant uptake by plants and animals during and after dredging operations.
- e. Control of gaseous or volatile emissions.

Available options

73. Depending on the particular dredging operation, one or all of the above restrictions may be required. The particular restriction or combination of restrictions may eliminate certain disposal options. For the purposes of developing a technical management strategy, three options are considered available for confined disposal with restrictions. These options include:

- a. Long-term storage - dredged material and associated contaminants are contained within the disposal site.
- b. Treatment - dredged material is modified physically, chemically, or biologically to reduce toxicity, mobility, etc.
- c. Reuse - dredged material is held for a temporary period at the site and later removed to another site for long-term disposal. Dredged material may also be classified and beneficial uses made of reclaimed materials.

Obviously, combinations of the above options are available for a particular dredging operation.

74. Long-term storage of contaminated dredged material can be either in an existing or a new facility. These facilities can be designed or modified to handle a wide variety of contaminants. Most contaminated sediments can be disposed of in an existing site where special controls have been incorporated in consideration of the previously discussed restrictions. In the case of highly contaminated sediments, a more secure disposal facility would be required, and, in all probability, disposal restrictions would dictate the design of a new facility.

75. The treatment option can be associated with either existing or new facilities. Some form of physical, chemical, or biological treatment would probably be associated with the disposal of highly contaminated dredged material. Treatment may also be combined with other options for disposal of slightly to moderately contaminated dredged material in confined disposal sites.

76. Of the three available options, reuse can serve two beneficial functions: continued use of confined sites located close to dredging areas, and use as a rehandling facility for contaminated dredged material prior to later disposal offsite. The concept of a reuse option may also incorporate beneficial uses of materials reclaimed by the classification/separation process. Such materials could include sand and gravel or slightly contaminated construction fill to be used for raising dikes or for acceptable offsite uses.

Design considerations

77. Contaminated dredged material management includes methods for dewatering, transporting, storing, treating, and disposing of contaminated material. The most technically and economically effective strategy to handle contaminated dredged material will depend on many site-specific variables, which include the following:

- a. Method of dredging used - hydraulic vs. mechanical.
- b. Method of dredged material transport - pipeline vs. truck or hopper or barge.
- c. Physical nature of removed material - consistency (solids/water content) and grain-size distribution.
- d. Volume of removed material.
- e. Nature and degree of contamination; physical and chemical characteristics of contaminants.
- f. Proximity of acceptable treatment, storage, containment, or reuse facilities.
- g. Available land area for construction of new or expansion of existing facilities.

Effluent controls

78. Effluent controls at conventional confined disposal areas are generally limited to chemical clarification. The clarification system is designed to provide additional removal of suspended solids and associated adsorbed contaminants as described in Schroeder (1983). Additional controls can be used to remove fine particulates that will not settle or to remove soluble contaminants from the effluent. Examples of these technologies are filtration, adsorption, ion exchange, chemical oxidation, and biological treatment processes. Beyond chemical clarification, only limited data exist for treatment of dredged material (Gambrell, Khalid, and Patrick 1978).

Runoff controls

79. Runoff controls at conventional sites consist of measures to prevent the erosion of contaminated dredged material and the dissolution and discharge of contaminants from the oxidized dredged material surface. Control options include maintaining ponded conditions, planting vegetation to stabilize the surface, liming the surface to prevent acidification and to reduce dissolution, covering the surface with synthetic geomembranes, and/or placing a lift of clean material to cover the contaminated dredged material (Gambrell, Khalid, and Patrick 1978).

Leachate controls

80. Leachate controls consist of measures to minimize ground-water pollution by preventing mobilization of soluble contaminants. Control measures include proper site selection as described earlier, dewatering to minimize leachate production, chemical admixing to prevent or retard leaching, lining the bottom to prevent leakage and seepage, capping the surface to minimize infiltration and thereby leachate production, vegetation to stabilize contaminants and to increase drying, and leachate collection, treatment, or recycling (Gambrell, Khalid, and Patrick 1978).

Control of contaminant uptake

81. Plant and animal contaminant uptake controls are measures to prevent mobilization of contaminants into the food chain. Control measures include selective vegetation to minimize contaminant uptake, liming or chemical treatment to minimize or prevent release of contaminants from the material for uptake by the plants, and capping with clean sediment or excavated material (Gambrell, Khalid, and Patrick 1978).

Other controls

82. The control of gaseous emissions that might present human health hazards can consist of physical measures such as covers, vertical barriers, control trench vents, pipe vents, and gas-collection systems. Wind-erosion control of contaminated surface materials is another type of management or operating control to minimize transport of contaminants offsite. Techniques for limiting wind erosion are generally similar to those employed in dust control and include physical, chemical, or vegetative stabilization of surface soils (US Army Corps of Engineers 1983).

83. Many of the contaminant controls described in the preceding paragraph are directly applicable to the control of highly contaminated sediments. These controls will be extremely site-specific. Special considerations that are based on the physical nature and chemical composition of the dredged material will be required to effectively design a confined disposal facility. For example, some contaminated dredged material may require in-pipeline treatment prior to discharging the material into the containment facility. Similarly, if the facility requires a bottom liner system, the liner materials (synthetic membrane or clay) must be chemically compatible (resistant) with the dredged material to be placed on them. Special compatibility testing will

be needed for selection of appropriate liner materials. Other requirements such as leachate detection and monitoring may be needed due to the potentially adverse environmental effects of the liner leaking.

PART V: CONCLUSIONS AND RECOMMENDATIONS

84. A technically feasible and environmentally sound management approach to the disposal of dredged material has been developed and presented. This strategy is based on results of many years of research and dredging experience by the Corps of Engineers and others. The evaluative procedures allow specific potential problem areas to be defined and addressed. A number of variations are presented for each of the major alternatives of open-water (aquatic) and confined (intertidal, nearshore or upland) disposal, each having a significant influence on the fate of contaminants at disposal sites. The management strategy provides a framework for assessing and choosing an appropriate alternative for disposal based on specific problem areas. It is applicable to materials ranging from clean sand to highly contaminated sediments. It is recommended that the strategy be implemented for managing all dredged material disposal. Application of the strategy should be thoroughly documented to allow refinement based on experience.

85. Although there has been much research and some field experience gained in handling and control of contaminated materials generated by industrial and chemical manufacturing operations (USEPA 1982), few applications to dredging can be cited. Considerable effort is needed to apply these control technologies to dredging operations. Research sponsored by the CE, EPA, and others will continue to provide input into management strategies for dredged material disposal that will reduce potential environmental impacts.

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