US Army Corps
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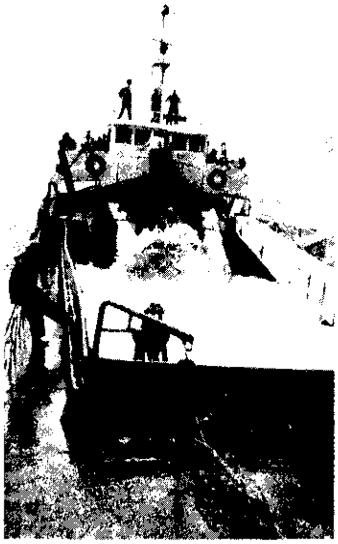

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DISPOSAL ALTERNATIVES FOR PCB-CONTAMINATED SEDIMENTS FROM INDIANA HARBOR, INDIANA

Volume I

by

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Indiana Harbor and Canal are part of a small, highly industrialized watershed in northwestern Indiana. The Grand Calumet River discharges into Lake Michigan via the Indiana Harbor and Canal. These waterways have a history of water quality problems and have been identified by the International Joint Commission on the Great Lakes as a major area of concern. The Corps of Engineers is authorized to maintain a deep-draft navigation project at Indiana Harbor and Canal. Two reaches of the navigation channel contain sediments with concentrations of polychlorinated biphenyls (PCBs) above 50 ppm. In addition, the sediments contain elevated concentrations of metals and other organic contaminants.

The purpose of this study was to evaluate alternative methods for dredging and disposing of the PCB-contaminated sediments from Indiana Harbor using appropriate testing protocols. The US Army Engineer Waterways Experiment Station has developed a management strategy for disposal of dredged material which describes a logical sequence for testing and
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19. ABSTRACT (Continued).

evaluation of disposal alternatives and a decisionmaking framework for logical application of the management strategy. These served as the basis for the testing and decisionmaking described in this study.

Three disposal alternatives (contained aquatic disposal (CAD) and two confined disposal alternatives) were identified for the PCB-contaminated sediments and evaluated to determine technical feasibility and control measures required for implementation. The magnitude and possible impacts of specific dredging and disposal problems were evaluated using appropriate testing protocols. These protocols included those for effluent quality, surface runoff quality, leachate quality, and direct uptake by plants or animals. Since there was no routinely applied laboratory testing protocol to predict leachate quality from dredged material confined disposal facilities (CDFs), research was conducted to develop a leaching test protocol. Additional research was performed to simplify and significantly reduce the costs of testing for evaluating surface runoff water quality in CDFs. Tests were conducted for use in evaluating the thickness of cap required to isolate contaminated sediments from the overlying water column and from aquatic and benthic biota. Innovative disposal alternatives and management techniques that were evaluated included confined disposal with appropriate restrictions and capping of contaminated sediments after controlled placement in the aquatic environment.

The feasible disposal alternatives identified for the PCB-contaminated sediments included CAD, in-lake CDF disposal, and upland confined disposal. With appropriate dredging equipment, disposal site designs, and contaminant control measures, any of the three disposal methods could be used to provide environmentally sound disposal of the PCB-contaminated Indiana Harbor sediments.

EXECUTIVE SUMMARY

General

Indiana Harbor and Canal are part of a small, highly industrialized watershed in northwestern Indiana. The Grand Calumet River discharges into Lake Michigan via the Indiana Harbor and Canal. These waterways have a history of water quality problems and have been identified by the International Joint Commission on the Great Lakes as a major area of concern. The Corps of Engineers is authorized to maintain a deep-draft navigation project at Indiana Harbor and canal. Two reaches of the navigation channel contain sediments with concentrations of polychlorinated biphenyls (PCBs) above 50 ppm. In addition, the sediments contain elevated concentrations of metals and other organic contaminants.

Sediments contaminated with PCBs at levels exceeding 50 ppm are subject to regulation under the Toxic Substances Control Act (TSCA). Disposal alternatives for materials regulated under TSCA include incineration, a chemical waste landfill, or some other disposal method approved by the US Environmental Protection Agency (USEPA) Regional Administrator. The estimated costs for incineration or placement in a chemical waste landfill in accordance with TSCA are far beyond the limits which could be justified under the Corps' navigation maintenance authority. Alternative methods of disposal approved by the USEPA Regional Administrator appear to be the only feasible option available for the removal of the contaminated bottom sediments under this authority.

The purpose of this study was to evaluate alternative methods for dredging and disposing of the PCB-contaminated sediments from Indiana Harbor using appropriate testing protocols. The US Army Engineer Waterways

Experiment Station (WES) has developed a management strategy for disposal of dredged material (Francingues et al. 1985) which describes a logical sequence for testing and evaluation of disposal alternatives. A decisionmaking framework (Peddicord et al. 1986) has also been developed to provide a logical methodology for application of the Management Strategy. The decisionmaking framework provides a basis for comparison of test results with standards or criteria to determine if contaminant control measures are required. These two documents served as a basis for the testing and decisionmaking described in this study.

Sampling and testing

The sediment used for testing in this study was a composite sample from Indiana Harbor. Field sampling was conducted within the harbor to collect samples from the PCB-contaminated areas. The samples were then combined to form the composite material used for testing. State-of-the-art testing protocols were applied to determine the potential for environmental harm from contamination, to examine the interrelationships of the problems and potential solutions, and to determine what restrictions are required for each disposal alternative under consideration. New emerging control technologies were evaluated for application to the highly contaminated sediments, but these technologies were limited to contaminant containment and immobilization techniques. No innovative contaminant destruction technologies were found that were appropriate for these sediments. However, if appropriate designs and operational controls are applied, a number of dredging and dredged material disposal options are available.

The magnitude and possible impacts of specific dredging and disposal problems were evaluated using appropriate testing protocols. These protocols included those for effluent quality, surface runoff quality, leachate quality, and direct uptake by plants or animals. Since there was no routinely applied laboratory testing protocol to predict leachate quality from dredged material confined disposal facilities, research was conducted to develop a leaching test protocol. Additional research was performed to simplify and significantly reduce the costs of testing for evaluating surface runoff water quality in confined disposal sites. Tests were conducted for use in evaluating the thickness of cap required to isolate contaminated sediments from the overlying water column and from aquatic and benthic biota. Innovative disposal alternatives and management techniques that were evaluated included confined disposal with appropriate restrictions and capping of contaminated sediments after controlled placement in the aquatic environment.

The testing results were compared with Indiana water quality standards and USEPA Federal water quality criteria. Plant and animal uptake tests were compared with the Food and Drug Administration's (FDA) allowable concentrations for foodstuffs. These comparisons were the basis of discussion of appropriate contaminant control measures for the disposal alternatives considered. The final design of the selected disposal alternative should be based on later comparisons of test results and specific criteria agreed upon by the concerned regulatory agencies.

Disposal alternatives

Three disposal alternatives were identified (contained aquatic disposal and two confined disposal alternatives) for the PCB-contaminated sediments and evaluated to determine technical feasibility and control measures required for implementation. Information and data were compiled and evaluated to provide decisionmakers with sufficient information for choosing an appropriate disposal alternative for the PCB-contaminated sediments in Indiana Harbor.

Contained aquatic disposal (CAD) was investigated in an effort to broaden the disposal options available. In laboratory tests, a 12 in. layer of Lake Michigan sediment overlying Indiana Harbor sediment was effective in preventing the transfer of heavy metals, PAHs, phenol, and PCBs from the contaminated sediment into the overlying water and aquatic biota. However, to protect against the effects of deep burrowing animals, a minimum cap depth of 20 in. is needed to maintain an effective chemical seal. The most likely area in Lake Michigan for CAD sites for disposal of the Indiana Harbor material is 4 to 8 miles east of Indiana Harbor in water depths of 40 to 60 ft. There were no feasible CAD sites identified in the entrance channel and canal areas of Indiana Harbor that were capable of handling the required volumes.

An in-lake confined disposal facility (CDF) has been proposed to confine Indiana Harbor sediments that are classified as moderately to heavily polluted. This CDF was considered for disposal of the 200,000 cu yd of PCB-contaminated material. The chronological order of the dredging projects should be arranged in a manner to seal the PCB-contaminated sediments subaqueously between layers of cleaner clays and silts. Encapsulation of the PCB-contaminated sediments should prevent any long-term plant and animal uptake and minimize leaching of contaminants and loss of volatile organics from the CDF. The effluent from the in-lake CDF would meet Indiana Lake Michigan water quality standards if mechanical disposal methods are used. PCB concentrations would approach ambient lake concentrations. The maximum quantity of PCBs expected to be released from an in-lake CDF during the disposal operation is 6.3 kg for the hydraulic transfer from scows alternative, 4.2 kg for the matchbox dredge alternative, and 0.0027 kg for the mechanical disposal alternative. The actual quantity of PCBs released through the filter dikes could actually be much less (orders of magnitude less) since PCBs are very hydrophobic and are adsorbed very easily. Design and operational considerations for the in-lake CDF should also include chemical clarification, and control of oils.

An upland CDF for the disposal of PCB-contaminated sediments was evaluated, though no specific site has been identified. Control measures would be required to reduce the release of contaminants in effluent, surface runoff, volatilization, leachate, and plant and animal uptake. Effluent from an upland CDF would exceed Indiana Harbor water quality standards for some parameters, even with treatment controls (filtration and carbon adsorption). A mixing zone would be required for the effluent discharge. Surface runoff would require control measures similar to the effluent, until a surface cover could be applied. A surface cover of compacted clay would restrict infiltration and present surface runoff and plant and animal uptake. Volatile loss could be reduced by codisposal with less contaminated sediments. A liner of compacted clay would restrict seepage of leachate. Leachate collection and treatment could enhance liner performance.

Equipment demonstrations

Demonstrations of a clamshell dredge, a cutterhead suction dredge, the Dutch matchbox dredge, and a submerged diffuser were conducted in Calumet Harbor to evaluate sediment resuspension and possible release of contaminants during dredging and disposal.

The suspended sediment concentrations observed in the cutterhead and matchbox plumes were generally less than 20 mg/ℓ at distances of 100 ft or greater from the dredges. Based on the results of the field studies, both the matchbox and cutterhead dredges are capable of removing the PCB-contaminated sediments with little sediment resuspension. If a clamshell dredge is selected, the bucket should be enclosed to reduce resuspension.

The submerged diffuser demonstration proved that sediment could be hydraulically placed in water with a minimum amount of resuspension and spread. The diffuser was able to significantly reduce the slurry velocity, confine the discharged material to the lower 20 to 30 percent of the water column, and reduce suspended sediments effects in the upper water column.

Conclusion

The feasible disposal alternatives identified for the PCB-contaminated sediments included CAD, in-lake CDF disposal, and upland confined disposal. With appropriate dredging equipment, disposal site designs, and contaminant control measures, any of the three disposal methods could be used to provide environmentally sound disposal of the PCB-contaminated Indiana Harbor sediments.

PREFACE

The studies described in this report were conducted to evaluate the dredging and dredged material disposal requirements for the PCB-contaminated sediments in Indiana Harbor, Indiana. The work was conducted by the Environmental Laboratory (EL), Hydraulics Laboratory (HL), and Coastal Engineering Research Center (CERC) of the US Army Engineer Waterways Experiment Station (WES). Funding was provided by the US Army Engineer District, Chicago, under Intra-Army Order for Reimbursable Services No. NCC-IA-85-11, dated 30 October 1984. The Chicago District Project Manager for the studies was Mr. Shamel Abou-El-Seoud.

Part I of this report was written by Dr. Michael R. Palermo, EL, and Mr. Jan Miller of the Chicago District. Part II was written by Drs. Palermo, Paul R. Schroeder, Bobby L. Folsom, Jr., Tom L. Hart, James M. Brannon, Douglas L. Gunnison and Mr. Tommy E. Myers, all of EL, and Mr. Miller. Part III was written by Drs. Brannon, Dixie M. Griffin, Jr., and Messrs. Myers and John G. Skogerboe, all of EL. Part IV was written by Mr. Clifford L. Truitt, and Drs. Schroeder, Brannon, and Palermo, all of EL, and Mr. Miller. Part V was written by Mr. T. Neil McLellan, EL. Appendixes A-J are included in Volume II.

The WES Study Manager was Dr. Raymond L. Montgomery, Chief, Environmental Engineering Division, EL, WES. This work was coordinated with other dredging studies by Dr. Robert M. Engler, Manager, Environmental Effects of Dredging Programs, EL.

The work was conducted under the general supervision of Dr. John Harrison, Chief, EL, WES.

COL Dwayne G. Lee, CE, was the Commander and Director of WES. Dr. Robert W. Whalin was the Technical Director.

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
acre-feet	1,233.489	cubic metres
cubic feet	0.02831685	cubic metres
cubic feet per second per foot	0.093	cubic metres per second per metre
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
gallons	3.785412	cubic decimetres
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	2.54	centimetres
knots (international)	0.5144444	metres per second
miles (US statute)	1.609347	kilometres
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per square foot	4.882428	kilograms per square metre
square inches	6.4516	square centimetres
yards	0.9144	metres

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* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use $K = (5/9)(F - 32) + 273.15$.

DISPOSAL ALTERNATIVES FOR PCB-CONTAMINATED SEDIMENTS FROM INDIANA HARBOR, INDIANA

PART I: INTRODUCTION

Background

1. Indiana Harbor and Canal are part of a small, but highly industrialized watershed located in East Chicago, Indiana. The Grand Calumet River drains approximately 77 square miles of Lake and Porter counties and discharges to southwestern Lake Michigan via the Indiana Harbor and Canal. Major industries along the waterway include steel and petro-chemical. The Grand Calumet River (GCR)/Indiana Harbor Canal (IHC) has a long history of water quality problems and has been identified by the International Joint Commission on the Great Lakes as a major area of concern.

2. The Indiana Harbor deep-draft navigation project, shown in Figure 1, was authorized by the River and Harbor Act of 1910. Authorized depths in the Federal navigation channels are from 22 to 29 ft*. Channel widths range from 160 to 800 ft. The Chicago District, US Army Corps of Engineers (CE), maintains the navigation channel by periodic dredging. Prior to 1968, dredged material from the project was placed in the open waters of Lake Michigan. After 1968, Federal environmental regulations prohibited the unconfined disposal of contaminated dredged material. The CE has been unable to maintain the navigation channel at Indiana Harbor since 1972 because no acceptable

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page x.

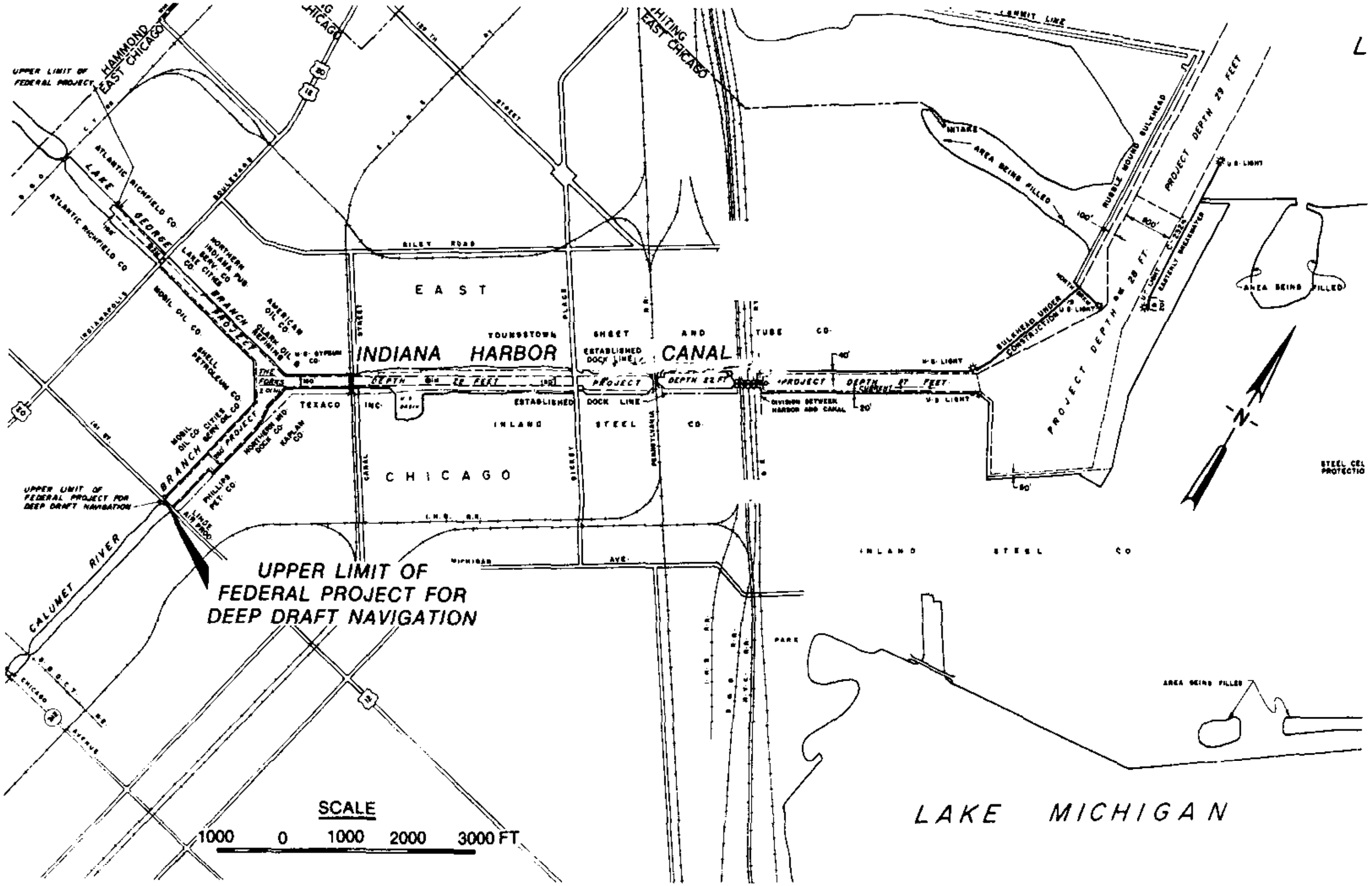


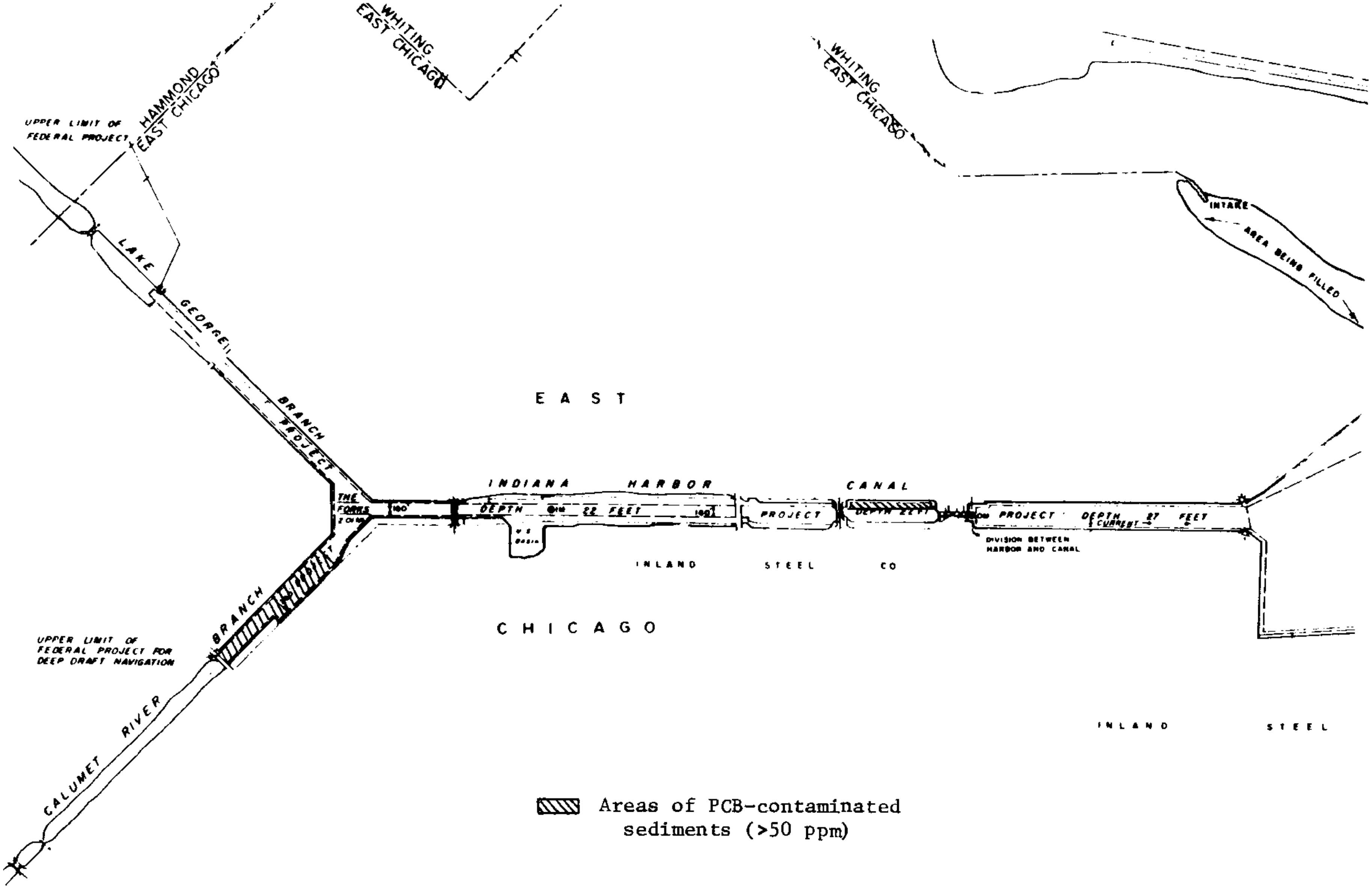
Figure 1. Project location

disposal site was available. The CE could not locate a site or local sponsor for over 10 years.

3. The bottom sediments in Indiana Harbor and Canal contain a variety of contaminants, including oil and grease, nutrients, heavy metals, and organics. The US Environmental Protection Agency (USEPA) Region V developed criteria in 1977 for classification of sediments from Great Lakes harbors. These criteria are used to classify sediments as non-polluted, moderately-polluted, or heavily-polluted based on the bulk chemical concentrations of selected contaminants. The sediments from Indiana Harbor and Canal have been sampled and analyzed by the CE and USEPA. The USEPA has determined that most of the sediments in the navigation channel are heavily-polluted according to these criteria. Sediments in two localized reaches of the Canal were found to contain levels of polychlorinated biphenyls (PCBs) exceeding 50 mg/kg dry weight. These reaches are shown in Figure 2. Not all the sediments in these reaches exceeded 50 ppm PCBs, but averaging of discrete samples for purposes of determining pollution classification was not allowed by the USEPA. One reach contains about 50,000 cu yd of PCB-contaminated** sediment while the other contains about 150,000 cu yd.

4. Because of the contaminated nature of the sediments and the fact that municipal drinking water intakes are located in the lake near the Indiana Harbor mouth, special precautions are required during dredging and ultimate disposal of the sediments from the PCB-contaminated reaches. Studies were therefore required to identify dredging and dredged material disposal techniques for material from these two reaches.

** For purposes of this report, the term "PCB-contaminated sediments," refers to those Indiana Harbor sediments with PCB concentrations above 50 ppm.



▨ Areas of PCB-contaminated sediments (>50 ppm)

Figure 2. Locations of contaminated sediments

5. In 1983, the Chicago District completed a Site Selection Study for potential disposal sites. The Lake County Board of Commissioners and city of East Chicago supported construction of a confined disposal facility (CDF) in Lake Michigan for the disposal of moderately to heavily polluted sediments from Indiana Harbor and Canal. A Draft Environmental Impact Statement (EIS) was prepared for this disposal facility (USACE 1986). Public opposition and the lack of support by state and federal regulatory agencies made construction at this site infeasible. At the time of this report, the Chicago District is examining the feasibility of an alternate CDF site recommended by the State of Indiana.

6. On a national basis, the CE must sometimes dredge and dispose of highly contaminated sediments from Federal projects. The CE is committed to accomplishing this task in an environmentally acceptable manner. Therefore, the situation found in the Indiana Harbor is not unique. Through extensive research and experience, the CE has developed the expertise to dredge and dispose of such sediments using best available disposal management techniques. Each of the potential problems associated with dredging and disposing of contaminated sediments, such as those found in Indiana Harbor, can be resolved by application of the best dredging and dredged material disposal practices.

7. This study includes application of existing testing protocols appropriate to the disposal needs, development of protocols for leachate and surface runoff water quality evaluations, and demonstrations of innovative and environmentally sound dredged material disposal techniques.

Objective

8. The objective of this investigation was to evaluate dredging and dredged material disposal requirements for approximately 200,000 cu yd of PCB-contaminated sediment for Indiana Harbor. Appropriate testing protocols (existing and being developed) were used to identify environmentally sound management strategies for dredging, transporting, and disposing of the material.

Scope

9. The diversity of disposal alternatives and techniques required for management of highly contaminated dredged material requires that detailed evaluations be made based on testing protocols developed specifically for dredged material. This report presents the results of studies and testing protocols performed to provide a technically sound basis for managing the contaminated dredged material from Indiana Harbor. The information presented provides a framework for decisionmaking to select appropriate disposal alternatives and to identify control measures required to resolve potential environmental problems associated with disposal of the sediments. The information presented herein consists of the following:

- a. Evaluation to assess contamination potential.
- b. Evaluation of potential disposal alternatives.
- c. Identification and assessment of potential problems associated with the proposed alternatives.
- d. Assessment of the need for disposal restrictions.
- e. Identification of available control options.

The magnitude and potential impacts of contaminants in the sediments, as related to disposal alternatives, were evaluated using appropriate testing protocols. Only the tests deemed necessary by an initial evaluation and problem assessment were conducted. Since there was no routinely applied laboratory testing protocol to predict leachate quality from dredged material confined disposal facilities, research was conducted to develop a leaching test protocol. Additional research was performed to simplify and significantly reduce the costs of testing for evaluating surface runoff water quality in confined disposal sites. Tests were conducted for use in designing contaminant control measures which may be required for the disposal alternatives under consideration. Innovative disposal alternatives and management techniques evaluated included confined disposal with appropriate restrictions and capping of the contaminated sediments after controlled placement in the aquatic environment.

10. The results of these investigations are presented in two volumes. Volume I presents the detailed evaluations of dredging and dredged material disposal alternatives for the PCB-contaminated sediments from Indiana Harbor Canal. Volume II contains the following technical appendices:

a. Appendix A: Sedimentation and Filtration.

b. Appendix B: Effluent Quality.

c. Appendix C: Results from Previous Settling and Filtering Tests.

d. Appendix D: Plant and Animal Bioassay Procedures and Data.

e. Appendix E: Quantification of Surface Runoff Water Quality.

f. Appendix F: Evaluation of the Effectiveness of Capping in Isolating Contaminated Indiana Harbor Dredged Material: Biological and Chemical Aspects.

g. Appendix G: Leachate Testing Results.

h. Appendix H: Procedures for Evaluating Solidification/Stabilization Technology.

i. Appendix I: Feasibility Study of Contained Aquatic Disposal in Indiana Harbor Canal and Entrance Channel.

j. Appendix J: Contained Aquatic Disposal: Site Location and Cap Material Investigations for Outer Indiana Harbor and Southern Lake Michigan.

Identification of Alternatives

11. Several alternatives for the PCB-contaminated sediments have been identified:

a. Leave the sediments in-place (no-action alternative).

b. Remove and dispose of the sediments using approved procedures for disposal of chemical waste.

c. Remove the sediments by dredging, and dispose of the dredged material using appropriate contaminant control measures.

No-action alternative

12. Obviously, one alternative is to leave the sediments in-place. However, the sediments are known to exert a long-term impact on water quality and biota. This impact is indicated by the high sediment toxicity to aquatic organisms, and it is doubtful that recolonization of the GRC/IHC by aquatic organisms will occur with the PCB-contaminated sediments in-place. The no-action alternative was evaluated as a part of this study. A summary of the evaluation is discussed as a separate alternative in Part V.

Authorities for removal of sediment

13. There are three existing authorities which may be applicable to the removal and disposal of PCB-contaminated sediments in Indiana Harbor Canal. The first is the Corps' authority under the River and Harbor Act to operate

and maintain the Federal navigation project. This is not a "cleanup" authority, but can be used if an environmentally acceptable solution is cost-effective, based on the benefits to navigation. The Chicago District will only proceed with a project under this authority if a local governmental agency (City, County, State) actively sponsors the proposed project.

14. The second authority is Section 115 of the Federal Water Pollution Control Act. It authorizes the USEPA to identify in-place toxic materials in harbors and navigable waterways, and, acting through the Secretary of the Army, make contracts for the removal and confinement of these materials. Although $15 million was authorized by Congress to carry out the provisions of this Section, this authority has not been used to implement any significant in-place contaminant cleanup to date.

15. The third authority is under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Superfund). Under this authority, the USEPA must inspect a potential cleanup site and rate the site using the Hazardous Ranking System (HRS). If the ranking exceeds specified numerical cutoff, the ranking is referred to the State for concurrence. The site may then be proposed for inclusion on the National Priorities Listing which requires it to be published in the Federal Register for public review and comment. Presently there are over 800 proposed or final sites for Superfund cleanup on the National Priorities List. Once finalized, a site is prioritized along with others by the State which must provide 10-percent matching funds for any cleanup. The USEPA performs a remedial investigation of the site and presents a feasibility study of alternative plans. The USEPA makes a record of decision as to the proposed plan to be implemented through the CE, which is responsible for contracting design and construction. To date, Indiana Harbor has not been considered for listing as a Superfund site.

Toxic Substances Control Act considerations

16. Sediments contaminated with PCBs at levels exceeding 50 ppm are subject to regulation under the Toxic Substances Control Act of 1976 (TSCA). The USEPA's Final Rule for Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions was published in the Federal Register (40 CFR, Part 761) on 31 May 1979. Disposal alternatives for any material contaminated with PCBs (>50 ppm) include incineration, a chemical waste landfill, or a disposal method approved by the USEPA Regional Administrator.

17. A conceptual evaluation of TSCA-approved disposal alternatives was conducted for purposes of a cost comparison. The estimated costs and project duration for the handling and disposal of PCB-contaminated sediments from Indiana Harbor Canal by TSCA-approved methods of incineration and chemical waste landfill are summarized as follows:

	Estimated total cost (millions)	Cost per cubic yard	Time frame (years)
Incineration onsite	\$205-305	\$1030-1540	17
Incineration offsite	\$277-7352	\$1385-1760	8
TSCA landfill	\$ 74- 92	\$ 370- 460	6-8

The above costs are in sharp contrast to the estimated costs of the proposed confined disposal facility for the bulk of contaminated sediments from Indiana Harbor and Canal. The CDF, designed to receive about 1,300,000 cu yd of dredged material, is estimated to cost $30 million ($23 per cu yd), including construction, dredging, operation, and maintenance. The conceptual evaluation of TSCA-approved alternatives which serves as the basis of the above cost estimates is presented in Part IV as a separate alternative.

18. The estimated costs of the above TSCA-approved disposal alternatives for PCB-contaminated sediments are far beyond the limits which could be

justified under the Corps' navigation maintenance authority. Alternative methods of disposal approved by the USEPA Regional Administrator appear to be the only feasible option available to the Corps under the presently available funding authority.

Dredging and disposal alternatives

19. Dredging and disposal of the PCB-contaminated sediments with appropriate contaminant control measures is an alternative under the TSCA category of alternative methods to be approved by the USEPA Regional Administrator, other than the approved TSCA alternatives of incineration and chemical waste landfill. The following parts of this report will present results of investigations conducted at WES to evaluate dredging and disposal alternatives for PCB-contaminated dredged material. A Management Strategy, developed by the Corps to serve as a decisionmaking framework will be described in Part II and applied throughout for the specific case of Indiana Harbor. Laboratory analyses performed to evaluate disposal alternatives and determine appropriate control measures will be described in Parts II and III. The evaluations of disposal alternatives and dredging equipment are presented in Parts IV and V, respectively. For purposes of comparison, discussions of the no-action alternative and TSCA-approved alternatives are also included in Part IV.

PART II: DISPOSAL PROBLEM DEFINITION

20. This part of the report is concerned with identification of problems associated with the dredging and disposal of Indiana Harbor PCB-contaminated sediments. A description of the nature of PCB chemistry and properties is presented. The magnitude and possible impacts of dredging and disposal operations are evaluated using a Management Strategy which includes testing protocols and procedures specifically designed to consider the unique nature of these materials and the physicochemical conditions of each disposal alternative. Procedures used to collect samples and protocols for testing are described. Test results are used to determine the potential for environmental harm from contamination, examine the interrelationships of the problems and potential solutions, and determine what controls are needed for each disposal alternative.

General

21. All waterways carry sediment, and sedimentation is a natural process resulting in the deposition of suspended particles. Sediments enter urban waterways from runoff and from controlled or uncontrolled discharges. Pollution enters waterways by the same routes. Sediments are predominantly soil particles and water. Fine-grained soils, such as silts and clays have a high affinity for many pollutants. Hydrophobic contaminants, such as PCBs, have an especially high affinity for sediments containing organic matter. As a result, deposited sediments have been a significant sink for pollutants discharged to waterways. Bottom sediments in many rivers may contain pollutants accumulated from years of environmental abuse.

22. Federal and state regulations of the past twenty years have sought to curb the discharge of pollution to waterways, and have had considerable success in the regulation of point discharges. Nonpoint discharges are less easily regulated and for the most part remain. Bottom sediments may represent a significant nonpoint source of pollution in some waterways. Rivers now having well controlled point discharges may have water quality improvements limited by the persistence of nonpoint sources of pollution, including in-place bottom sediments. Removal of polluted bottom sediments in all waterways would be a cleanup effort of mammoth proportions. Funding for removal of in-place polluted sediments is either sparse or nonexistent. Only a handful of sediment cleanups, generally associated with spills or specific point dischargers have been planned or implemented. In rivers having authorized navigation channels, maintenance dredging may represent the only means by which in-place polluted sediments can be removed.

23. Nationwide, over 300 million cu yd of sediments are dredged by the Corps of Engineers every year. Less than 20 percent of these dredged materials are considered polluted, and a far smaller percentage may be considered highly contaminated. Despite the variety of terms used to characterize dredged materials (nonpolluted, polluted, contaminated, toxic, etc.) they are predominantly soil particles (sand, silt, and clay) and water.

Polychlorobiphenyl Chemistry and Properties

Description and nomenclature

24. Polychlorinated biphenyls (referred to collectively as PCBs) are the contaminant of most concern which are found in the Indiana Harbor sediments. PCBs consist of two benzene rings joined at two of their apices to form

biphenyl; this is then substituted with up to 10 chlorine atoms at the remaining apices. PCB isomers can be distinguished by numbering the apex of each ring, starting at the junction point of each ring and using primes (') to differentiate rings (Kornreich et al. 1976). Numbering from the ring junction can be either clockwise or counterclockwise, but must be chosen to give the lowest number(s) or sum of numbers assigned to the points of chlorine attachment. For example, as shown in Figure 3, the compound illustrated is 3,4'-dichlorobiphenyl, not 4',5-dichlorobiphenyl.

25. PCBs are commonly found in the environment as mixtures of congeners (individual PCB compounds), since commercial PCBs were produced only as mixtures by the Monsanto Chemical Company, the sole US producer. Monsanto gave PCBs the trade name Aroclor; particular congener mixtures are identified by the word Aroclor followed by a four-digit number. The first two digits of the four digit identification number can be either 12, which identifies biphenyl, or a 44 or 54, which identifies terphenyl. The second pair of numbers in the four-digit identification number identifies the percentage of the total weight of the Aroclor that is contributed by chlorine. One exception is Aroclor 1016, which does not follow the nomenclature rules. Aroclor 1016 is similar to Aroclor 1242 and contains about 40 percent chlorine.

26. PCBs possess high resistance to thermal degradation and, except for PCBs with a low level of chlorination, are nonflammable. PCBs also exhibit excellent electrical insulating properties (Hutzinger et al. 1974) and are relatively insoluble in water, with solubility tending to decrease with increasing chlorine content (Wallnofer et al. 1973, Haque and Schmedding 1975, Wiese and Griffin 1978). The same properties that make PCBs excellent

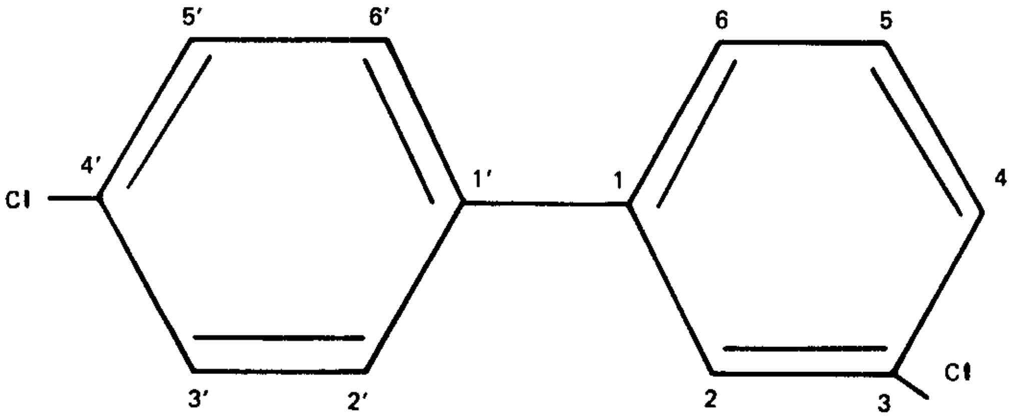


Figure 3. 3,4'-dichlorobiphenyl

compounds for industrial use in transformers, fire retardants, and heat transfer operations, also make them resistant to degradation in the environment.

Significance of Aroclors, isomer groups, and congeners

27. In the past, PCBs in the environment have been widely identified and measured on the basis of Aroclors, primarily because it was the only practical approach. This method of identifying PCBs, however, does have a number of marked disadvantages. Gas chromatographic (GC) patterns produced by PCBs in extracts from environmental samples frequently are different from Aroclor patterns. This is due to the slower microbial degradation of more highly chlorinated PCBs compared with degradation of PCBs with a lower degree of chlorination. Results of many workers (Ahmed and Focht 1973, Wong and Kaiser

1975, Tucker et al. 1975, Furukawa and Matsumura 1976) have shown that the PCBs with a lower degree of chlorination will be preferentially degraded under aerobic conditions. Other differences in Aroclor patterns can be caused by variations among different commercial batches of the Aroclor, differing solubility in water, and irreversible adsorption of some PCB congeners (and individual chlorobiphenyl compound) in the environment. These problems are further complicated if more than one Aroclor residue is present in the environmental sample or if the PCBs were not introduced into the environment as Aroclors.

28. In addition to the analytical difficulties discussed in the previous paragraph, there are other disadvantages to quantifying PCBs as Aroclors. For many environmental samples, determination of a particular Aroclor or mixture of Aroclors will not yield particularly useful information. For example, calculations relying on equilibrium partitioning theory are difficult to conduct using Aroclor analysis because Aroclors are a mixture of compounds having widely differing octanol-water partitioning coefficients. Information on the potential toxicity of PCB compounds is also not provided by analysis of Aroclors because only a few of the PCB congeners constituting an Aroclor may be toxic and of concern.

29. Other means of quantifying PCB concentrations in sediments are as isomer groups (by number of chlorine atoms) or as congeners. Isomer group quantitation of PCBs has been used at the US Army Engineer Waterways Experiment Station (WES) in lieu of Aroclor analysis. This method of analysis avoids many of the difficulties inherent in Aroclor analysis, such as quantitation of degraded Aroclor patterns. However, the information gained from results of isomer group analysis has not proved to be substantially more useful than that obtained from Aroclor analysis. Congener analysis appears to be the methodology that will be followed in the future since the USEPA has recently

promulgated Method 680 for determination of PCB congeners in water and sediment (Alford-Stevens et al. 1985).

PCB association with sediment

30. PCBs as a class are highly insoluble in water and therefore tend to become closely bound to sediment. Fisher, Petty, and Lick (1983) stated that sediments of any water body must be viewed as the largest sink-source for PCBs. Other workers (Steen, Paris, and Baughman 1978; Hiraizumi, Takahashi, and Nishimura 1979) have demonstrated that particle-size distribution and total sediment organic carbon were important factors affecting the adsorption of PCBs to sediment. Chiou, Peters, and Freed (1979, 1981) have shown that sorption of nonionic organic compounds from water onto soil consists primarily of partition into the soil organic phase with adsorption by the soil mineral fraction in wet soils showing relatively little importance. Chiou, Porter, and Schmedding (1983) later showed that the extent of solute insolubility in water is the primary factor affecting the partitioning of nonionic organic compounds, such as PCBs, onto soil organic matter.

31. There has not been as much work conducted on desorption of PCBs as on adsorption of these compounds by soils and sediments. However, some conclusions can be drawn based on the behavior of PCBs and other hydrophobic organic chemicals. Karickoff (1984), in a review of the relevant literature, showed that adsorption partitioning of neutral organic chemicals by soils and sediment is a function of the weight fraction of sediment organic carbon and the octanol-water partition coefficient of the chemical. Di Toro (1985) analyzed the data from numerous adsorption/desorption studies and developed a particle interaction model of reversible organic chemical adsorption. He reported that the desorption of neutral organic chemicals was a function of the particle concentration, fraction of organic carbon on the particles, and Koc, the

organic carbon normalized adsorption partition coefficient. Adsorption and desorption in sediment-water systems are therefore complicated and subject to many variables that can influence the results obtained in either field or laboratory studies.

Application of Management Strategy for Contaminant Testing and Controls

32. A strategy for selecting the most appropriate disposal alternative from an environmental standpoint is essential when the disposal of contaminated or potentially contaminated dredged material is required. The CE has recently developed an evaluation strategy (Francingues et al. 1985) and decisionmaking framework (Peddicord et al. 1986) for use in selecting alternatives and for determining what contaminant control measures are appropriate. This strategy has been recommended as USACE policy for studies involving disposal of contaminated sediments (Kelly 1985). This strategy was applied in evaluating disposal alternatives for the contaminated Indiana Harbor sediments. For purposes of simplicity, they are herein referred to as the Management Strategy and Decisionmaking Framework.

33. The Management Strategy is an environmentally sound approach for selecting alternatives for the disposal of dredged material with any level of contamination. The Management Strategy is based on findings of research conducted by the CE, USEPA, and others over the past 15 years and on experience in actively managing dredged material disposal.

34. 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. Further, 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.

35. The selection of an appropriate disposal alternative is partially dependent on the nature of the dredged material, the 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 final dredged material disposal alternative selection. The Management Strategy used in this report 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.

These steps are graphically presented in Figure 4.

36. The first step in the application of the Management Strategy is an initial evaluation of whether or not there is reason to believe the sediments are contaminated. This is most commonly done from a survey of existing data on sediments or sources of pollution. For the case of Indiana Harbor, previous

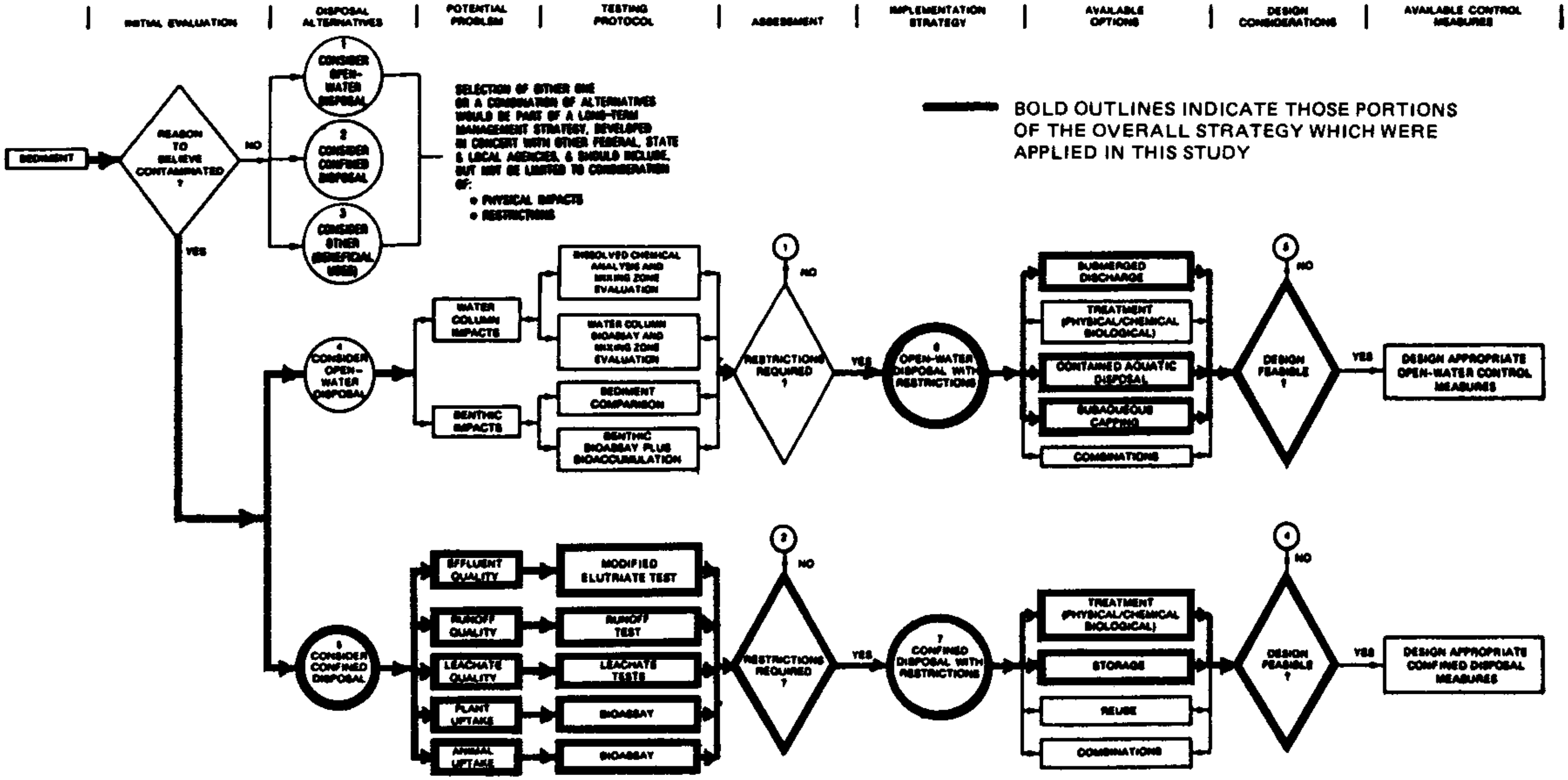


Figure 4. Management strategy flowchart

sampling by the USEPA and Corps had shown that the sediments were highly contaminated. For this reason the consideration of unconfined open-water disposal was not appropriate and tests used to evaluate this disposal alternative were not performed. This leaves two general disposal alternatives available; open-water disposal with restrictions, and confined disposal. Three specific alternatives for the disposal of PCB-contaminated sediments from Indiana Harbor were considered in detail:

a. Contained aquatic disposal (CAD).

b. Confined disposal in an in-water facility.

c. Confined disposal in an upland facility.

37. Testing protocols appropriate to these disposal alternatives were selected in applying the Management Strategy. The tests were designed to evaluate potential water quality (effluent, surface runoff, and leachate) and biological (plant and animal uptake) impacts for confined disposal and to provide engineering guidance for contained aquatic disposal (cap thickness and gradation). Those testing protocols and control options which were evaluated as part of this study are indicated with bold outlines in Figure 4. Most of these testing procedures are standardized and have been used widely for evaluation of dredged materials. The remainder of this part provides details on the chemical and engineering characteristics of Indiana Harbor sediment and testing protocols used in assessing the disposal alternatives. In Part III, testing protocols developed as part of this research study are described and results with Indiana Harbor sediments presented.

Criteria for Selection of Controls

38. The results of dredged material testing protocols are compared to state or Federal regulatory criteria to determine where control measures (treatment, liners, capping, etc.) are appropriate. Around the Great Lakes the discharge of dredged material to navigable waters is regulated under Section 404 of the Clean Water Act (CWA). For disposal of maintenance dredgings, the Corps of Engineers will seek approval from the appropriate state regulatory agency under Section 401 of the CWA. This water quality certification applies to the discharge of dredged material or discharge from a confined disposal facility to navigable waters. For the disposal of dredged material from Indiana Harbor, the Indiana Department of Environmental Management (IDEM) is responsible for issuance of certification under Section 401.

39. Specific numerical standards have been established by the State of Indiana for the waters of Lake Michigan, Indiana Harbor, and the Grand Calumet River. Results from effluent and runoff tests were compared with these Indiana water quality standards and USEPA criteria for the protection of aquatic life. These standards are summarized in Table 1. Results from plant and animal uptake tests were compared with the US Food and Drug Administration (FDA) allowable concentrations for foodstuffs. There were no appropriate criteria for comparison with leachate test results.

40. The comparisons of test results and criteria were the basis of discussion of appropriate contaminant control measures for the disposal alternatives considered. The final design of the selected disposal alternative should be based on later comparisons of test results and specific criteria agreed upon by the concerned regulatory agencies.

Table 1

Summary of Water Quality Standards

Constituent	Constituent Concentrations, ppm Drinking Water Standards	USEPA Maximum Criteria	Indiana Harbor WQ Standard	Lake Michigan WQ Standard
Arsenic	0.05	0.44	-	0.050
Cadmium	0.01	0.0015-0.0024	-	0.010
Chromium	0.05	2.2-9.9	-	0.050
Copper	1.0	0.012-0.043	-	-
Lead	0.05	0.074-0.400	-	0.050
Mercury	0.002	0.0017	0.0005	0.00005
Nickel	-	1.1-3.1	-	-
Zinc	5.0	0.18-0.57	-	-
Iron	0.3	-	0.300	0.150
Manganese	0.05	-	-	-
Total phosphorus	-	-	0.1	0.03
NH3-N	-	-	1.5	-
PCB-1248	-	0.014	0.000001	0.000001
Phenol	-	-	0.01	0.001
Dissolved solids	-	-	500	172

Sediment Collection and Preparation

Sediment collection

41. Sediment samples were collected from Indiana Harbor using a CE clamshell dredge. Two sites had been selected by Chicago District personnel for sample collection. These sites were selected because previous studies indicated the sediments had very high PCB concentrations (>50 ppm). An additional site in Lake Michigan was selected for collection of an uncontaminated sediment. The uncontaminated Lake Michigan sediment was to be used in the capping study. Forty drums (each 55 gal) of sediments were collected from the two contaminated sites (20 drums from each site). Five drums of sediment were collected from the uncontaminated site. The drums were new and had been steam-washed prior to shipment to the collection site. The dredge was positioned over the selected site during sampling and the clamshell lowered to the desired depth. After filling, the drums were sealed immediately with the included seal and lid. The 45 drums of sediment were loaded into a temperature-controlled, refrigerated (4°C) truck and transported to WES.

Sediment preparation

42. The sediments were mixed at WES. Each drum (from the PCB-contaminated sediment) was taken from the truck, the lid removed, and the sediment poured into a previously washed and cleaned concrete mixer. When the last of the drums had been poured into the mixer, the sediment was mixed for 30 min for complete homogenization. Homogenized sediment was placed back into washed drums and distributed to the various principal investigators for testing. The five drums of uncontaminated sediment to be used for the capping experiment were also removed from the truck and given to the appropriate investigator.

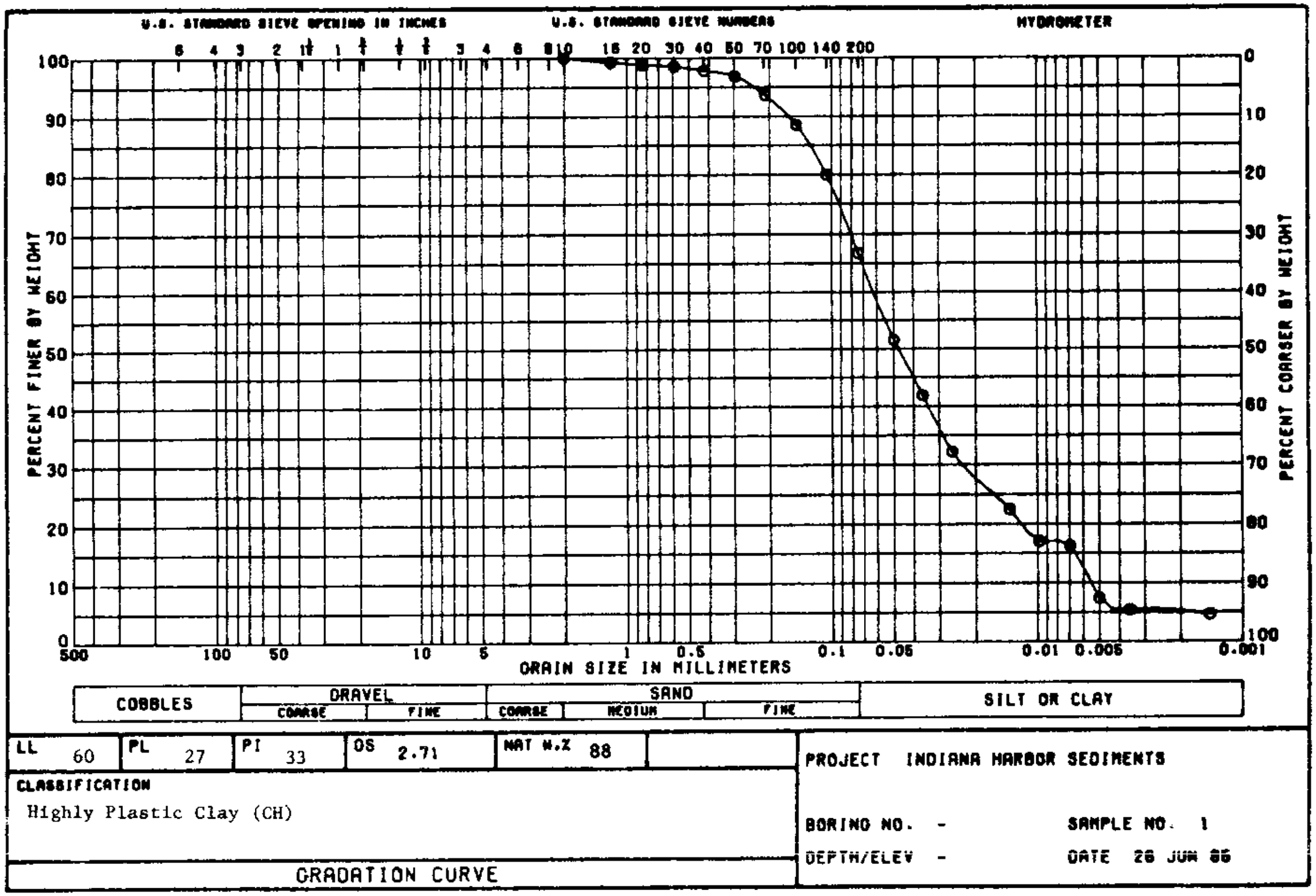
Sediment Characterization

Engineering characterization

43. Engineering characterization tests were conducted on the composite sediment sample to include grain size analysis, liquid and plastic limits, and specific gravity. The grain-size distribution is shown in Figure 5. Approximately 65 percent of the sample (dry weight basis) was silts and clays (passed the No. 200 sieve). The liquid and plastic limits were 60 and 27 percent, respectively. The specific gravity was 2.71. The Unified Soil Classification was highly plastic clay (CH). This characterization was similar to that of a sample previously taken from nearby channel area in 1979 (Environmental Laboratory (EL) 1979).

Chemical characterization

44. Separate determinations of bulk sediment chemistry of the Indiana Harbor composite sample were made for material used in the elutriate tests (reported in Appendix B), plant and animal uptake tests (reported in Appendix D), capping tests (reported in Appendix F), and leachate tests (reported in Appendix G). Chemical concentrations of selected parameters for both the homogenized Indiana Harbor sediment and the Lake Michigan sediment are listed in Table 2 (taken from Appendix F). The sediment from Indiana Harbor had higher concentrations of metals and pesticides than did the Lake Michigan material. For example, metal concentrations of cadmium, lead, and zinc in Indiana Harbor sediment were nearly 200, 80, and 80 times that in Lake Michigan sediment while concentrations of organic chemicals ranged from more than thirty times (PCB-1248) to several orders of magnitude (Aldrin) higher.



LL 60	PL 27	PI 33	OS 2.71	NAT W.% 88	

CLASSIFICATION
Highly Plastic Clay (CH)

PROJECT INDIANA HARBOR SEDIMENTS
BORING NO. -
SAMPLE NO. 1
DEPTH/ELEV -
DATE 26 JUN 86

Figure 5. Grain size distribution for Indiana Harbor sediment

Table 2

Comparative Chemical Composition of Indiana Harbor and Lake Michigan Sediments

Parameter	Concentration in Sediment, mg/kg dry weight	
	Indiana Harbor	Lake Michigan
Metals		
Arsenic	29.5	10.1
Cadmium	20.0	0.1
Chromium	650.0	4.4
Lead	879.0	11.9
Mercury	0.5	BD*
Zinc	4,125.0	54.1
Pesticides		
Aldrin	2.55	0.0006
Polyaromatic hydrocarbons		
Acenaphthene	96	BD
Acenaphthylene	22	BD
Anthracene	62	BD
Benzo(a)anthracene	86	BD
Benzo(b)fluoranthene	140	BD
Benzo(a)pyrene	87	BD
Benzo(g h i)perylene	35	BD
Chrysene	92	BD
Fluoranthene	150	BD
Fluorene	69	BD
Indeno(1,2,3-c d)pyrene	50	BD
Naphthalene	2,000	0.46
Phenanthrene	200	BD
Pyrene	140	BD
Polychlorinated biphenyls		
PCB-1248	33.4	BD
PCB-1254	BD	0.013
Total organic carbon	7.39% of sediment weight	1.83% of sediment weight
Total inorganic carbon	2.28% of sediment weight	0.47% of sediment weight
Oil and grease	3.88% of sediment weight	1.71% of sediment weight
Phenol	3	BD

* BD = below detection.

45. Indiana Harbor sediment contained much higher levels of polynuclear aromatic hydrocarbon (PAH) compounds than did the Lake Michigan material (Table 2). The only PAH compound present in detectable quantity in Lake Michigan sediment was naphthalene. However, the level of this compound in Indiana Harbor sediment was more than three orders of magnitude greater than in the Lake Michigan material. The remaining PAH compounds found in Indiana Harbor sediment were not detected in Lake Michigan sediment.

46. Sediment from Indiana Harbor was found to contain PCB-1248, which was not detected in Lake Michigan sediment (Table 2). By contrast, Lake Michigan sediment contained a trace amount of PCB-1254, a compound not found in the material from Indiana Harbor. Indiana Harbor sediment also contained substantial quantities of total organic carbon, oil and grease, and a small amount of phenol (Table 2); these were either not present or present in much smaller amounts in Lake Michigan sediment. Additional data on contaminant concentrations in Indiana Harbor sediment are found in the Appendices (Vol. II).

Water Quality Evaluations

47. Water quality evaluations were conducted for the upland and in-lake CDF alternatives. These included evaluations of effluent (water discharged during filling operations), surface runoff (water discharged as runoff due to precipitation), and leachate (water moving through the dredged material into groundwater).

Effluent quality

48. Procedures. 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 both dissolved and particulate-associated contaminants. A large portion of the total contaminant concentration is particulate associated.

49. The standard elutriate test is sometimes 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 CE Long-Term Effects of Dredging (LEDO) Program (Palermo 1985), was used to predict both the dissolved and particulate-associated concentrations of contaminants under confined disposal conditions. The test reflects the sedimentation behavior of dredged material, the retention time of the containment area, and the chemical environment in ponded water during active disposal of hydraulically dredged materials. The acceptability of the proposed confined disposal operation was evaluated by comparing the predicted contaminant concentrations with applicable water quality criteria while considering an appropriate mixing zone.

50. Results. The prediction of the effluent requires interpretation and analysis using the modified elutriate test results, the leaching test results, settling test results, and design information. Based on results of the modified elutriate and other tests presented in Appendices A and B, the effluent quality is a function of the disposal alternative used. For evaluation of in-lake CDFs, effluent quality predictions were made for the case of hydraulic transfer of the material to a CDF from scows, direct pumping from a hydraulic dredge using a matchbox type dredgehead, and mechanical placement. For upland disposal, effluent quality following suspended solids (SS) removal is considered equal to dissolved concentrations as determined by the modified elutriate test. Additional contaminant removals could be achieved by other processes such as carbon adsorption. The results for parameters above

detection are summarized in Table 3. The CDF estimates assume that the water in the CDF prior to disposal has no contaminants, the quantity of water available for dilution is the minimum to maintain one foot of ponding, the effluent following filtration contains 0.5 mg/ℓ suspended solids, and the concentration of dissolved contaminants does not change while passing through the filter dikes. Significant adsorption of hydrophobic contaminants such as PCBs onto the filter material is expected and, therefore, the estimates are conservative, and are very conservative for several of the contaminants. Furthermore, depending on the sequencing of the disposal projects, the volume of water available for dilution may be as much as four times as large as assumed in calculating the effluent quality.

51. In general, the contaminant concentrations for hydraulic transfer from scows are about 5 to 6 times as high as for matchbox dredging and about 50 to 150 times as high as for mechanical disposal. Considering the discharge volume, the quantities of contaminants released by the hydraulic transfer alternative are about twice as large as by the matchbox dredge alternative and about 70 to 200 times as large as by the mechanical disposal alternative.

52. The maximum quantity of PCBs expected to be released from the proposed CDF during the disposal operation is 6.3 kg for the hydraulic transfer from scows alternative, 4.2 kg for the matchbox dredge alternative, and 0.0027 kg for the mechanical disposal alternative. The actual quantity of PCBs released through the filter dikes could actually be much less (orders of magnitude less) since PCBs are very hydrophobic and are adsorbed very easily. However, the PCBs are likely to move with the oil in the system and, if the oil passes through the dikes, the PCBs will pass through also. Significant oil adsorption is also expected since it is also hydrophobic.

Table 3

Summary of Estimated Effluent Water Quality

	Estimated Constituent Concentrations, ppm*			
		In-Lake CDF		
Constituent	Modified Elutriate Filtered Water	Hydraulic Transfer	Matchbox Dredge	Mechanical Disposal
Arsenic	0.004 ± 0.003 ppm	0.014	0.003	0.0003
Cadmium	0.0023 ± 0.0005 ppm	0.0080	0.0015	0.00005
Chromium	0.035 ± 0.005 ppm	0.122	0.022	0.0013
Copper	0.035 ± 0.008 ppm	0.122	0.022	0.001
Lead	0.064 ± 0.031 ppm	0.224	0.041	0.052
Nickel	0.032 ± 0.000 ppm	0.112	0.020	0.0007
Zinc	0.430 ± 0.046 ppm	1.505	0.275	0.066
Iron	0.686 ± 0.104 ppm	2.402	0.440	0.066
Manganese	0.039 ± 0.007 ppm	0.136	0.025	0.0009
Total phophorus	0.38 ± 0.10 ppm	1.33	0.25	0.008
NH3-N	44.2 ± 0.5 ppm	154.7	28.3	1.0
Aldrin	0.00011 ± 0.00003 ppm	0.00039	0.00007	0.000002
Heptachlor epoxide	0.00004 ± 0.00006 ppm	0.00014	0.00003	<0.000001
PCB-1248	0.0034 ± 0.0017 ppm	0.0238	0.0051	<0.00001
Total organic	44.5 ± 3.7 ppm	156	28.6	1.
carbon	0.037 ± 0.004 ppm	0.130	0.024	0.0008
Phenol	-	0.5	0.5	0.5
Suspended Solids	-	347,000	1,070,000	260,000
Discharge volume		cu yd	cu yd	cu yd

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* Assuming that the water in the CDF has no contaminants prior to disposal, that the water available for dilution is the volume for initial storage for the new lift of material plus the ponded volume for a 1-ft ponding depth, that the effluent following filtration contains 0.5 mg/P suspended solids, and that the concentration of dissolved contaminants does not change while passing through the filter dikes.

53. Only the concentrations of PCBs for all three alternatives exceeds the water quality standards. The concentrations of chromium, lead, iron, manganese, total phosphorus, ammonia, phenol, and probably total organic carbon for the hydraulic transfer from scows alternative exceed the water quality standards. The concentrations of total phosphorus, ammonia, phenol, and possibly total organic carbon for the matchbox dredging alternative barely exceed the water quality standards without considering a mixing zone. Detailed results are presented in Appendix B.

Surface runoff quality

54. Procedures. 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 processes which occur during drying and the contaminants present in the dredged material.

55. 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 was therefore used to predict surface runoff water quality from dredged material (Lee and Skogerboe 1983). This test protocol involves taking a sediment sample from a waterway and placing it in a soil-bed lysimeter. 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. From these results, control measures can be formulated to treat surface runoff water, if required, to minimize the environmental impact to surrounding areas.

56. Results. During the early, wet, anaerobic stages, contaminants were mostly bound to the SS in the surface runoff and were mainly in the unfiltered samples. As the sediment dried, the SS concentrations decreased, thereby decreasing the unfiltered contaminant concentrations. Filtered concentrations during this period were low compared with the unfiltered concentrations but would still be of concern when compared with the USEPA Maximum Criteria for the Protection of Aquatic Life. Until the sediment became oxidized and the pH decreased to about 6.5, the filtered concentrations of contaminants would also decrease significantly. Results of the lysimeter tests represented the worst possible case that could occur during the wet, anaerobic stage. Control measures during this period should concentrate on control of the SS in the surface runoff after considering an appropriate mixing zone outside of the disposal site. If an appropriate mixing zone does not exist, control measures such as the use of sedimentation basins, control structures, filters, or chemical flocculants should be considered.

57. After the sediment dried and oxidized, the surface runoff water quality constituents of concern changed. Organic compounds were present in low concentrations or were not detected in runoff from oxidized sediment. Most of the organic compounds had been lost from the sediment during this stage due to volatilization into the atmosphere or adsorption to soil particles. Some naphthalene was present in both the filtered and unfiltered samples but the total PAHs were very low. No PCBs were detectable in runoff from the dry, oxidized sediment. Heavy metals did, however, continue to be a potential problem. Filtered concentrations of the metals cadmium, copper, nickel, zinc, manganese, and lead were not statistically different from the unfiltered concentrations. These metals were present in soluble forms, which are more difficult to control. Chromium also increased in solubility but not to the

extent of the other metals. Filtered concentrations of cadmium, copper, zinc, and lead were high enough to be of concern as they were greater than or equal to the USEPA criteria. As the sediment continues to age, hard aggregate chunks will weather and break apart. Concentrations of SS will probably increase by as much as 10 to 20 times as the material becomes more erosive. Concentrations of filtered and unfiltered metals should increase by similar amounts. Therefore, some type of restriction or control measure should be required, or a mixing zone should be considered if the sediment is placed in an upland environment. Control measures might include liming the sediment, vegetating the site, capping, or treating the runoff. Results are presented in detail in Part III and in Appendix E. A testing program aimed at developing a simplified screening test for surface runoff was conducted as a part of the research effort described in Part III.

Leachate quality

58. Procedures. 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 and consolidate with water percolating out, but the settlement process may require some time for self-sealing to develop. Since most contaminants potentially present in dredged material are adsorbed to particles, only the dissolved fraction will be present in leachates. The site-specific nature of subsurface conditions is the major factor in determining possible impact (Chen et al. 1978).

59. An appropriate leachate quality testing protocol was needed to predict which contaminants may be released in leachate and the relative degree of release. There was no routinely applied laboratory testing protocol to predict leachate quality from dredged material disposal sites. Therefore, an evaluation was made of available leaching procedures for use in the development of a

leaching test protocol for confined dredged material. These evaluations were made as part of the research effort described in Part III. From these evaluations, leach tests were identified that provide information on the intrinsic release characteristics of dredged material. Probably the most important release characteristic measured in these tests is the distribution or partitioning coefficient. Distribution coefficients are used to determine interstitial pore water quality of in situ sediments (necessary for evaluation of water quality impacts of mechanical disposal) and to model the fate and transport of PCBs and other hydrophobic organics (Karickhoff, Brown, and Scott 1979).

60. The leach tests showed the majority of the contaminants in Indiana Harbor sediment to be tightly bound to sediment particles. The results showed that equilibrium controlled desorption is a conservative assumption for anaerobic sediment. The fraction of metals resistant to leaching was generally greater than 99 percent for both anaerobic and aerobic sediment. The data showed organic contaminants releases to be very low. A detailed discussion of results is found in Part III and Appendix G.

Engineering Evaluations

61. Engineering evaluations were conducted to determine the physical behavior of dredged material for the upland and in-lake CDF alternatives. These tests included settling and consolidation tests for the homogenized Indiana Harbor sediment.

Settling tests

62. Procedures. Settling tests were required to define the sedimentation characteristics of the sediment to be dredged. These test results were used to

determine the required disposal area ponding depth and surface area required for effective retention of suspended solids during the dredging operation and to predict the concentration of suspended solids in the effluent resulting from gravity settling. The tests were conducted using 8-in.-diameter settling columns and procedures found in Palermo, Montgomery, and Poindexter (1978).

63. Results. Based on the settling tests, the proposed in-lake CDF is sufficient to store the volume of dredged material to be disposed. The effluent quality of the supernatant and the loading on the filter dikes are highly dependent on the dredging and disposal methods. The suspended solids loading on the filter dikes can be as high as 2.1 g/ℓ for hydraulic dredging, 1.3 g/ℓ for hydraulic transfer of mechanically dredged sediments, and 20 mg/ℓ for mechanical disposal. The loadings for hydraulic disposal may be much lower if the influent concentration is kept high and the settling is controlled by zone settling instead of flocculent settling. Under this condition, the loadings for hydraulic transfer and hydraulic dredging would be about 250 and 400 mg/ℓ, respectively. Results are presented in Appendix A.

Consolidation tests

64. Consolidation tests were required to define the consolidation properties of the sediment to be dredged. Results of these tests were used to evaluate the consolidation properties of the sediments after being removed from the harbor. A large-strain controlled rate of strain testing device at WES was used to perform these tests. The results from these tests are important in the evaluation of capacity required for each of the disposal alternatives being considered for the Indiana Harbor sediments.

Biological Evaluations

Plant bioassay

65. Procedures. The biological tests were designed to evaluate biological impacts of confined disposal. The tests include both upland and wetland conditions which may exist at a confined disposal site. A plant bioassay was conducted using the method of Folsom and Lee (1981) to evaluate uptake and potential mobility of contaminants through plants into the environment under simulated flooded (reduced) and upland (oxidized) disposal environments.

66. Enough sediment to conduct the upland portion of the plant bioassay and for chemical and physical analysis was poured into aluminum drying flats and allowed to air-dry. Samples of the wet-flooded sediment were also taken as the sediment was being poured into the flats. In preparation for the flooded portion of the plant bioassay, four inner containers of the Experimental Unit (EU) were filled with wet sediment, the containers capped with their included lids, and placed into cold storage ($4^{o}C$) until the upland sediments had dried. A schematic diagram of the EU is illustrated in Figure 6. The upland sediment was turned daily to facilitate drying. The air-drying process was conducted for about four weeks in the greenhouse to minimize airborne contamination of the sediment and to keep rainfall from rewetting the sediment. The air-dried sediment was subsequently ground to pass a 2-mm screen. Samples of air-dried sediment were taken for both chemical and physical analysis. Holes were drilled in the bottom of the inner container, and a polyurethane sponge overlaid with a layer of washed quartz sand was placed on the sponge. The sand and sponge acted as a filter to keep the sediment from draining out the bottom of the inner container through the small holes. The holes in the inner containers also allowed water movement into and out of the sediment.

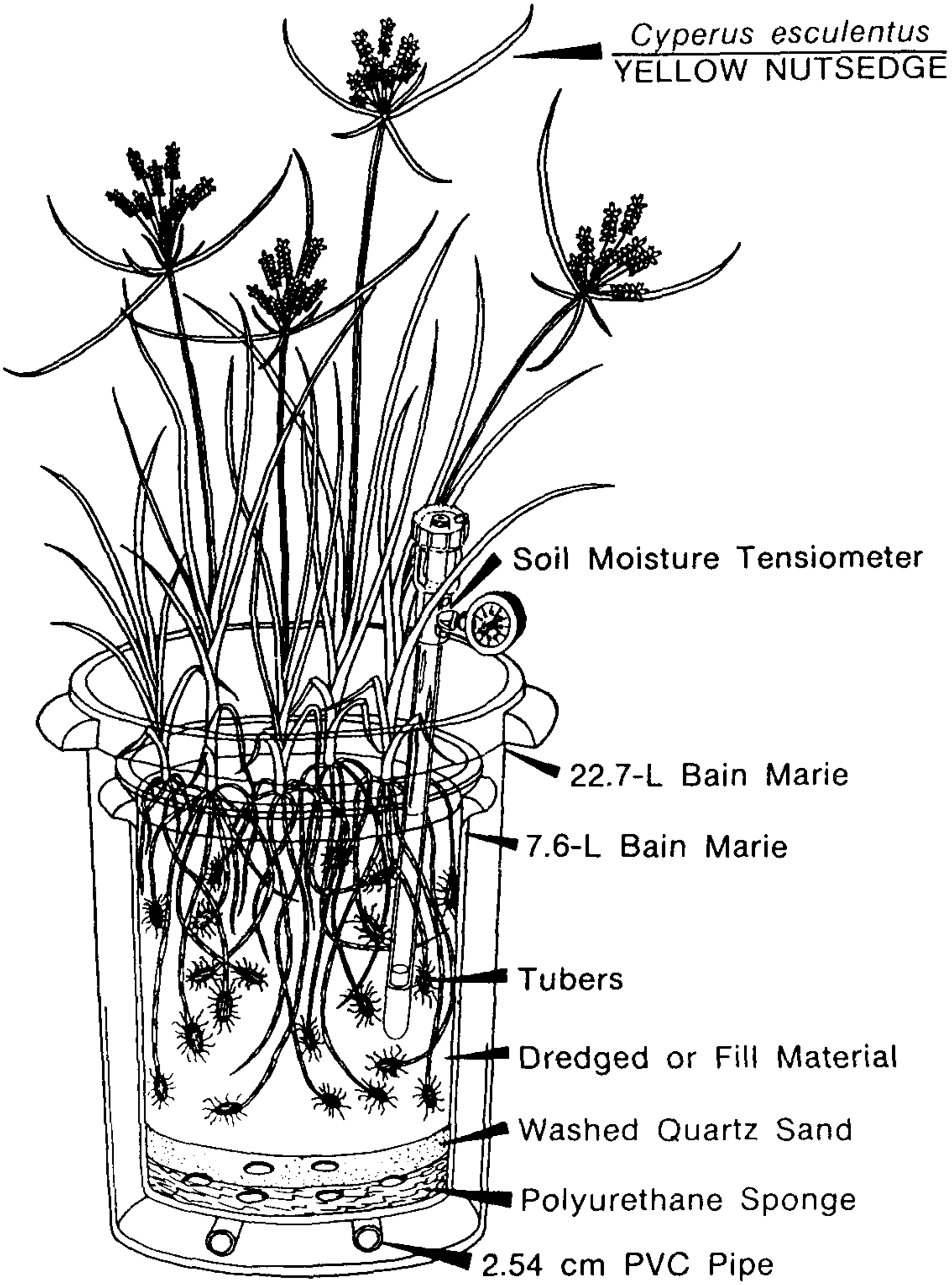

Figure 6. Plant bioassay experimental unit.

67. After the sediment has been placed into the container, a soil-moisture tensiometer was placed into each EU for the measurement of sediment moisture. Sediment moisture of all the upland treatments was maintained between 0.03-0.05 Megapascal (MPa) (a reading between 30 and 50 percent on the dial of the tensiometer, 0.00 MPa equals field capacity). Deionized water (from this point on the term water means deionized water) was added as needed. The sediment was not allowed to drain or dry out for the flooded treatment. At least a 5-cm depth of water was maintained over the surface of the sediment in the flooded treatment by addition of water as needed.

68. An EU containing WES reference soil fertilized for adequate plant growth was included with the test to ensure an adequate greenhouse environment was maintained during the course of the experiment. Plant growth and yield were the only parameters of the WES EU used for comparative purposes. Three sprouted Cyperus esculentus (common name, yellow nutgrass) tubers were planted in each of the four replicates of flooded sediment and in each of the four replicates of air-dried sediment and allowed to grow for 45 days before harvest (Figure 7).

69. Plants in the upland EU were watered when the reading on the tensiometer was greater than 0.05. The tensiometers were monitored daily; all upland EU were maintained between 0.03 and 0.05 MPa. Temperature of the greenhouse was maintained at 90°F from 0600 hrs to 2200 hrs, and 70°F from 2200 hrs to 0600 hrs. After 45 days, the plants were cut 5 cm above the sediment surface with stainless steel scissors and placed in a plastic tray containing water. The plant leaves were swirled about in the water to remove any leaf surface adsorbed particulates. The leaves were placed in a second plastic tray filled with water and rinsed again. The leaves were removed from the water and blotted dry. One-half of the leaf tissue was put into a labeled acid rinsed

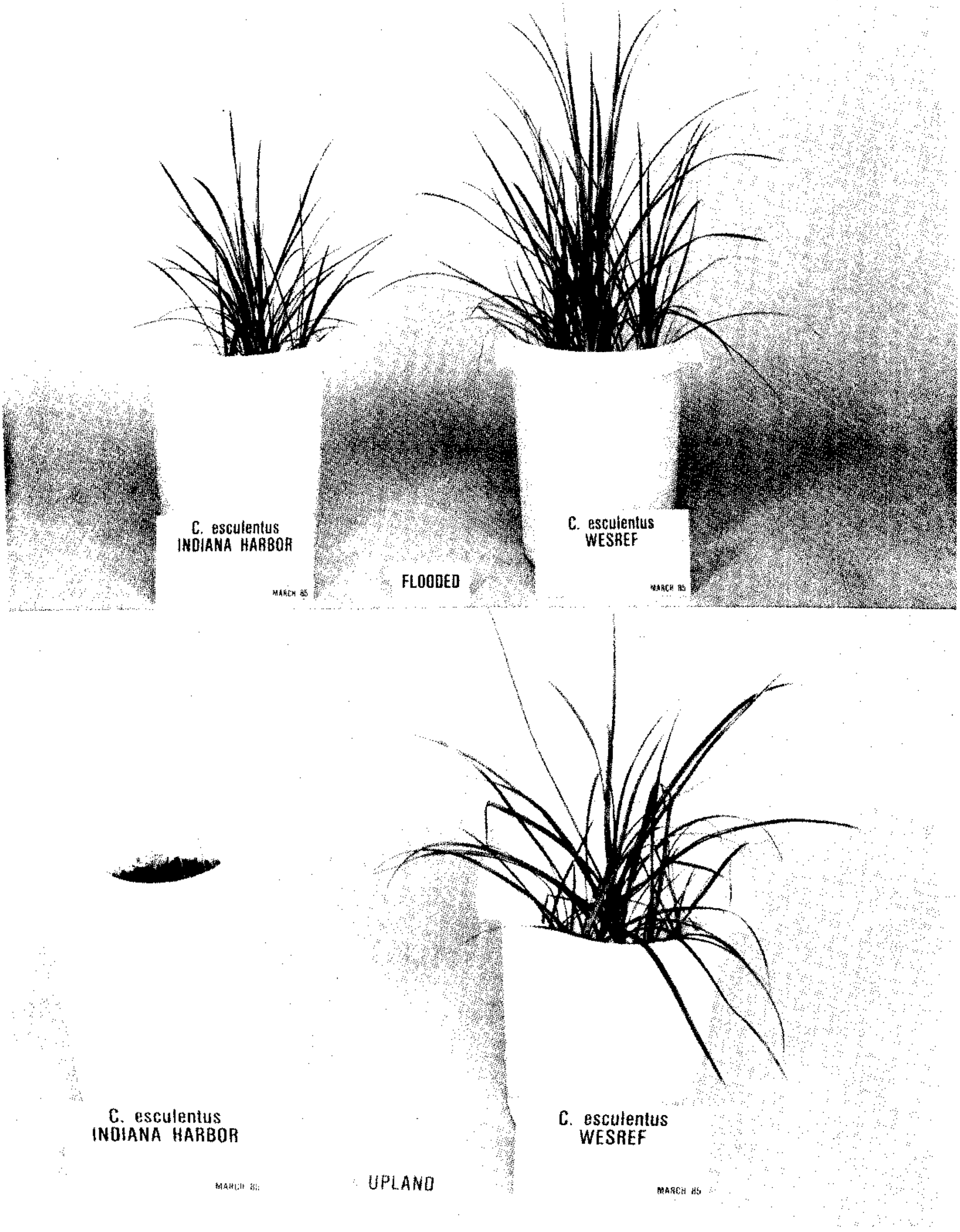

Figure 7. Plant growth of <u>Cyperus esculentus</u> on sediments from Indiana Harbor and the WES reference soil (WESREF) under flooded and upland conditions

glass jar (this tissue was to be used for organic analysis). The other half (this tissue was to be used for heavy metal analysis) was placed into a paper bag and oven-dried at 70°C until constant weight. This procedure was repeated for each EU.

70. The upland EUs did not have sufficient plant growth in each replicate to allow chemical analysis for either metals or organics. Therefore, a composite sample was made by combining the plant tissue from all four replicates to give enough tissue for subsequent analyses. The sediments were analyzed for pH, lime requirement, particle size, cation exchange capacity, and electrical conductivity. Total and Diethylenetriaminepentaaceticacid (DTPA) extractable metals were determined on both the flooded and air-dried sediments using the procedures of Folsom et al. (1981). Sediments were also analyzed for PCB, PAH, and pesticides using standard USEPA procedures (USEPA 1982). The plant tissues and sediments were analyzed for the metals zinc, cadmium, copper, iron, manganese, arsenic, mercury, nickel, chromium, and lead. Plant tissue was also analyzed for PCB, PAH, and pesticides according to procedures outlined in USEPA (1982). More detailed procedures and the data are presented in Appendix D.

71. Results. The data presented in Appendix D indicate that the sediment was originally a neutral to slightly alkaline, organic, sandy silt. Results of the sediment analysis also indicated a fairly high electrical conductivity, potentially low available nitrogen and phosphorus, and very low concentrations of unknown organics that may limit plant growth. Air-drying of the original flooded sediments resulted in reduced levels of organic matter and several of the PAH compounds. Volatile organics, such as napthalene, acenaphthalene, and acenaphthene showed over a 50 percent loss by air drying.

72. Plant growth (Figure 7) on the flooded sediments was greater than that on the upland sediment. Reduced plant growth under upland conditions

could be due to nutrient limitations, inhibition of root function by organic compounds, and/or toxic metals. Organic contaminants were not found in plant tissues and, apparently, are not being mobilized into the environment through plant uptake.

73. However, heavy metal content of plants grown on the upland sediment was generally greater than that grown on the flooded sediment and is consistent with behavior of metal uptake found in other studies (Folsom, Lee, and Bates 1981; Folsom and Lee 1981). Plant cadmium and lead were quite high in the plants grown on the upland sediments (14.5 μg/g and 47.0 μg/g, respectively). The cadmium value is above the FDA allowable level of 10 μg/g cadmium and should be cause for concern if the sediments were allowed to drain and dry out (become oxidized) and vegetation were allowed to flourish. Uptake and subsequent mobilization of cadmium and lead can be minimized by maintaining the sediment under a flooded reduced condition.

Animal bioassay

74. Procedures. An earthworm bioassay test was conducted on Indiana Harbor sediment in its original reduced state, and the sediment found to be extremely toxic to earthworms. Various treatments were conducted on the sediment to simulate aging and drying of the sediment under upland disposal conditions. Earthworm survival was not possible until the sediment was aged for 6 months in sunlight and maintained in a moist condition. The earthworms that survived were analyzed for contamination. Details of procedures and test results are described in Appendix D.

75. Results. The 6-month aging process resulted in substantial changes in the concentrations of organic compounds present in the original Indiana Harbor sediment but had relatively little effect on the metals. The concentration of 15 total PCB congeners in the aged sediment decreased to near

10 percent of their original PCB concentration. The most dramatic effect of the aging process was on the PAHs, particularly naphthalene, which dropped to about 2 percent of its original concentration. The total of all 16 PAHs analyzed dropped an entire order of magnitude, largely as the result of the loss of naphthalene.

76. The earthworms burrowed as rapidly into the aged sediment as into the manure controls. Periodic examination of the test sediment indicated that the worms actively burrowed throughout the entire volume of sediment in each cylinder and were not balled up in a state of inactivity within the cracks and air pockets. The worms remained active and no dead or moribund worms were observed on the sediment surface throughout the entire 28-day exposure period. Earthworm recovery at the end of the exposure period exceeded 95 percent in both the manure controls and the aged sediments. Tissue biomass was sufficient to allow chemical analysis of the earthworms for toxic metals, PCBs, and PAHs.

77. The concentrations of arsenic, cadmium, copper, lead, and nickel increased significantly in earthworm tissues during the 28-day exposure period, whereas, chromium, mercury, and zinc did not. Computation of concentration factors (ratios of metal concentrations in bioassay worms to those in the aged sediments), however, showed that most of the metals found in the sediments were not readily available to earthworms.

78. The uptake of PCBs by earthworms was significant during the 28-day exposure period. The earthworms accumulated PCB concentrations that were about 25 percent of those in the aged sediments. Of the 15 PCB congeners analyzed in the sediments and worms, significant bioaccumulation occurred in only one tetrachlorinated, two pentachlorinated, one hexachlorinated, and one heptachlorinated biphenyl congener. Bioaccumulation was marginally significant

($p > F = 0.0754$) in one additional tetrachlorinated congener. Other congeners were near or below detection limits in both worms and sediments.

79. The bioaccumulation of PAHs by earthworms was significant only for 5 of the 16 compounds analyzed [pyrene, benzo(b)fluoranthene, benzo(a)pyrene, and indeno(1,2,3-c,d)pyrene]. The remaining PAHs were near or below the detection limits in the worms, except chrysene, which also showed marginally significant ($p > F = 0.0701$) bioaccumulation. All PAHs which bioaccumulated significantly were present in the tissues in concentrations about 50 percent of those found in the aged sediments; these PAHs apparently were the least labile of those in the original sediments.

80. Very little is known about bioaccumulation and effects of chemicals on earthworms, except for some pesticides and metals. The initial toxicity of the Indiana Harbor sediment apparently was the result of high concentrations of the volatile (and more water soluble) organic compounds, particularly naphthalene. The presence of the metals probably did not contribute significantly to the observed worm mortality, as the concentrations of metals in both the sediments and earthworms were generally below the levels demonstrated to be toxic or to inhibit growth and reproduction of earthworms (Migula et al. 1977; Hartenstein, Neuhauser, and Narahara 1981; Malecki, Neuhauser, and Loehr 1982; Neuhauser et al. 1984). Zinc concentrations in the sediments were in the range reported to reduce reproduction by earthworms (Neuhauser et al. 1984). The presence of substantial concentrations of copper and zinc in the earthworms should be of little concern, as these metals are essential nutrients and generally are well regulated in animal tissues. Cadmium bioaccumulation may become a potential problem in the food chain, as cadmium is readily mobilized and is known to cause adverse effects at relatively low levels of exposure. The effects of PCBs and PAHs on earthworms are essentially unknown. Existing

literature indicates that metals, PCBs, and some PAHs are bioaccumulated from sediments by earthworms (Marquenie and Simmers 1984; Simmers, Lee, and Marquenie 1984; Simmers, Wilhelm, and Rhett 1984; Marquenie, Simmers, and Kay, in preparation).

81. Of immediate concern in the upland disposal of Indiana Harbor dredged material would be the potential for acute toxicity to soil invertebrates due to volatile PAHs, especially naphthalene. These compounds would be expected to decrease rapidly with time through a combination of volatilization, microbial activity, and photodegradation. Following the loss of the more labile organic compounds, the sediments possibly would be colonized by earthworms and other soil-dwelling invertebrates. Bioaccumulation of metals and the less labile organic compounds then would be the major concern, as indicated by the earthworm bioassay.

82. The results from the 6-month aging of the Indiana Harbor sediment indicate that, with time, Indiana Harbor sediment placed under confined upland conditions may become habitable and develop into a viable, productive ecosystem. This has occurred at the Times Beach disposal site at Buffalo, New York (Marquenie, Simmers, and Kay, in preparation), as well as elsewhere in the Great Lakes area. Therefore, upland disposal of Indiana Harbor sediment would require a monitoring and management strategy to address contaminant bioaccumulation as the site became biologically productive.

Summary

83. The Indiana Harbor sediments are contaminated with PCBs, an organic contaminant which is highly insoluble in water and tends to be closely bound to sediment particles. The problems associated with dredging and disposal of the

PCB-contaminated sediments were evaluated using a Management Strategy which incorporates testing protocols designed especially for dredged material. Settling, consolidation, modified elutriate, surface runoff, leachate, plant uptake, and animal uptake tests were performed and results were used to determine if control measures are appropriate. The control measures were incorporated in the evaluation of disposal alternatives presented in Part IV.

PART III: APPLICATION OF RESEARCH TECHNOLOGY

84. 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 biological 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. Depending on the disposal methods selected and the properties of the dredged material, changes in the physicochemical conditions at the disposal site may result in substantial mobilization of certain contaminants. Understanding the interactions between contaminants, dredged material properties, and physical, chemical, and biological conditions at the proposed disposal sites will permit selection of disposal methods and control measures that will minimize potential contaminant release.

85. Testing protocols required for the application of the dredged material management strategy include water quality, biological, and engineering evaluations. The testing protocols described in Part II involved methodologies which have been standardized and widely used. In order to provide data for decisionmaking in the selection of appropriate disposal alternatives and identify control measures, evaluations of leachate and surface runoff water quality were conducted. In addition, dredged material treatment alternatives in conjunction with confined disposal were evaluated. These evaluations required specific research on contaminant leaching, surface runoff, and contaminant immobilization because there either were no standardized testing protocols available or the existing protocol was too costly to be applied on a

routine basis. This research with Indiana Harbor sediments made possible the completion of several goals:

- a. A thorough evaluation of disposal alternatives for PCB-contaminated sediments from Indiana Harbor.
- b. A total application of the Management Strategy for a specific case.
- c. Initial development of testing protocols for dredged material leachate and surface runoff evaluations.

The results of this dredged material research are summarized in Part III, and the control measures for each disposal alternative discussed in Part IV.

Development of Techniques for Predicting Leachate Quality

Background

86. When the potential for adverse environmental impacts exists, disposal of contaminated material must be planned to limit these impacts by restricting contaminant mobility. To design facilities and systems necessary to satisfy site-specific requirements for environmental protection, a prime requirement is information on potential contaminant mobility. Lacking specific quantitative information on contaminant mobility, project engineers are forced to adopt contaminant containment strategies that are possibly more conservative than necessary, resulting in greatly increased costs.

87. Confined disposal is one option for Indiana Harbor dredged material. However, when contaminated dredged material is placed in a CDF, the potential exists for generating leachates that may adversely impact surface and groundwaters. At present, there is no routinely applied laboratory testing protocol capable of predicting, or even approximating, leachate quality from confined dredged material disposal sites. Testing procedures to predict leachate

quality are therefore needed to fully evaluate the confined disposal alternative for Indiana Harbor dredged material. If the CE can predict leachate quality and quantity, the potential impacts of using an in-water or upland CDF for disposal of contaminated dredged material can be determined, allowing the most cost-effective site design to be utilized.

Objective and approach

88. The objective of this phase of the Indiana Harbor study was to develop, evaluate, and apply appropriate testing procedures for estimating leachate contaminant levels from Indiana Harbor sediment for the in-water and upland CDF disposal alternatives. Laboratory evaluations of various leaching tests considered appropriate for the prediction of both short- and long-term leachate quality were conducted. These laboratory evaluations included sequential batch leach tests and permeameter testing (a modified, continuous flow column test). Results from these tests were coupled with equations describing contaminant movement in a saturated flow system. Details of these test procedures are described in detail in Appendix G.

89. The laboratory tests and mass transport equations used in this study were based on recommendations of a technical working group assembled to review methods for predicting leachate quality (Environmental Laboratory 1984). The theoretical framework developed therein provides the technical basis (systematic application of mass transport theory) for the extrapolation of laboratory leach data to a field situation. The results reported here are the first concurrent application of the laboratory procedures and the mass transport equations to a specific sediment.

Results

90. A thorough analysis of the data from all the tests conducted in this study is presented in Appendix G. The following discussion is orientated to

questions regarding the pollutant potential of Indiana Harbor sediment via leaching. Only the highlights are discussed. For a more detailed analysis of the data and an evaluation of the testing protocol, the reader is referred to Appendix G.

91. Batch testing. The intrinsic release characteristics of Indiana Harbor sediment for arsenic, cadmium, chromium, lead, zinc, PAHs, and PCBs were determined using sequential batch leach tests. Tests were also conducted to determine shaking time required to reach steady-state values, the proper liquid-solids ratio at which to conduct batch tests, and the potential for alteration of sediment release characteristics caused by changes in the oxidation status of the sediment.

92. Operational difficulties were pronounced during the batch testing because of the oil content in the sediment. During batch testing, this oil emulsified and could only be separated from the water by extensive centrifugation. The lower the liquid-solids ratio, the more centrifugation was required to break the emulsion. For example, nine centrifugations were required to completely remove oil from the anaerobic interstitial water sample for organic analysis. Oil removal was necessary because the oil was highly contaminated with PAHs and PCBs (Appendix G). Oil remaining in the leachate would therefore result in experimental artifacts that would result in extremely high organic contaminant leachate concentrations, biasing the results of the batch testing. The bias would occur because oil was not observed in leachate from the permeameters and would therefore not be expected in the field.

93. Desorption isotherms were developed using data from the sequential batch leaching tests. The sequential batch leaching tests involved exposing sediment to successive inputs of fresh distilled deionized water and analyzing

the leachate. Procedures used in the sequential batch leaching tests are summarized in Table 4. The sequential batch leaching tests were conducted using sediment maintained under anaerobic conditions and sediment that had been exposed to air for 6 months. From the desorption isotherms, the leachable contaminant concentration, q_L, and the steady-state distribution coefficients, K_d, for each contaminant were obtained. The desorption isotherms for anaerobic and aerobic Indiana Harbor sediment fall into three distinct groups, as follows:

- a. Category I. q_L is very small, i.e., $q_L < 1\%$ of the bulk sediment concentration, and $1 < K_d < 10$ (ℓ/kg).
- b. Category II. q_L is very, very small, i.e., $q_L < 0.1\%$ of the bulk sediment concentration, and K_d is approaching zero.
- c. Category III. q_L is not easy to determine, and may be large but K_d is very large, i.e., $K_d \geq 10^3$ ℓ/kg.

Category I desorption isotherms typify the desorption data obtained for metals from anaerobic sediment. A small fraction of the metals are leachable; this fraction is preferentially partitioned to the sediment, resulting in low leachate concentrations. When K_d is greater than one, the contaminant has a stronger affinity for the solid phase than for the aqueous phase. Category II desorption isotherms typify desorption data obtained for metals from aerobic sediment. A very small fraction of the metals are mobile. The leachable concentration is so small that a distribution coefficient is difficult to measure reliably. Because the leachable concentration in the sediment is so small, the leachate concentrations were near or below the detection limits. Category III desorption isotherms typify the desorption data obtained for PAHs and PCBs from both anaerobic and aerobic sediment. The releases were so low that the leachable concentration was difficult to estimate. The high distribution

Table 4

Test Sequence for Sequential Batch Leaching and Challenge Testing of Anaerobic Indiana Harbor Sediment for Metals and Organic Contaminant

STEP 1	Load sediment into appropriate centrifuge tubes: 500 m polycarbonate for metals and 450 m stainless steel for organic contaminants. Add sufficient water to each tube to bring final water-to-sediment ratio to 4:1. Sufficient stainless steel tubes must be loaded to obtain enough leachate for analysis and for use in leaching fresh sediment.
STEP 2	Shake mixtures horizontally at 160 cycles per minute for 24 hr.
STEP 3	Centrifuge for 30 min at 6500 X g for organics and 9000 X g for metals. Prior to filtering, centrifuged leachate is passed through acid-washed glass wool for metals and acetone-washed glass wool for organics. Samples for organic analysis require repetition of Step 3 using clean stainless steel centrifuge tubes to remove oil.
STEP 4	Filter leachate through 0.45- m membrame filters for metals or through a Whatman GD/F glass fiber prefilter followed by passage through a Gelman AE glass fiber filter of 1.0 m nominal pore size.
STEP 5	Set aside a small amount of leachate for analysis of pH and conductivity, then acidify leachate for organic analysis with HCl and leachate for metals analysis with Ultrez nitric acid. Store leachate for organic analysis in acetone-rinsed glass bottles and leachate for metals analysis in plastic bottles.

Note: The anaerobic integrity of the sample was maintained during sample addition to centrifuge tubes, shaking, centrifugation, and filtration during testing of anaerobic Indiana Harbor sediment.

coefficients indicate that these organics have a strong affinity for the sediment solids. In terms of leaching potential, the higher the K_d , the lower the leachate concentration that a given q_L will support. The lower the q_L , the less contaminant available for release.

94. A series of batch leaching tests was run to determine if exposure of leachate from a batch test to unleached sediment would change the intrinsic leaching characteristics of the sediment. These tests involved challenging unleached anaerobic Indiana Harbor sediment with leachate developed in batch leaching tests of anaerobic and aerobic Indiana Harbor sediment. Results indicated that distribution coefficients for metals in anaerobic leachate did not change appreciably following exposure to unleached anaerobic sediment. Exposure of leachate from aerobic sediment to unleached anaerobic sediment resulted in marginally higher distribution coefficients for arsenic, chromium, lead, and zinc.

95. Permeameter testing. Continuous flow column leaching tests were conducted in divided-flow stainless steel permeameters (Figure 8). Specific details of permeameter loading and operation are presented in Appendix G. Permeameter leaching tests were conducted using both anaerobic and aerobic Indiana Harbor sediment. One problem was encountered in conducting the permeameter leaching tests on aerobic sediment. Even after 6 months of exposure to the air, the residual sediment oxygen demand was such that the "aerobic" columns went anaerobic shortly after the test began.

96. A permeant-porous media equation was used to predict permeameter leachate quality as a function of volume throughput. The source term in the predictive equation for interphase transfer of contaminant from the dredged

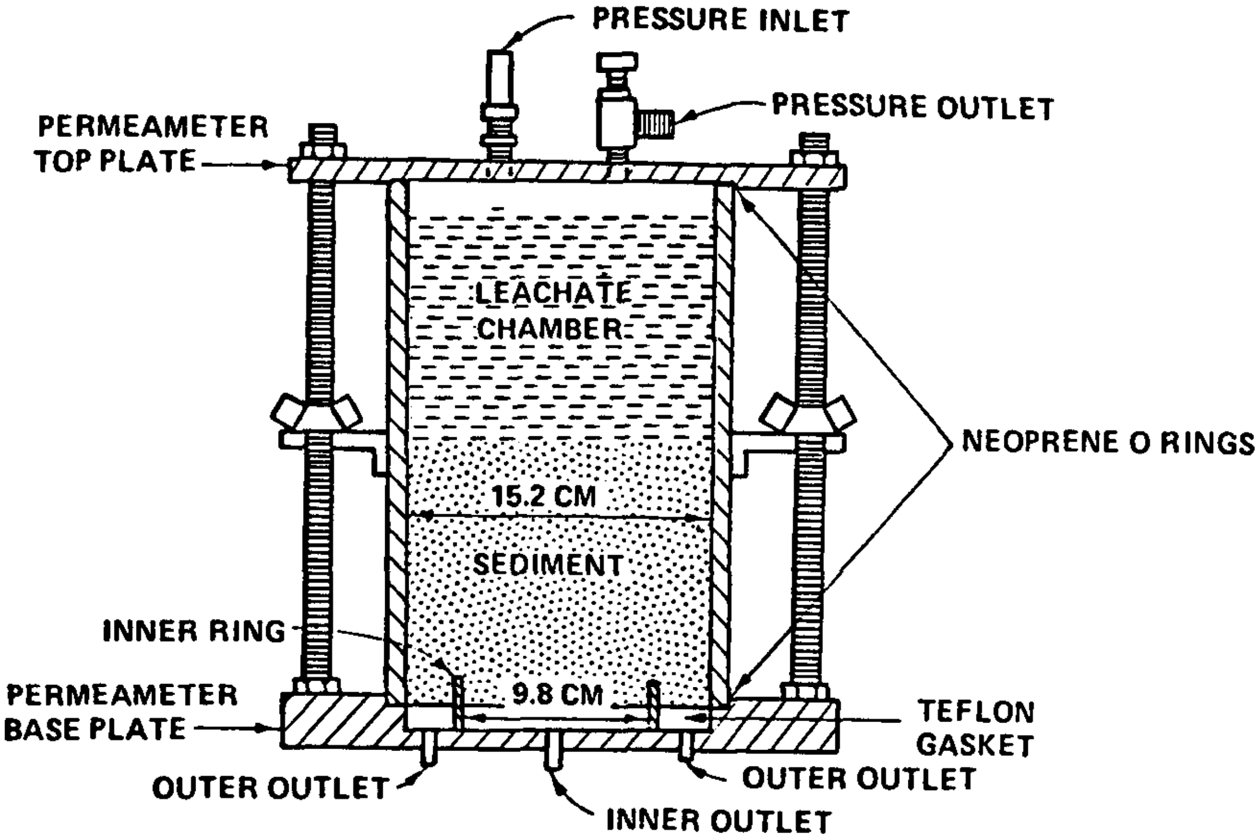

Figure 8. Divided-flow permeameter

material solids to the leachate was modeled as equilibrium-controlled, linear desorption. Details of this approach are presented in Appendix G.

97. Figure 9 shows arsenic and cadmium concentrations in leachate from the permeameters plotted as a function of cumulative pore volume for anaerobic sediment. On the same plots are shown predictive curves which were developed from an analytical solution of the permeant-porous media equation containing an equilibrium source term (Ogata and Banks 1961). Two curves are shown, one for the distribution coefficient obtained in sequential batch leach tests and one that assumes K_d is equal to zero (no desorption). The observed data from the permeameters are represented by squares. The arsenic and cadmium permeameter concentrations fall between the predictive curves, suggesting that some desorption is occurring, although to a lesser extent than predicted using batch coefficients.

98. The results presented in Figure 9 are representative of the observed and predicted anaerobic permeameter leachate concentrations for the other contaminants that were studied. Figures that compare observed to predicted anaerobic permeameter leachate concentrations for other contaminants are presented in Appendix G. The anaerobic permeameter leachate data for these contaminants are briefly described below.

99. For lead most of the observed data fall between 0.002 and 0.004 mg/ℓ. These data are too close to the detection limit to be considered significant. The observed lead concentrations were below those predicted. Similarly, for chromium most of the observed values are just above the detection limit and below those predicted. The dissolved organic carbon values also indicate that some desorption is occurring.

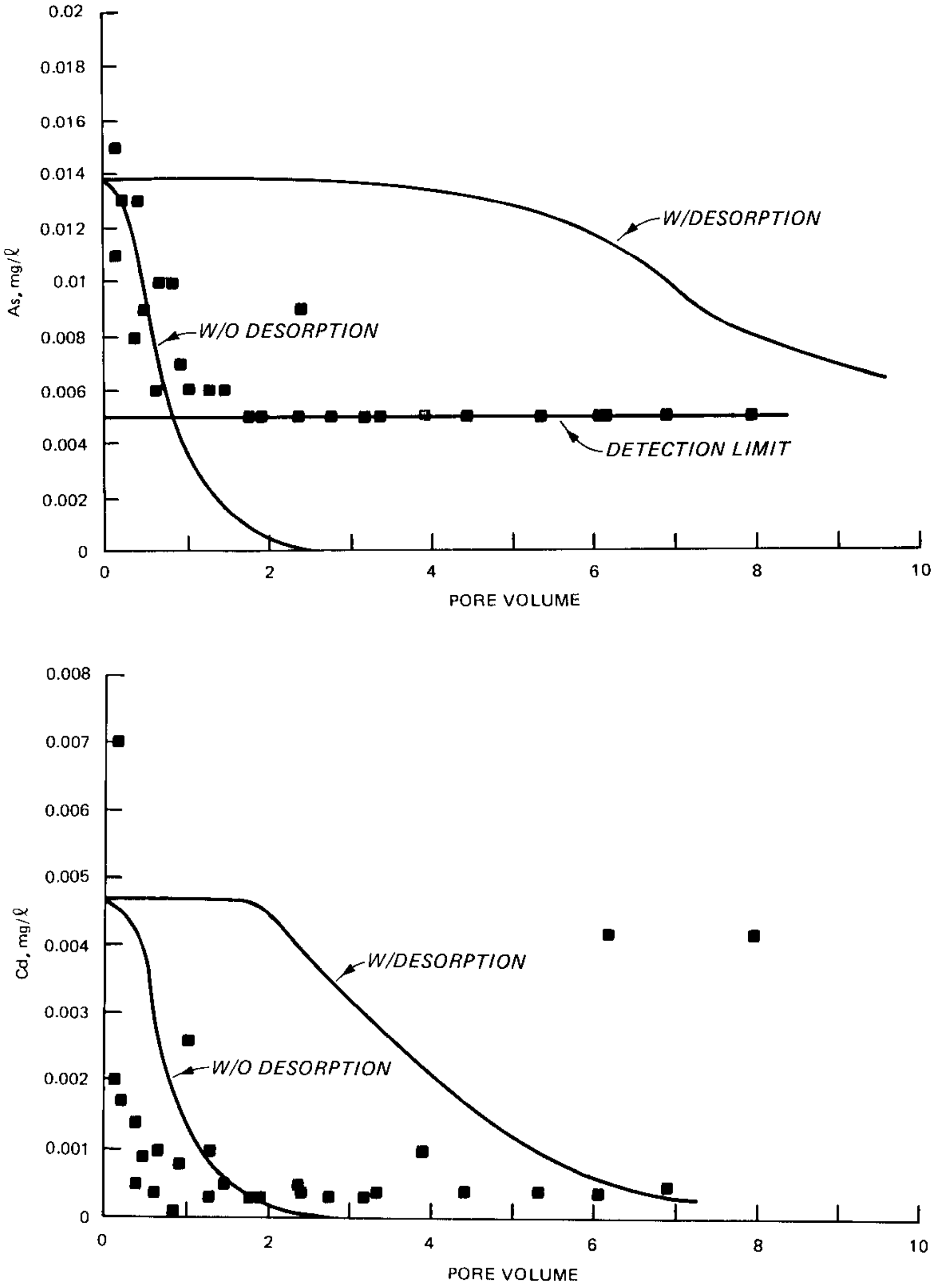

Figure 9. Comparison of arsenic and cadmium concentrations in anaerobic permeameter leachate with predicted values

100. PAHs in the permeameter effluent for anaerobic sediment were below the detection limit (0.005 mg/ℓ) in practically all of the samples analyzed. PCBs were usually below the detection limit (0.00001 mg/ℓ), but not always. Trace amounts of PCB congeners were usually present. The sequential batch data showed the PAHs and PCBs to be strongly partitioned toward the sediment phase. When the distribution coefficient determined in the batch tests is large, the leachate concentrations in continous flow systems are expected to initially take on some very low concentration and then to persist at this value. The PCB curve was somewhat nonideal in that a tendency for concentrations to decrease or wash-out was observed.

101. The effluent curves from the aerobic permeameters were not compared with the aerobic batch test results because the aerobic permeameter leach tests did not undergo equivalent leaching conditions. Due to residual oxygen demand, the "aerobic" permeameters became anaerobic soon after being placed in operation. Hence, data from the aerobic batch tests cannot be used to predict the effluent curves from a partially oxidized sediment that has gone anaerobic. It is difficult, if not impossible, to determine exactly what the "aerobic" permeameters simulate. When compared with the effluent concentrations from the anaerobic permeameters, there was no consistent difference in arsenic, chromium, lead, and PAHs. Zinc, cadmium, PCBs, and dissolved organic carbon were consistently higher in the leachate from the aerobic permeameters.

Summary

102. Batch and continuous flow leach tests showed the majority of the contaminants in Indiana Harbor sediment to be tightly bound to the sediment. Predicted and observed permeameter effluent concentrations for anaerobic metals were reasonably close (within an order of magnitude). The batch and

permeameter data showed that linear, equilibrium controlled desorption is a conservative assumption for anaerobic sediment. The fraction of metals resistant to leaching was generally greater than 99 percent for both anaerobic and aerobic sediment. The batch leaching data showed organic contaminants releases to be very low, and this was confirmed in the permeameter tests for the PAHS and most of the PCB congeners. A summary of probable maximum leachate contaminant concentrations is presented in Table 5.

Surface Runoff Evaluations

Background

103. Dredged material removed from waterways by CE construction projects may contain high concentrations of contaminants such as heavy metals, PCBs, PAHs, and pesticides. When this dredged material is placed in an upland CDF or an in-water CDF that is mounded above the water level, significant quantities of these contaminants may be discharged from the site through surface runoff if left uncontrolled. Surface runoff occurs when rainfall events deposit more precipitation on the disposal site surface than can infiltrate into the dredged material. This is especially important on dredged material where infiltration rates are usually very low compared to typical soils. The potential for contaminated dredged material causing adverse environmental impacts through surface runoff depends on several factors including the chemical form of the contaminants and the physical properties of the dredged material. Dredged material from Indiana Harbor in its original condition is anaerobic with a pH > 7. Most contaminants are tied up in the sediment solids and are insoluble and not bioavailable. Movement of contaminants in surface runoff during this period is primarily the result of sediment transport.

Table 5

Summary of Probable Maximum Leachate Contaminant Concentrations for Indiana Harbor Sediment

Contaminant	Concentration (mg/ℓ) Anaerobic	Concentration (mg/ℓ) Aerobic
Arsenic	0.034	0.016
Cadmium	0.009	0.0995
Chromium	0.195	0.013
Lead	0.370	0.055
Zinc	1.27	0.454
Total PCB	0.00054	0.0032
Total PAH	1.82	0.0674

Erosion can result in suspended solids concentrations ranging from 5,000 to 50,000 mg/ℓ in surface runoff. Concentrations of contaminants in unfiltered runoff could be very high during this period, but dissolved concentrations in filtered runoff may be very low.

104. When material is placed in a confined upland disposal site, physicochemical changes occur as the wet, anaerobic material dries and oxidizes. The extent to which these changes occur may significantly affect the surface runoff water quality, particularly the dissolved portion. As the sediment dries and oxidizes, it becomes more resistant to erosion, with suspended solids decreasing to 10 to 1,000 mg/ℓ. Unfiltered concentrations of contaminants will be several orders of magnitude less than during the wet stage. If high levels of sulfides are present in the sediment, then oxidation may cause the formation of sulfuric acid lowering the sediment pH to 4.0 where contaminants such as heavy metals become very soluble in surface runoff.

105. The WES Rainfall Simulator is a modified version of a rotating disk type rainfall simulator originally developed at the University of Arizona (Morin, Goldberg, and Seginer 1967) to simulate the kinetic energy of natural rainfall. Calibration tests showed the WES Rainfall Simulator to be extremely effective at simulating the kinetic energy (95 percent) of natural rain over a standard plot area of 5.5 sq m (4.6 m X 1.2 m). The soil lysimeters used in the WES Rainfall Simulator-Lysimeter System were constructed of aluminum with surface dimensions of 4.6 m by 1.2 m. The lysimeter depth could be adjusted in increments of 15 cm to a total depth of 1.2 m. The lysimeter slope could also be varied from 0 to 20 percent. Surface runoff water quality tests were initiated immediately after placing the dredged material in the greenhouse lysimeters using a 5 cm/hr, 30 min storm event. A second series of surface

runoff tests were then conducted 6 months later after the sediment had dried and oxidized.

106. The WES Rainfall Simulator-Lysimeter System has proven to be effective in predicting surface runoff water quality from proposed dredged material disposal sites. Material can be collected from the proposed dredging site, brought to the WES, and placed in lysimeters to simulate a confined upland disposal site (Lee and Skogerboe 1984). As the material dries and oxidizes, rainfall simulations can be conducted and the runoff water quality monitored. However, the lysimeter evaluations require highly specialized equipment, large quantities of sediment, and are relatively expensive to conduct. Therefore, a simplified laboratory test is required that will be easy, relatively inexpensive, and can be conducted by CE laboratories to screen sediments that may cause adverse environmental impacts. When a sediment is found to have the potential for causing environmental problems, then the sediment may be brought to the WES for more extensive tests to determine the magnitude of the problem.

107. The WES has selected several laboratory procedures from the published literature and applied them to the Indiana Harbor sediment. These procedures include air drying the sediment for various lengths of time, oven drying, a DTPA extract, and peroxide extract. The purpose of these tests is to duplicate, as closely as possible, the natural drying and oxidizing of sediment placed in an upland environment. The air-dried and oven-dried tests will determine how quickly a small amount of sediment can naturally be dried and oxidized. The DTPA extract has proven to be very useful in predicting the availability of several heavy metals in plants (Lee, Folsom, and Bates 1983). The peroxide test was originally developed as a test for quickly oxidizing pyrite in acid mine spoils to determine potential soil acidity and lime requirements (Barnhisel 1976).

Predicted surface runoff water quality

108. Wet, anaerobic sediment. Potential runoff water quality problems during the wet, anaerobic sediment stage will result primarily from heavy metals and PAHs (Table 6). The only PCB found above detectable limits in either the sediment or runoff analysis was PCB-1248. The pesticide DDE was detected in the filtered portion of the runoff, but was extremely low. The SS concentrations in the surface runoff were high with an average of 6,600 mg/ℓ and a range of 2,000-12,000 mg/ℓ. Runoff pH and conductivity values were normal for freshwater sediment during the early stages of drying.

109. High concentrations of PAHs were found in the bulk sediment analysis (Table 2). Naphthalene had the highest sediment concentration at 2000 μg/g, and the remaining PAHs varied from 22 to 200 μg/g. Unfiltered runoff concentrations of PAHs mirrored the sediment concentrations. Unfiltered concentrations of all PAHs were high at 18 mg/ℓ and several individual PAH values exceeded 1 mg/ℓ. Naphthalene had the highest unfiltered runoff concentration of 6.91 mg/ℓ. Filtered PAHs were detected mostly in the lower molecular weight PAHs (naphthalene through phenanthrene), and solubility seemed to decrease with increased molecular weight. Unfiltered metal concentrations in surface runoff also mirrored sediment concentrations. Filtered metal concentrations were significantly lower than unfiltered concentrations.

110. The results indicated that contaminants in surface runoff from wet, anaerobic Indiana Harbor sediment were in poorly soluble forms and were generally dependent on runoff SS concentrations. However, because of the

Table 6

Lysimeter Surface Runoff Water Quality During Early, Wet, Unoxidized Stage

Parameter	Mean Unfil. Runoff Conc. mg/ℓ	Mean Filt. Runoff Conc. mg/ℓ	USEPA Maximum Criteria
pH	7.64	7.66	NA*
Conductivity** S/m	0.0052	0.0052	NA
SS	6,600	NA	NA
DDE	<0.00001	0.00004	NA
PCB-1248	0.096	0.0015	0.014
PAHs	18.03	0.148	NA
Naphthalene	6.91	0.115	NA
Acenaphthylene	0.212	<0.005	NA
Acenaphthene	0.857	0.0131	NA
Fluorene	0.780	0.010	NA
Phenanthrene	1.67	0.0097	NA
Anthracene	0.494	<0.005	NA
Fluoranthene	1.57	<0.005	NA
Pyrene	1.35	<0.005	NA
Chrysene	0.853	<0.005	NA
Benzo(a) anthracene	0.787	<0.005	NA
Benzo(b) fluoranthene	1.12	<0.005	NA
Benzo(k) fluoranthene	1.12	<0.005	NA
Indeno(1,2,3-C D) pyrene	0.194	<0.005	NA
Dibenzo(A H) anthracene	<0.010	<0.005	NA
Benzo(G H) perylen	0.124	<0.005	NA
Heavy Metals			
Cadmium	0.154	0.0021+	0.0015-0.0024
Copper	1.79	0.0237+	0.012-0.043
Nickel	0.707	0.0297	1.1-3.1
Zinc	30.9	0.360 +	0.180-0.570
Manganese	9.04	0.0170	NA
Chromium	4.06	0.0567	2.2-9.9
Lead	6.80	0.0670	0.074-0.400
Iron	627	1.39	NA
Mercury	0.0037	<0.0002	0.0017
Arsenic	0.232	<0.005	0.440

* NA = Standards not available.

** S/m = Siemans per mieter = 0.1 X mmhos per centimetre.

\+ Concentrations eqal or exceed USEPA Maximum Water Quality Criteria Protection of Aquatic Life.

extremely high concentrations of contaminants present in the sediment, particularly PAHs and heavy metals, significant amounts of contaminants were also present in the filtered portion of the runoff.

111. *Dry, oxidized sediment*. As the Indiana harbor sediment dried and oxidized, physicochemical changes occurred. Sediment moisture was lowered from 35 percent to 5 percent, and the sediment became very hard with extensive cracking occurring. The sediment pH also decreased to an average of 6.3. These changes had a significant effect on surface runoff water quality. Suspended solids concentrations decreased to an average of 56 mg/ℓ, ranging from about 20 to 200 mg/ℓ. Surface runoff pH also decreased to 6.3, similar to the sediment pH.

112. Unfiltered concentrations of organic compounds were measurable in only four PAHs. No PCBs were detected and only naphthalene was significantly above the detection limit of 0.005 for PAHs. Filtered PAH compounds were detected for only naphthalene and phenanthrene and appeared to be equal to the unfiltered concentrations. Unfiltered concentrations of organic compounds decreased by an amount greater than the unfiltered concentrations of heavy metals. This is in part the result of volatile loss of PAH's in the dried sediments (see discussion of volatilization in Appendix G).

113. Unfiltered heavy metal concentrations declined significantly from the wet stage due to the decrease in SS concentrations (Table 7). Average concentrations decreased by about two orders of magnitude. Filtered concentrations, however, increased due to the physicochemical changes that occurred. Filtered concentrations of cadmium, copper, nickel, zinc, and manganese were statistically equal to the unfiltered concentrations, indicating that these

Table 7

Lysimeter Surface Runoff Water Quality During Dry, Oxidized Stage

Parameter	Mean Unfil. Runoff Conc. mg/ℓ	Mean Filt. Runoff Conc. mg/ℓ	USEPA Maximum Criteria
pH	6.3	6.3	NA*
Conductivity Sm	4.9	NA	NA
SS	56	NA	NA
PCB-1248	<0.0002	<0.0002	0.014
PAH			
Naphthalene	0.025 A	0.023 A	N
Acenaphthylene	<0.005	<0.005	N
Acenaphthene	<0.005	<0.005	N
Fluorene	<0.005	<0.005	N
Phenanthrene	0.0069 A	0.0056 A	N
Anthracene	<0.005	<0.005	N
Fluoranthene	0.0067	<0.005	N
Pyrene	0.0061	<0.005	N
Chrysene	<0.005	<0.005	N
Benzo (a) anthracene	<0.005	<0.005	N
Benzo (b) fluoranthene	<0.005	<0.005	N
Indeno-1,2,3,_C D pyrene	<0.005	<0.005	N
Benzo (g h i) perylene	<0.005	<0.005	N
Heavy metals			
Cadmium	0.0011	0.0026 **,+	0.0015-0.0024
Copper	0.054	0.072 **,+	0.012-0.043
Chromium	0.027	0.0043	0.021
Nickel	0.038	0.046 **	1.1-3.1
Zinc	0.34	0.53 **,+	0.180-0.570
Manganese	0.28	0.40 **	NA
Lead	0.032	0.008 **	0.74-0.400
Iron	5.74	0.041	NA
Mercury	<0.0002	<0.0002	0.0017
Arsenic	<0.005	<0.005	0.440

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* NA = No values available.

** Filtered concentrations are not statistically significantly different from unfiltered concentrations.

\+ Concentrations exceed USEPA Maximum Water Quality Criteria for Protection of Aquatic Life.

metals were mostly soluble. The solubility of chromium and lead also increased significantly but were not as soluble as the other metals. Iron concentrations were relatively high, but still were less than 1 percent soluble.

Potential problems

114. Wet, unoxidized sediment. Filtered runoff concentrations were compared to the USEPA Water Quality Criteria for the Protection of Aquatic Life. Filtered concentrations of PCBs were below USEPA criteria; however, several heavy metals were equal to or slightly above USEPA criteria (Table 6). Concentrations of zinc, cadmium, and chromium were in the range of USEPA criteria, however, none of the contaminants were significantly greater. Any dilution of discharged runoff from the disposal site will reduce soluble concentrations of contaminants to below the USEPA criteria. Surface runoff water from Indiana Harbor dredged material was also compared to the Lake Michigan water quality standards for lead and PCB which were less than the USEPA criteria (lead = 0.00005 ppm and PCB = 0.000001 ppm). These Indiana Lake Michigan water quality criteria were exceeded by surface runoff water from the Indiana Harbor dredged material during the wet, anaerobic stage and therefore could require some control measures, restrictions or consideration of a mixing zone.

115. Contaminants in surface runoff water were present in poorly soluble forms closely associated with the particulates (Table 6) for which no criteria exist. The USEPA Criteria for the Protection of Aquatic Life and the Lake Indiana Michigan Water Quality Criteria were based on filtered or dissolved data and thus should only be compared to filtered concentrations. Unfiltered

concentrations of PCBs, cadmium, copper, zinc, manganese, chromium, lead, iron, mercury, and arsenic were high and of concern so that restrictions for controlling the movement of SS from an upland disposal site should be investigated.

116. Dry, oxidized sediment. Filtered concentrations in surface runoff from dry, oxidized sediment were also compared to the USEPA Maximum Water Quality Criteria for the Protection of Aquatic Life (Table 7). The metals cadmium, copper, nickle, zinc, manganese, and lead were present primarily in the dissolved form, and of these, cadmium, copper, and zinc, were equal to or greater than the USEPA maximum criteria. Surface runoff water during the dry, oxidized stage equaled or exceeded the Indiana Lake Michigan water quality criteria for lead, but because the criteria for PCB were below the detection limits for surface runoff analysis, it was unkown whether the surface runoff exceeded this criteria after drying and oxidation. Other heavy metals in surface runoff that equaled or exceeded the Indiana Lake Michigan criteria were zinc and manganese from the dry, oxidized dredged material.

117. Surface runoff water quality tests were conducted on the Indiana Harbor sediment in the dry, oxidized stage, while the sediment was hard and cracked into large blocks. With time these hard blocks could be weathered and broken apart. If this occurs, the material will become more erodible during storm events, thereby increasing the SS concentrations in the runoff. The SS would also increase both the unfiltered and filtered concentrations of contaminants in the surface runoff. Past tests under the Field Verification Program (FVP) indicate that contaminant concentrations could be increased by 10-20 times. The erodibility of the dried sediments would be greatly limited

if they became vegetated. Dense vegetation is commonplace on dried dredged materials, and usually has to be controlled rather than promoted. Additional restrictions on the dissolved portions of the surface runoff from Indiana Harbor sediment may, therefore, be required if the sediments are dried and vegetation is restricted for whatever reason. The availability of an appropriate mixing zone should be considered prior to the implementation of surface runoff treatment. If an appropriate mixing zone is not available, then treatment of surface runoff should be investigated.

Laboratory tests as an alternative to the rainfall simulator-lysimeter tests

118. Based on the laboratory test results from this study presented in Appendix E, an extraction procedure, utilizing hydrogen peroxide, can estimate the physicochemical changes that occur in a dredged material when it is dried and oxidized. This extraction procedure used peroxide to quickly oxidize a sediment which could require at least 6 months by natural means. Filtered concentrations from wet, anaerobic dredged material can be estimated using the simple water sediment dilution method. Further refinement and testing of the hydrogen peroxide procedure will greatly improve its accuracy and reliability. Additional verification on several different types of dredged material is required before this procedure can be widely used as a standard procedure for predicting surface runoff water quality from contaminated dredged material. These verification tests should include both freshwater and estuarine dredged material as well as dredged material with a wide range of particle size distributions and organic matter contents.

Summary

119. During the early, wet, anaerobic stages, contaminants were mostly bound to the SS in the surface runoff and occurred mostly in the unfiltered samples. Filtered concentrations during this period were low compared to the unfiltered concentrations, but would still be of concern when compared to the USEPA Maximum Criteria for the Protection of Aquatic Life or Lake Michigan Water Quality Standards. As the sediment dried, the SS concentrations decreased, thereby decreasing the unfiltered contaminant concentrations. Results of the lysimeter tests represented the worst possible case that could occur during the wet, anaerobic stage. Control measures during this period should concentrate on control of the SS in the surface runoff after considering an appropriate mixing zone outside of the disposal site. If an appropriate mixing zone does not exist, control measures such as the use of sedimentation basins, control structures, filters, or chemical flocculants should be considered.

120. After the sediment dried and oxidized, the surface runoff water quality constituents of concern changed. Organic compounds were not a problem during this stage since most of the compounds had been lost from the sediment due to volatilization into the atmosphere or adsorption to soil particles. Some naphthalene was present in both the filtered and unfiltered samples, but the total PAHs were very low. No PCBs were detectable in runoff from the dry, oxidized sediment. Heavy metals did, however, continue to be a potential problem. Filtered concentrations of the metals cadmium, copper, nickel, zinc, manganese, and lead were not statistically different from the unfiltered concentrations. These metals were present in soluble forms which are more difficult to control. Chromium also increased in solubility, but not to the extent

of the other metals. Filtered concentrations of cadmium, copper, zinc, and lead were high enough to be of concern, as they were greater than or equal to the USEPA criteria or Indiana Lake Michigan water quality criteria. As the sediment continues to age, hard aggregate chunks will weather and break apart. Concentrations of SS will probably increase by as much as 10 to 20 times as the material becomes more erosive. Concentrations of filtered and unfiltered metals should increase by similar amounts. Therefore, some type of restriction or control measure should be considered, or a mixing zone should be considered if the sediment is placed in an upland environment. Control measures might include soil amendments, vegetating the site, capping, or runoff treatment.

Contaminant Immobilization Research

Background

121. Because of sediment contamination in parts of the Indiana Harbor Canal, innovative contaminant immobilization techniques may be needed in order to satisfy site-specific environmental constraints for disposal. One promising technique is solidification/stabilization. Solidification/stabilization is an emerging technology for producing stable solids with improved contaminant isolation and containment characteristics. Contaminant immobilization research as applied to sediment from Indiana Harbor Canal refers to the application of solidification/stabilization technology and this technology's capability to eliminate or significantly reduce the pollutant potential of contaminated dredged material from Indiana Harbor.

122. Solidification is the process of eliminating the free water in a semi-solid by hydration with a setting agent(s). Typical setting agents include portland cement, lime, fly ash, kiln dust, slag, and combinations of these materials. Co-additives such as bentonite, soluble silicates, and other materials are sometimes used with the setting agents to give special properties to the final products. Stabilization can be both physical and chemical. Physical stabilization refers to improved engineering properties such as bearing capacity and trafficability. Chemical stabilization is the alteration of the chemical form of the contaminants to make them less soluble and/or less leachable. Solidification usually provides physical stabilization but not necessarily chemical stabilization.

123. Since physical stabilization and solidification are equivalent in terms of the end products, the terms are often used interchangeably, with solidification being the more commonly used term. The literature also uses the terms "chemical stabilization" and "stabilization" interchangeably, albeit not without some confusion. In this report, physical stabilization and chemical stabilization are discussed together as solidification/stabilization technology. Unless otherwise noted, the term "solidification/stabilization" refers to physical/chemical stabilization. Where appropriate, contaminant immobilization is described as primarily physical stabilization, chemical stabilization, or a combination of physical and chemical stabilization.

124. Solidification (physical stabilization) immobilizes contaminants through alteration of the physical character of the material. The development of structure immobilizes contaminated solids, i.e., the solid mass is dimensionally stable, and the solids do not move. Since most of the contaminants

in dredged material are tightly bound to the sediment phase, solidification is an important immobilizing mechanism (Kita and Kubo 1983). Solidification also reduces the accessibility of water to the contaminated solids within a cemented matrix. Water accessibility to the contaminated solids is an important factor because it partially determines the rate at which contaminants are leached.

Objective and approach

125. The objective of the contaminant immobilization research was to investigate the technical feasibility of reducing contaminant mobility in Indiana Harbor sediments using solidification/stabilization technology. The technical approach consisted of laboratory-scale applications of selected solidification/stabilization processes to Indiana Harbor sediment, and an evaluation of the solidified/stabilized products on the basis of physical and chemical properties.

Solidification/stabilization processes

126. Solidification/stabilization processes are characterized by the type of setting agent(s) used. The processes selected for this study were portland cement, portland cement with fly ash, portland cement with fly ash and/or sodium silicate, Firmix (a proprietary additive), portland cement with Firmix, Portland cement with WEST-P (a proprietary polymer), Firmix with WEST-P and fly ash with lime. There are several commercially available solidification/stabilization processes in the United States that use one or more of these setting agents (Malone and Jones 1979; Malone, Jones, and Larson 1980). Most of the processes are either patented or use proprietary formulations of the various setting agents.

127. The proprietary additive Firmix is a low-cost, commercially available setting agent. The proprietary polymer WEST-P was obtained from Philip W. West, retired Professor of Chemistry, Louisiana State University. The polymer is still in the research and testing stage of development and is not commercially available at this time. The polymer is designed to immobilize contaminants by adsorption.

Results

128. Physical stabilization. Certain chemicals interfere with the setting reactions responsible for the development of hardened mass (Jones et al. 1985). Interferences by waste constituents are poorly understood in terms of the range of chemicals that interfere, the threshold concentrations at which they begin to interfere, and the specific mechanism(s) by which they interfere. For these reasons, knowledge of the chemical characteristics of a sediment is not enough to design a process formulation. It is, therefore, necessary to conduct laboratory testing in order to evaluate the effectiveness of various processes.

129. The laboratory data on physical properties (Appendix H) indicated that Indiana Harbor sediment can be effectively solidified by a variety of processes and that the contaminants in the sediment do not seriously interfere with the setting reactions. Various physical tests (unconfined compressive strength, trafficability, and permeability) were selectively run on products from various processes. Unconfined compressive strength (UCS) was used as the key indicator of physical stabilization.

130. The range in 28-day unconfined compressive strength was 48.5 psi (33 kPa) to 682 psi (4700 kPa) for the processes not involving sodium

silicate. Higher strengths were obtained using portland cement with sodium silicate and portland cement with fly ash and sodium silicate. The UCS data for the processes involving sodium silicate were provided by the PQ Corporation and are presented in Table 8. Depending on the agent(s) used for solidification and the dosage applied, there are trade-offs between the cost of the setting agent(s) and the quality of the product. Portland cement is a top quality setting agent that provides a product with excellent physical stability. Other processes using less expensive setting agents provide products that are solidified but are not as physically stable as a portland cement product.

131. During the course of testing, one potential problem was encountered. Retardation in set time was observed with some of the setting agents. Time for strength development for the Firmix process was slow as compared with the rate normally encountered with that process for clean sediments. With uncontaminanted sediments, the Firmix process sets in about 30 days; with sediment from the Indiana Harbor Canal, the set time was about 60 days. Strength versus cure time curves for the fly ash with lime process also indicated delayed set beginning about day 28. Additional testing is needed to determine if delayed setting is significant. If delayed setting is found to be significant, then trade-offs between delayed setting with low cost additives versus rapid set with high cost additives is another factor to consider.

132. Chemical stabilization. Chemical leach tests were conducted to evaluate the chemical stability of solidified/stabilized samples of Indiana Harbor sediment. Serial, graded batch leach tests (Houle and Long 1980) were used to develop desorption isotherms. The leaching tests are described in Appendix H. From the desorption isotherms, coefficients for contaminant

Table 8

28-Day Unconfined Compressive Strength for Portland Cement with Sodium Silicate and Portland Cement with Fly Ash and Sodium Silicate Solidification of Indiana Harbor Sediment

Process* Weight Ratios	Unconfined Compressive Strength** psi
PC/FA/SS/S (0.1/0.1/0.05/1)	1,223
PC/FA/SS/S (0.2/0.1/0.05/1)	1,662
PC/FA/SS/S (0.25/0.25/0.05/1)	1,395
PC/SS/S (0.25/0.05/1)	1,930
PC/SS/S (0.5/0.05/1)	2,070

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* PC = portland cement.
FA = fly ash.
SS = sodium silicate.
S = Indiana Harbor sediment.

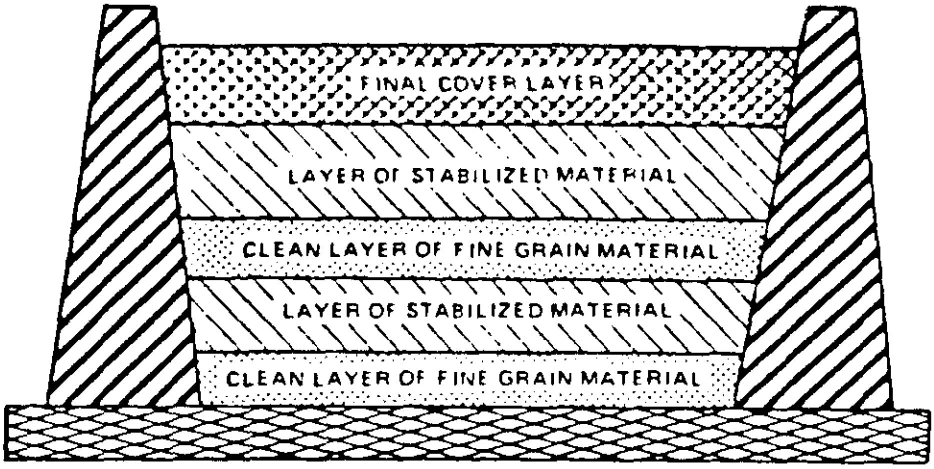
** Data provided by PQ Corporation, Valley Forge, PA.

release were determined for comparison to those obtained for untreated sediment. Most of the solidification/stabilization processes effectively reduced contaminant mobility, in particular the leachability of metals. Cadmium and zinc were completely immobilized by some processes. The processes involving Firmix and WEST-P were among the best. The fly ash with lime process in some cases actually increased the concentrations of leachable contaminants. Solidification/stabilization did not significantly alter the sorption capacity of the sediment for organic carbon. Data were not available to evaluate the potential of solidification/stabilization technology to reduce the leachability of specific organic compounds. Because some solidification/stabilization agents tend to increase the leachable contaminant concentration, careful process selection is needed to maximize chemical stabilization.

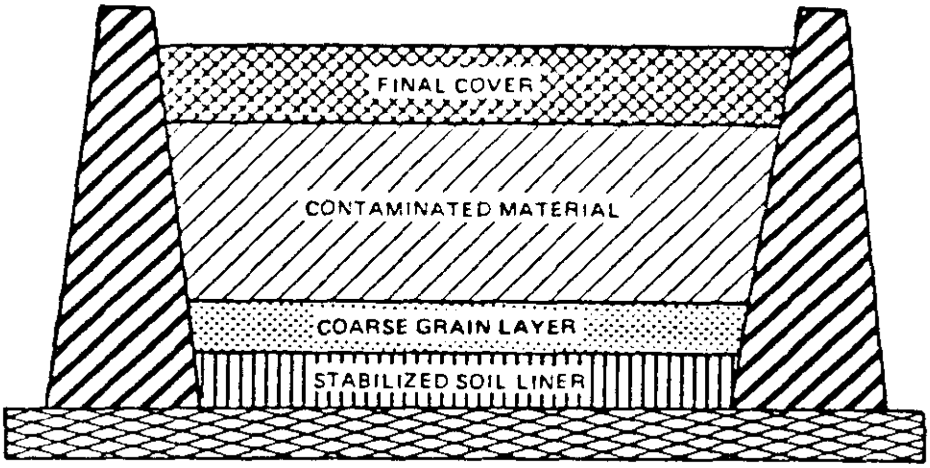
Implementation strategies

133. Disposal concepts. Solidification/stabilization technology can potentially be implemented in a variety of ways. Three concepts for implementing solidification/stabilization technology are considered applicable to confined upland disposal (Francingues 1984). These concepts are shown in Figure 10.

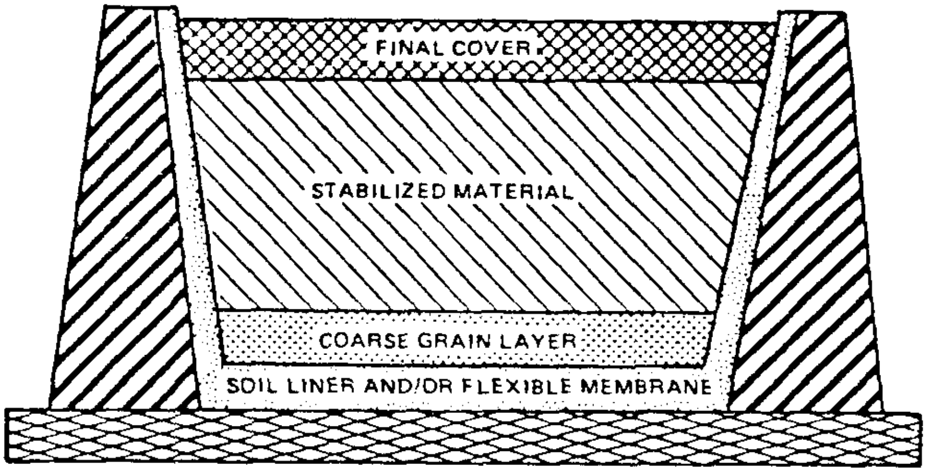
134. The "layered" concept (Figure 10a) involves alternating layers (thin lifts) of relatively clean dredged material and contaminated dredged material that is solidified/stabilized. The initial lift of clean, fine-grained sediments would be dewatered to promote densification and consolidation to provide a low permeability soil layer or foundation for the containment area. Once this layer has achieved the desired degree of consolidation and permeability, the contaminated material would be placed on top, dewatered, and solidified/stabilized in-situ. This layering process provides layers of clean material



a. DISPOSAL CONCEPT "A" ALTERNATING LAYERS OF STABILIZED MATERIAL



b. DISPOSAL CONCEPT "B" STABILIZATION FOR LINER SYSTEM



c. DISPOSAL CONCEPT "C" STABILIZATION IN SECURE FACILITY

Figure 10. Implementation concepts for solidification/ stabilization of Indiana Harbor sediment

that can adsorb contaminants in leachate draining from the contaminated layers during disposal. As an alternative, freshly solidified/stabilized dredged material from a processing facility would be placed on top of the clean material. Conventional earthmoving equipment would be used for shaping as necessary before the material hardened.

135. The "liner" concept (Figure 10b) incorporates soil stabilization (physical stabilization) as a treatment to produce a low permeability foundation. The low permeability liner provided by soil stabilization is used to contain leachate generated from the dewatering and long-term disposal of the contaminated dredged material. Appropriate setting agents are added and mixed with the disposal site soil. Then a layer of coarse material is added above the stabilized layer to facilitate dewatering and collection of leachate. The contaminated dredged material is then disposed and dewatered. A clean layer of dredged material is used as final cover. One modification to this concept would be the additional step of solidifying/stabilizing the contaminated dredged material to further protect against contaminant escape.

136. The final concept illustrated in Figure 10c, "secure disposal", provides the highest degree of environmental protection. A soil or flexible membrane liner, or both, is used to line the bottom and sides of the disposal site. Then a coarse-grained layer is used to facilitate dewatering and leachate collection. The contaminated sediment is disposed into the lined site, dewatered, and solidified/stabilized. An alternative would be to apply solidification/stabilization in a processing facility prior to placement of material in the confined disposal site. Capping would be accomplished in accordance with the intended utilization of the site.

137. Additive mixing. The implementation of onsite solidification/stabilization technology can also be classified according to the manner in which the setting agents are added to and mixed with the dredged material. Three basic onsite methods of agent addition and mixing are available (Francingues 1984). These are in-situ mixing, plant mixing, and area mixing.

138. In-situ mixing is suitable for dredged slurries that have been initially dewatered. In-situ mixing is most applicable for the addition of large volumes of low reactivity setting agents. This method incorporates the use of conventional construction machinery, such as a backhoe, to accomplish the mixing process. Where large containment areas are being treated, clamshells and/or draglines may be used. Data are not currently available on the mixing efficiency of the in-situ process when applied to field-scale projects.

139. An alternative to back-hoes, clamshells, and draglines involves setting agent(s) addition and mixing by injection. Specially designed equipment is commercially available that injects and mixes setting agents with the materials to be solidified/stabilized. The system moves laterally along the perimeter of a facility solidifying the material within reach of the injection boom. As soon as one pass is completed and the material has set long enough to support the injection carrier, the process is repeated. The equipment advances in this manner until the job is complete.

140. Plant mixing is most suitable for application at sites with relatively large quantities of contaminated materials to be treated. In the plant-mixing process, the dredged material is mechanically mixed with the setting agents in a processing facility prior to disposal in a prepared site. If the volume of material to be processed does not justify the expense of a mixing plant, one alternative is to mix the solidification/stabilization

agents with the dredged material in a scow before it is unloaded. Mixing may be accomplished enroute to a docking site using a specially designed system mounted on the scow for this purpose, or by using a shore based injection system. In the latter, track mounted injection equipment would move along the dock and reach all parts of the scow. Solidifying agent in a dry state is piped directly from a tank truck to the injector. Since the setting process takes several days before freshly prepared solidified/stabilized dredged material is hardened and cannot be reworked, the risk of having the material set-up before it can be removed from the scow is minimal.

141. Area-wide mixing is applicable to those confined disposal sites where high solids content slurries must be treated, and thus is not applicable to dredged material that has not been dewatered. The term "area-wide mixing" is used to denote the use of rotovators and agricultural-type spreaders and tillers to add and mix the setting agent(s) with the dredged material. Area-wide mixing is land-area intensive, requiring a relatively large land area to carry out the process. Area-wide mixing strategies present the greatest possibility for fugitive dust, organic vapor, and odor generation. The typical area-wide mixing strategy will require that the dredged material be sufficiently dewatered to support construction equipment.

Limitations

142. Careful process selection involving laboratory tests is needed to maximize physical and chemical stabilization because some constituents in contaminated dredged material may interfere with the setting reactions responsible for the development of hardened mass (Jones 1985). The performance expected from solidified/stabilized dredged material can be evaluated using

laboratory tests. Information on several important aspects of field application, however, is not readily available. Therefore, field testing and evaluation are needed to address mixing efficiency and scale-up factors, long-term stability of solidified/stabilized dredged material, and construction procedures and quality control before full-scale application will be practical.

Cost

143. Actual project cost data for solidification/stabilization of dredged material are not available. Application of the technology to industrial waste is estimated to cost \$30 to \$50 per ton (Cullinane 1985). Actual cost will vary with the amount of setting agent(s) and the retention of water normally removed by drying and/or consolidation. Setting agents may represent 25 to 150 percent of the dredged material (wet) volume. As a result, a much larger area/volume is required to hold the solidified/stabilized dredged material.

Summary

144. Solidification/stabilization offers a variety of contaminant immobilization alternatives for the design engineer to choose. Evaluation of the physical properties of solidified/stabilized products for selected processes showed that sediment from Indiana Harbor Canal can be physically stabilized by a variety of solidification/stabilization processes (Appendix H). There are no major technical obstacles, such as chemical interference, when applying solidification/stabilization technology to Indiana Harbor sediments. The technology has the flexibility and versatility to meet specifications for physical stability ranging from primarily immobilizing sediment solids in a low strength product to producing a material suitable for end-uses typical of low strength concrete. The chemical leach data (Appendix H) showed that

solidification/stabilization of Indiana Harbor sediment reduced the mobility of some contaminants, depending on the type of setting agent(s) and additive dosages used. The mobility of most metals was reduced, while the mobility of organic carbon was not different from the untreated sediment. The economic feasibility of solidification/stabilization is probably affected as much by the implementation strategy that is selected as it is by the unit cost for additives and increased volume requirements.

145. The contaminant immobilization strategies discussed in this report embody solidification/stabilization techniques that are state-of-the-art for improving the environmental quality of upland disposal of dredged material. Due to the developmental nature of the technology, additional testing and evaluation are recommended before the technology is applied full-scale. Additional testing and evaluation should address scale-up factors, long-term stability of the solidified/stabilized product, immobilization potential for selected organic contaminants such as polychlorinated biphenyls, construction procedures, quality control, and engineering economy.

PART IV: EVALUATION OF ALTERNATIVES

146. Disposal alternatives to be considered in this part include no-action, approved TSCA methods, contained aquatic disposal, and confined disposal. The evaluations made are based on the results of laboratory testing of Indiana Harbor sediments, site investigations, existing information on sediment and site conditions, information from District personnel, experience and knowledge gained from dredged material research programs, and innovative technologies from domestic and foreign sources. Information and data from these sources were compiled and evaluated to provide the Chicago District with sufficient information for choosing an appropriate disposal alternative for the PCB-contaminated sediments in Indiana Harbor.

147. The no-action alternative is evaluated in terms of effects on water quality resulting from leaving the sediments in-place. The evaluation of the TSCA-approved techniques includes separate evaluations of incineration and placement of the sediment in a chemical waste landfill. These evaluations are performed at a conceptual level for purposes of establishing comparative costs.

148. The Management Strategy has been applied to the PCB-contaminated sediments from Indiana Harbor in order to organize the evaluation of dredging and disposal alternatives in a logical framework. Preliminary evaluation has eliminated one alternative: unconfined disposal to open-water. This has been followed by a structured sequence of testing protocols. The next step in the application of the Management Strategy (Figure 4) is to determine the technical feasibility of the remaining disposal alternatives and determine control measures required for implementation. The need for control measures was determined by comparison of test results with applicable standards or

criteria. The selection of appropriate control measures is dependent on the nature and level of contamination, site-specific conditions, economics, and socioeconomic conditions.

Evaluation of the In-Place Effects of Bottom Sediments from the Grand Calumet River and Indiana Harbor on Water Quality (No-Action Alternative)

Background

149. Bottom sediments contaminated with organic matter, heavy metals, oil and grease, nutrients, and pesticides are present in most urban waterways. Federal navigation channels often act as catchment basins for these polluted sediments. As a consequence, the CE must, as required by Federal statutes, determine the environmental impacts of dredging and the disposal of these sediments before initiating dredging activities. Previously, the CE analyzed bottom sediments only for the purpose of assessing the effects of dredging and disposal of these materials. No effort was made to determine the environmental effects of polluted bottom sediments on the overlying water column and biota or the environmental benefits derived from the removal and confined disposal of contaminated sediment on a waterway.

150. Many environmental groups voice strong objections to the dredging and disposal activities of the CE when heavily contaminated sediments are involved; the belief seems to be that such materials are better left in place on the river bottom--out of sight and mind. Heavily contaminated sediments, however, are rarely stationary or inert. The presence of these materials can exert a significant oxygen demand; support few, if any, benthic organisms, and provide a long-term source of contaminants. The resuspension of contaminated sediments can greatly affect the quality of the overlying water column and

impact downstream water quality. Although Federal channels are authorized for navigation, the maintenance of these channels may also provide long-term environmental benefits through the removal and confinement of heavily contaminated sediments. If the CE can demonstrate or quantify these benefits, it can then offer them as a form of mitigation to the short-term impacts of dredging and disposal.

151. The objective of these evaluations is to assess the influence of polluted bottom sediments on the quality of water in the GCR/IHC. Existing information on sediment-water interactions in general was analyzed, as well as relevant information on the chemical, biological, and physical properties of the GCR/IHC.

Mechanisms affecting water quality and contaminant loading

152. The scientific literature consistently identifies suspended sediment as the major mechanism for transport of sediment contaminants. Other routes of contaminant mobilization from the sediment are through release of adsorbed contaminants from resuspended sediments and diffusion of contaminants from in-place sediment. The relative importance of mechanisms controlling contaminant movement from sediment in the GCR/IHC is in the order: transport of contaminants associated with particulates > transport of contaminants desorbed from suspended particulates > transport of soluble contaminants released from deposited sediment. Another mechanism for contaminant movement is through bioaccumulation. At present, this last mechanism is of minor importance in the GCR/IHC. The existing aquatic life is limited to pollution tolerant species of variable numbers and lower numbers of less pollution tolerant fish species. The studies conducted at WES have shown that the high toxicity of Indiana Harbor Canal sediment may be a contributing factor to the low

diversity of fish and benthic biota. Therefore, before other than a rough approximation of the benefits of dredging the Indiana Harbor Canal can be made, a thorough knowledge of the sources of sediment and how these sediments move through the system is needed.

Wastewater reallocation

153. In order to understand the role of sediment as a source of contaminants in the GCR/IHC, it is necessary to understand the relative importance of sediment and water as contaminant sources to Lake Michigan. To accomplish this, existing data on sources of pollutants to the GCR/IHC was examined and a waste load allocation model was developed for the Grand Calumet River.

154. Data from the National Pollution Discharge Elimination System (NPDES) on municipal and industrial point sources are available for use in calculating loads of conventional and some nonconventional pollutants. Estimates have also been made for some conventional pollutant loads from combined sewer overflows and urban runoff; however, due to lack of data, pollutant load estimates for waste fills could not be made. Further, existing information is inadequate to either predict toxic organic loading from pollution sources or to confirm the presence of toxic organics. Existing data will not allow separation of sediment contaminant inputs from those of point and nonpoint riverine sources.

155. Evaluation of the waste load allocation model developed for the Grand Calumet River system by the Indiana State Board of Health showed that the model simulates field water quality data for dissolved oxygen and conservative pollutants (subject only to transport) within a reasonable range of accuracy. At present, the model is unsuitable for nonconservative contaminants such as PCBs, PAHs, and heavy metals. Weaknesses identified by this study in the existing database included unmonitored loads and limited flow data for the

stream and harbor. Review at WES has also identified surprisingly low values of sediment oxygen demand in the waste load allocation models as a potential weakness. The values appear to be low because the waste loads for the Grand Calumet River are similar to or heavier than waste loads in other systems that have much higher sediment oxygen demands. The low levels of the sediment oxygen demand constitute a weakness because unrealistically low values may not trigger the release from suspended sediment of metals that are normally released in the GCR/IHC. Finally, the waste load allocation model study did not consider toxic organics, resuspension of sediment, stormwater loads, pollutant release from sediment, or oil and grease.

156. Waste load allocation models currently in use are of limited value for evaluating the transport of sediment contaminants out of the system or for quantifying the impacts of contaminated sediment on water quality. Their value resides in the evaluation of such parameters as dissolved oxygen, total dissolved solids, chlorides, and sulfates. These models are currently unsuitable for evaluating remobilization and transport of nonconservative chemical contaminants.

Sediment oxygen demand

157. Sediment oxygen demand (SOD) is an important oxygen consumption process and is also instrumental in turning on and off the sediment surface layer as a "valve" for oxidized and reduced materials. SOD is also a key parameter in any water quality model that includes dissolved oxygen utilization and balance. From the data available for waterways in the Chicago area, it appears that SOD is frequently found to be quite high; this is not unexpected in streams that are moderately to heavily polluted. However, it is not possible to state with any degree of certainty the existing SOD values for the GCR/IHC system. The values given in HydroQual (1984) are much lower than

values given for similarly polluted streams in the Chicago area and thus are probably too low. In addition, the investigators who obtained the data for HydroQual (1984) were often unable to obtain satisfactory SOD readings within the Indiana Harbor Canal region. The reasons for this were not clear from HydroQual (1984).

Equilibrium partitioning

158. Diffusion rates of PCB into the water column from deposited sediments were developed by estimating equilibrium partitioning values of PCB in sediment interstitial waters and appropriate diffusion equations. The estimated diffusion ratts of PCBs in the Indiana Harbor Canal sediments indicate that, in the absence of disturbances, movement of soluble PCBs is relatively minor. On the average, 1 sq m of bottom sediment would annually contribute 0.025 ng of PCBs to the overlying water. This value would be increased in the presence of bioturbation, but would remain a fairly minor component of contaminant input into the overlying water.

159. Results of equilibrium partitioning calculations made using data specific for the GCR/IHC system indicate that FDA limits on PCB concentrations in fish tissue for human consumption will be exceeded, provided that fish survive in the Indiana Harbor Canal for a sufficient period to come to equilibrium with sediment PCBs. Unfortunately, equilibrium partitioning cannot be conducted on compounds other than hydrophobic organics. This means that polar organic compounds and inorganic heavy metals cannot be evaluated by this procedure. In addition, a major weakness of the equilibrium partitioning approach is that the time necessary to reach equilibrium between sediment contaminants and the biota is unknown. Thus, it is impossible to predict how long a fish population must remain in an area before the equilibrium concentration is reached.

Sediment resuspension and transport

160. Under nondredging conditions, there are two major avenues for the resuspension and transport of sediment from the GCR/IHC system--normal ship traffic and storm events. The ability of the Indiana Harbor Canal to act as a sediment trap is illustrated by the annual removal of an average of 100,000 cubic yards of dredged material from the channel between 1955 and 1972 (US Army Engineer District, Chicago, 1986). This represents approximately 60 percent of the estimated annual suspended solids loading to the GCR/IHC in 1974. Examination of data from bathymetric surveys for the years 1972, 1976, 1980, and 1984 indicate that the Indiana Harbor Canal has reached a shoaled equilibrium with the channel thalweg provided by passage of boat traffic. Shoaled equilibrium means that incoming sediment is equal to outgoing sediment, which moves into Indiana Harbor and Lake Michigan. A sharp decrease in the channel depths was found between the years 1972 and 1976 with progressively smaller depth changes since 1976. The 1984 survey shows only a small overall change from the 1980 survey, an indication that the total amount of shoal material has not changed, but may only be redistributed through undocumented mechanisms (Lake Michigan seiches, local storm action, etc.).

161. The database for the GCR/IHC has only limited data on contaminant releases during interactions between suspended sediment and water. Current velocity data and information on sediment resuspension are also very limited. To determine the mass of contaminants transported from the sediments during dredging and nondredging conditions, it may be necessary to use mathematical models. More detailed hydrodynamic and suspended sediment transport data are necessary to allow use of more sophisticated analytical techniques for evaluating sediment sources, and quantifying resuspension and sediment transport in the system. Additional data must also be collected before

analytical techniques more sophisticated than those already conducted can be applied to the GCR/IHC system for either metals or toxic organics. Therefore, the immediate detailed application of either hydrodynamic or contaminant models is not recommended.

162. The relative importance of mechanisms controlling contaminant movement from sediment in the GCR/IHC was examined during this study. The movement of sediment particulates is consistently identified as the major factor. Results of this study have shown that the data available allow only rough estimates, such as conducted by the Chicago District for the Indiana Harbor CDF Draft EIS (USAE District Chicago, 1986), of sediment loadings and sediment yield, and benefits that would accrue from dredging the Indiana Harbor Canal. More detailed hydrodynamic and suspended sediment transport data are necessary to allow use of more sophisticated analytical techniques for evaluating sediment sources, sediment resuspension, and sediment transport. Historical dredging data strongly suggest, however, that dredging the Indiana Harbor Canal would allow it to act as a sediment trap, retaining contaminated sediment that would otherwise be transported into Lake Michigan. Additional data must also be collected before analytical techniques more sophisticated than those already conducted can be applied to the GCR/IHC system for either metals or toxic organics. Therefore, the immediate detailed application of either hydrodynamic or contaminant models is not recommended.

163. Any studies conducted in the GCR/IHC system require a knowledge of the system's hydrodynamic and sediment transport properties. The information required for an assessment of GCR/IHC system hydrodynamics and sediment transport will necessitate both short-term (on the order of a day) and longer-term (on the order of four to six days) field data sets. Following these hydrodynamic studies, one or more options presented in this report can be

utilized. These include: 1) quantifying mass loadings to the water column during dredging and nondredging conditions; 2) determining relative loadings from sediments prior to and following dredging operations and between sediment and nonsediment loadings to the GCR/IHC; and 3) determining the long-term fate of contaminants in the GCR/IHC system.

164. We know that in-place contaminated sediment in the GCR/IHC can exert a long-term impact on water quality and biota. This long-term impact is indicated by the high sediment toxicity to aquatic organisms. It is doubtful that the GCR/IHC could be recolonized by diverse aquatic biota so long as the contaminated sediments remain in the system.

165. The detailed results of these studies on the "no-action" alternative are presented in a separate report entitled "Analysis of Impacts of Bottom Sediments from Grand Calumet River and Indiana Harbor Canal on Water Quality" (Brannon et al., in preparation).

TSCA-Approved Disposal Alternatives

166. The following paragraphs address the feasibility of disposing of the PCB-contaminated sediments from Indiana Harbor Canal by the approved TSCA alternatives of incineration and chemical waste landfill. The purpose is not to present a detailed design or cost estimate, but rather to provide a range of costs (on a per cu yd of dredged material basis) that could be expected for these alternatives. Major cost items associated with a project of this nature were determined in order to come up with a reasonable idea of the total costs. The estimated costs will be used as the basis for determining if either method could be implemented under the Corps' navigational authority.

167. From existing sediment data it is known that the subject sediments contain levels of PCBs ranging from 1 to 100 ppm dry weight. Bathymetric surveys of the Canal indicate that there are approximately 200,000 cu yd of sediments within the Federal navigation channel defined as PCB-contaminated and subject to TSCA regulation. This represents approximately 240,000 tons of in-place sediments (50-percent solids) or about 120,000 tons of dry solids.

Removal and handling

168. There are a variety of methods for dredging contaminated sediments. These methods will be reviewed more fully later in this report (Part III). In order to either incinerate the PCB-contaminated sediments or transport and dispose of them in a licensed chemical waste landfill, the sediments must first be dredged and placed into a storage and rehandling facility. The reasons for this are that dredged material can not be transported or incinerated without removal of standing water. In addition, the storage area is necessary because the rehandling/transportation/incineration can not keep pace with the dredging. The entire volume of sediments could be dredged in a matter of 2-3 months. Rehandling for transport to a chemical waste landfill or incineration will take a far more extended time period. Dredging the PCB-contaminated sediments in a piecemeal fashion (in several separate operations) would be costly. It might also be environmentally unacceptable because of possible increased sloughage and dispersal of contaminated sediments during the intermittent dredging.

169. A storage/rehandling facility would be required for either incineration or disposal to a licensed chemical waste landfill. This storage facility must be compatible with the dredging operation. For this reason, the facility must be located in close proximity to the navigation channel. The facility must be designed so that it can receive the dredged material, facilitate

dewatering, collect and treat the return water and runoff. A conceptual design of such a holding area would be a diked facility having two or three "cells." Dredged material would be rehandled from one cell at a time. The diked facility would be sized to facilitate dewatering, which is achieved by surface drainage, drying, and cracking. Underdrainage is of limited effectiveness due to the low permeability of the silt and clay sediments. Mechanical dewatering could be accomplished. However, this type dewatering for dredged material is expensive and could not keep pace with the dredging operation.

170. A dredged material lift (thickness) of 10 ft was assumed for the conceptual design of the storage/rehandling facility. A diked facility of approximately 15 acres would be required and this facility would be lined with a minimum of three ft of compacted clay to prevent groundwater contamination.

171. The process of dewatering requires collection and treatment of dredged water and surface runoff. Water would be collected and pumped to "package" treatment facilities. The treated effluent would be returned to Indiana Harbor Canal. The end product of dewatering would be dredged material with a moisture content of about 25 percent by weight. Although dewatering and consolidation may reduce the volume of sediments within the storage facility by about 20-30 percent, this volume will be returned due to the bulking factor from rehandling.

172. The approximate costs of the storage/rehandling facility and dredging are as follows:

Construction costs	$3,000,000
Land and easement costs	500,000
Dredging costs	2,000,000
	$5,500,000

However, this cost could be as high as $7,500,000.

Incineration

173. Incineration is currently widely used for the thermal destruction of contaminated waste material. Other processes which use a thermal process to destroy contaminated wastes are emerging but are not in common usage at the present time.

174. Disposal of PCB-contaminated wastes is controlled by provisions of TSCA. Specific reference to the incineration of PCB-contaminated wastes can be found in subpart E, Annex II of 40 CFR 761. Facilities which incinerate PCBs are regulated by the USEPA and must be licensed by that agency. Currently, there are five commercial, permanently located, facilities operating in the US which have been licensed by the USEPA to accept and incinerate PCB-contaminated material. Three of them accept solid wastes while the remaining two accept only liquid wastes. The facilities that accept solid wastes are located in Deer Park, Texas (Rollins); El Dorado, Arkansas (ENSCO), and Chicago, Illinois (SCA Chemical Services, Inc.). These facilities will be referred to as "offsite TSCA incinerators."

175. Portable (mobile) incineration facilities are also available to process contaminated wastes. These units can be assembled at the site and dismantled when the destruction is complete. Only one manufacturer of portable units is currently licensed by the USEPA to handle PCB-contaminated wastes (GA Technologies located in San Diego, California) but in the near future as the technology is developed and tested, it is expected that there

will be more portable incineration units available. The portable incinerator units will be referred to in this section as "onsite TSCA incinerators."

176. Though incineration has proven to be an effective means of contaminant destruction for small-scale toxic and hazardous waste cleanup projects, incineration has not been attempted on a scale and complexity that would be required for the Indiana Harbor dredging project. Many hidden costs and variables would probably turn up if a detailed analysis of the incineration alternative was performed.

177. The major obstacles to incineration of dredged material include volume of material, water content, operations problems, volume of residue, and interference of other contaminants. Dredged material should be dewatered to a moisture content of about 25 percent to improve burning efficiency. The sediments from Indiana Harbor Canal have a total volatile solids content of approximately 25 percent. This means that 25 percent of the solids are combustible, and that 75 percent are inert and will remain as residue or ash. This poses handling problems during incineration. In addition, the ability of an incinerator to treat Indiana Harbor Canal sediments and maintain compliance with applicable air quality standards would have to be proven with several trial burns. The interaction of the PCBs and other organic contaminants with inorganic pollutants present in the sediments could require elaborate emission controls.

178. The residue or ash from the incineration of dredged material must be disposed of. This will likely represent over half of the initial volume of material. The sediments from Indiana Harbor Canal contain elevated levels of non-combustible contaminants, such as lead, zinc, cadmium, and chromium. The residue from incineration would still be classified as highly contaminated and require confined disposal. In addition, the oxidation of these sediments may

make certain inorganic contaminants more mobile. It is conceivable that the PCB-contaminated sediments could be incinerated, only to generate a residue classified as hazardous according to the EP-toxicity test analysis.

179. Since a detailed analysis of the technical feasibility of incineration of Indiana Harbor Canal sediments is outside the scope and intent of this report, certain assumptions had to be made in order to proceed. These assumptions are as follows:

a. The dredged material will be dewatered to a water content of not more than 25 percent by weight in order to improve burning efficiency in the incinerator.

b. The operators of the closest offsite TSCA facility to the dredge site (Chicago, Illinois) would be willing to accept a large quantity of dredged material that has a high nonorganic content.

c. The dredging operation itself will take place over a 2-3 month period and the dredged material can be stored onsite until it can be dewatered (1-2 year time frame) and incinerated.

d. Other contaminants that might be present in the dredged material such as oil and grease, nutrients, organics, and heavy metals will not limit the efficiency of the incineration process and not present a further hazard to the environment (i.e. air pollution from plant emissions).

e. If the dewatered sediments were transported to an offsite TSCA incinerator, some or all of the clay liner of the holding facility would also have to be removed and incinerated. Otherwise, the holding facility and its clay liner would be reused as the ultimate disposal site for the residue from the onsite TSCA incinerator.

f. The materials used in the treatment unit of the holding facility will be incinerated after the holding facility has been emptied.

180. Onsite incineration. The steps involved in onsite incineration would be as follows:

a. Construction of an onsite storage/rehandling facility and treatment system (1 year).

b. Dredge 200,000 cu yd of material from the Indiana Harbor Canal and dispose in the storage/rehandling facility (3 months).

c. Dewater dredged material (1-2 years).

d. Assemble the portable incinerator onsite (2 years).

e. Incinerate the dredged material after dewatering (approximately 200,000 cu yd) and the filtration material (approximately 30 cu yd). It is estimated at a feed rate of 40 cu yd a day and 290 days of operation per year, it will take one onsite incinerator approximately 15 years to complete the incineration.

f. The residue from the incineration process will be disposed of permanently in the storage/rehandling facility.

181. The costs for onsite incineration used in this study were originally developed by the USEPA for similar studies involving PCB-contaminated sediments. The specific sites in which incineration cost data were estimated by the USEPA were Waukegan Harbor in Waukegan, Illinois and Fields Brook in Ashtabula, Ohio. The local USEPA office (Region V) supplied the Chicago District with data either from published reports or verbally from data in its files. The USEPA in Washington was contacted for information on incineration as well as the Illinois EPA in Springfield, Illinois.

182. Previous studies by the USEPA identified costs in the range of $1,000 to $1,500 per cu yd of dredged material for incineration using a portable incinerator and disposal. This does not include the cost of dredging or the cost of constructing the storage/rehandling facility. Based on these costs, incineration and disposal of 200,000 cu yd of contaminated sediments would be in the range of $200 million to $300 million. The time frame for the project would be approximately 17 years using one incinerator. This does not include time for site layout and obtaining necessary permits. These activities could add several years to the time frame. The time frame could be reduced by use of more than one portable incinerator. The capital cost would increase proportionately.

183. Offsite incineration. The procedure for offsite incineration would be as follows:

a. Construction of an onsite storage/rehandling facility with a treatment system (1 year).

b. Dredge 200,000 cu yd of material from the Indiana Harbor Canal and dispose in the storage/rehandling facility (3 months).

c. Dewater dredge material (1-2 years).

d. Contain the material in fiberglass or plastic drums as required by the incineration facility (1 year).

e. Transport the dewatered material to the offsite incinerator (a distance of approximately 15 miles one way). After the dredged material is removed, some or all of the clay liner and treatment material would be transported to the offsite incinerator (approximately 30,000 to 70,000 cu yd). Assuming 20 trucks a day and 10 cu yd of material per truck and 290 working days per year, this operation would take approximately 5 years to complete.

f. Incineration at the offsite facility and disposal of the residue there.

It is assumed that the dredged material is incinerated and disposed of as soon as it arrives. If the offsite incinerator can not keep pace with this delivery, the processing could take much longer.

184. The costs for offsite incineration were determined by contacting the nearest TSCA incineration facility which is SCA Chemical Services in Chicago, Illinois. A representative of that firm supplied the Chicago District with the data necessary to determine the cost of incineration and disposal.

185. The cost of offsite incineration and disposal at the incineration site is $0.60 per pound of waste (as quoted by a representative of the company). The dredged material represents approximately 180,000 tons following dewatering to 25-percent water content. The contaminated clay liner represents an additional 46,000 to 107,000 tons. The total cost for incineration and disposal of dredged material and liner ranges from $271 to $344 million. This figure does not include the cost of dredging, the construction, operation, and closure of the storage/rehandling facility,

containerization of the sediments, and transportation to the incinerator. The time frame for this project would be approximately eight years.

TSCA landfill

186. PCB-contaminated materials may be disposed in an approved chemical waste landfill. The specifications of a chemical waste landfill are described in Annex II, CFR 761.41. These requirements state that the approved landfill should be located in areas having relatively impermeable soil formations or compacted clay liners, synthetic membrane liners, and leachate collection systems. Further, the bottom of the landfill liner system should be at least 50 ft above the historical high water table.

187. The steps involved for disposal to a licensed chemical waste landfill would be as follows:

a. Construction of an onsite storage/rehandling facility with a treatment system (1 year).

b. Dredge 200,000 cu yd of material from the Indiana Harbor Canal and dispose in the storage/rehandling facility (3 months).

c. Dewater dredged material (1-2 years).

d. Transport the dewatered dredged material and some or all of the clay liner to the TSCA landfill.

188. The nearest approved TSCA landfill is located in Williamsburg, Ohio, which is near Cincinnati. The landfill site is about 270 highway miles from Indiana Harbor. The landfill is operated by CECOS International, which has provided much of the information used to develop this cost estimate.

189. It is assumed that the 200,000 cu yd of dredged material will be handled in accordance with existing Federal, State and local environmental laws and all contractors and their agents will comply with these laws. Special handling and special precautions will be required at each step of the

process moving the material from the onsite holding facility to the TSCA landfill. Trucking is one approved method of transport.

190. The volume of PCB-contaminated material to be sent to the TSCA landfill is estimated to include 200,000 cu yd of dredged material, 30,000 to 70,000 cu yd of clay liner from the storage/rehandling facility, and some 30 to 60 cu yd of filter media used in treatment processes. The transportation weight of this material (25-percent water content) is estimated to range between 230,000 to 280,000 tons. Based on 20 tons per truck, 11,500 to 14,000 trips will be required. Each round trip from the Indiana Harbor storage/rehandling facility to the TSCA landfill in Ohio is about 540 miles. Unit prices reflecting March 1986 prices were secured from the TSCA landfill operator. The unit trucking price is $3.50 per round trip mile, hence the cost of a single round trip is $1,890. Transportation costs would, therefore, range from $21.7 million to $26.5 million. Once at the TSCA landfill, the unit price of disposal is $205 per ton. The cost for use of the site would, thus, range from $47.2 million to $57.4 million.

191. Time required to implement use of a TSCA landfill as a disposal plan is significant and warrants discussion. As stated earlier, some 11,500 to 14,000 round trips will be required to move the material to the TSCA landfill. Assume that one truck can make three round trips of 540 miles each per week, that a fleet of 20 trucks is available, that no trips will be cancelled due to break down, weather, illness, or accident, and that handling and operating problems caused by cold weather will not impact on the schedule. It would take between 3.7 to 4.5 years to move the material to the TSCA landfill if the trucks were operated 52 weeks per year. If the number of trucks were increased, the transport period could be reduced, but this would concurrently increase traffic congestion at both the project site and the TSCA landfill.

The estimated costs of disposal of PCB-contaminated sediments to the closest approved TSCA landfill range from $69 to $84 million, or $345 to $420 per cu yd. This does not include the costs of dredging or the construction, operation, and closure of the storage/rehandling facility. This disposal alternative would take about 6-8 years to complete.

Conclusions

192. The estimated costs and project duration for the disposal of PCB-contaminated sediments from Indiana Harbor Canal by incineration and chemical waste landfill are shown on page 10. Based on economic considerations, the TSCA approved disposal methods are not feasible under the Corps' navigation authority. Based on technical considerations, it is uncertain if these sediments can be incinerated with acceptable air emissions. The ability of incineration to accommodate these high-ash materials is also uncertain. From an environmental standpoint, these disposal methods are limited by the necessity for on-site storage and rehandling. The storage/rehandling facility used to dewater the contaminated sediments represents a type of upland confined disposal facility (CDF). Although this facility would be "temporary" (6-17 years), and contain state-of-the-art controls, it would have no less environmental effect than a CDF. The TSCA disposal methods, therefore, begin with an environmental cost essentially equal to confined disposal.

Contained Aquatic Disposal

Background

193. Contained aquatic disposal was investigated in an effort to broaden the disposal options available to the Chicago District. The limited storage volume in existing CDFs, the costs and problems associated with acquisition of

new land, and the prohibition of conventional open water disposal of contaminated sediments into Lake Michigan all reinforce the need to explore innovative disposal alternatives.

194. The capping concept can be summarized as three basic components: controlled, accurate, subaqueous placement of the dredged material; isolation of the material from the receiving environment (typically with some type of covering or cap); and monitoring and maintenance of the site. There are a number of variations in techniques, equipment, and materials that can be combined to produce different configurations or to accommodate different requirements. Figures 11 and 12 are schematics of two types of capping projects, level-bottom capping and contained aquatic disposal. As the name suggests, level-bottom capping projects attempt to place the contaminated material on the existing flat or very gently sloping natural bottom in a discrete mound. Capping is then applied over the mound by one of several techniques, but usually in several disposal sequences to ensure adequate coverage. CAD would generally be used where the mechanical condition of the contaminated material and/or bottom conditions (e.g. slopes) requires a more positive lateral control measure during placement. Options might include the use of an existing depression, preexcavation of a disposal pit, or construction of one or more submerged confining dikes.

195. The CAD concept should not be thought of as merely a more elaborate version of conventional open-water "dumping." A CAD site is an engineered structure, just as is a CDF. Its successful performance depends on proper design and care during construction. Unlike CDF design procedures, however, the CAD concept is still evolving and experience with it is limited. CAD has been successfully applied both in the United States (Truitt 1986) and in Europe, and the necessary technology is available. But, it is still an

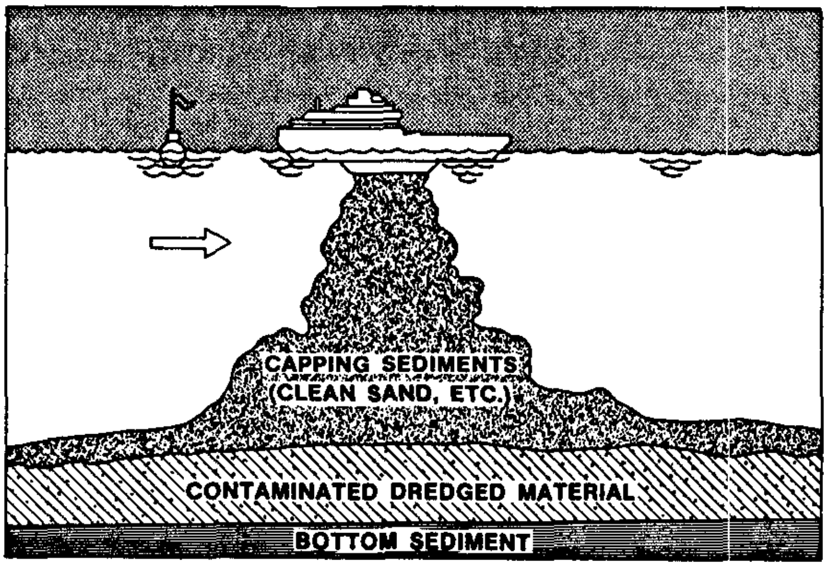


Figure 11. Schematic of typical level-bottom capping operation

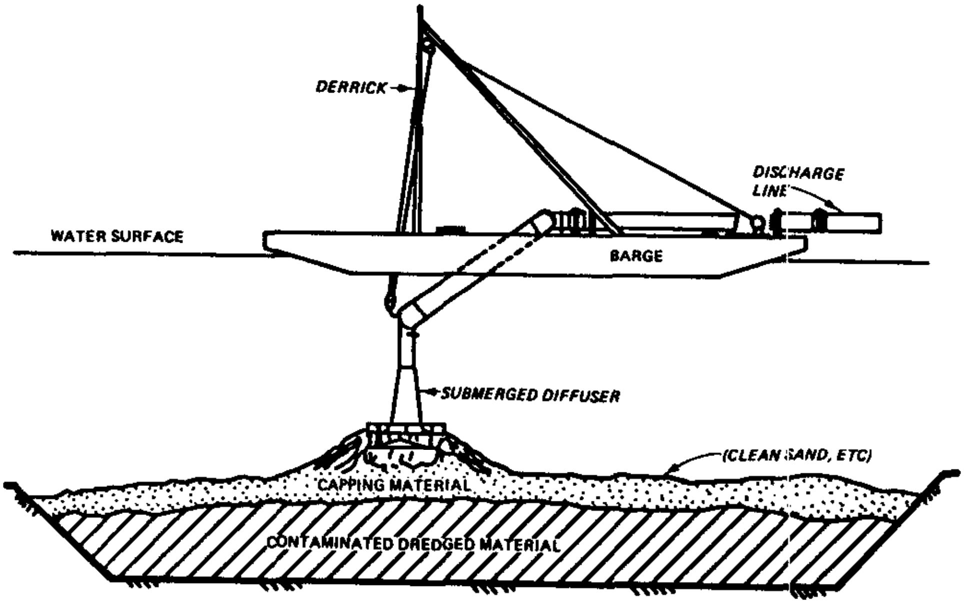


Figure 12. Schematic of CAD project also showing use of a submerged diffuser for placement

innovative approach, and the physical, chemical, and biological impacts and benefits must be understood before the project can be designed and constructed.

196. One of the principal design decisions in a CAD project is the nature and thickness of the capping or cover material placed over the dredged material mound. As described previously, Indiana Harbor sediments are known to be contaminated. The capping material provides the isolation necessary to control the movement of contaminants out of the dredged material and into the overlying water column, and to prevent direct contact between aquatic biota and the contaminated sediment. The cap also performs the important physical function of stabilizing the material and protecting it from transport or dispersion away from the site. The design of the cap, therefore, requires a twofold approach. It must result in a capping layer with a grain size and thickness that functions as an adequate seal, yet the material must not be easily suspended and transported by the design bottom shear stress at the site.

Objectives

197. The following objectives addressed the CAD alternative:

a. Determine the effectiveness of capping as a general approach to prevent the movement of contaminants out of the Indiana Harbor sediment into the aquatic biota and overlying water column.

b. Provide guidance to the District on the most effective and technically feasible combinations of capping material type, thickness, configuration, and siting to maximize contaminant isolation (i.e. provide an adequate seal).

c. Provide guidance to the District on the minimum grain size of capping material, thickness, configuration, and siting that will result in reasonable assurances that the cap preserves its isolating capability under the predicted bottom shear stresses at the sites (i.e. will not be easily eroded).

d. Produce a conceptual design of a CAD project incorporating the controlling requirements from above and the additional considerations of site availability, special controls or modifications necessary to improve the level of site performance, construction methods, and site monitoring.

198. The remainder of this section briefly describes the approach, and presents the findings and recommendations supporting these objectives. The section is organized into four major topic areas:

a. Site selection.

b. Cap materials.

   (1) Contaminant isolation studies.

   (2) Resuspension and transport studies.

c. Site design and construction.

d. Monitoring.

Considerable further detail on the test methods, laboratory findings, and site data can be found in Appendixes F, I, and J.

Site selection

199. In the early planning of the investigation it was realized that potential subaqueous disposal sites might be available within the area of the harbor itself, and/or in the more open waters of Lake Michigan. Because of the significant differences in the physical environment of these two areas and the different considerations that would influence site suitability, two parallel efforts were directed toward site selection. Among the criteria considered in evaluating potential sites were volumetric capacity of the site; nearby obstructions or structures; haul distances; bottom shear stresses in the area due to currents, waves, and ship traffic; and ice influences.

200. In both the harbor area and the lake, the evaluation began with a review of existing data contained in charts and District files. Site visits were made for familiarization, although no new field work was done. Limited

numerical modelling was performed to establish values for bottom shear stresses possible in the area. Both analytical and empirical methods were used to evaluate the stability of bottom materials under the predicted shear stresses.

201. The portion of the study directed toward potential sites in Lake Michigan focused on the area between the 30- and 70-ft depth contours. The 70-ft contour was selected as corresponding to a reasonable maximum haul distance from the harbor at a radius of roughly 11 miles from the harbor entrance. The 30-ft contour was similarly selected as an approximation of the minimum depth of water in which the site could be constructed without influencing local navigation draft requirements. Based on local historical observations it is also a reasonable approximation of the seaward limit of ice grounding.

202. A first analysis of the bathymetric in this area together with a very preliminary characterization of the wave climate indicated that much of the area immediately (within 4 to 6 miles) northeast of the harbor entrance consisted of shoals which could have breaking waves during storm events. Sites in this shoal zone (Figure 13) were eliminated from further consideration. No other major sites could be immediately eliminated in the remainder of the lake study area. This simply meant that with the exception of those areas with potential breaking wave activity (and any small-scale obstructions not evident from the bathymetric charts), unlimited sites could be placed in the lake study area <u>provided</u> that the cap material was selected and the site designed considering the local shear stress at the selected location. The effects of the variation in the predicted bottom shear stress on potential cap materials are discussed in a subsequent section.

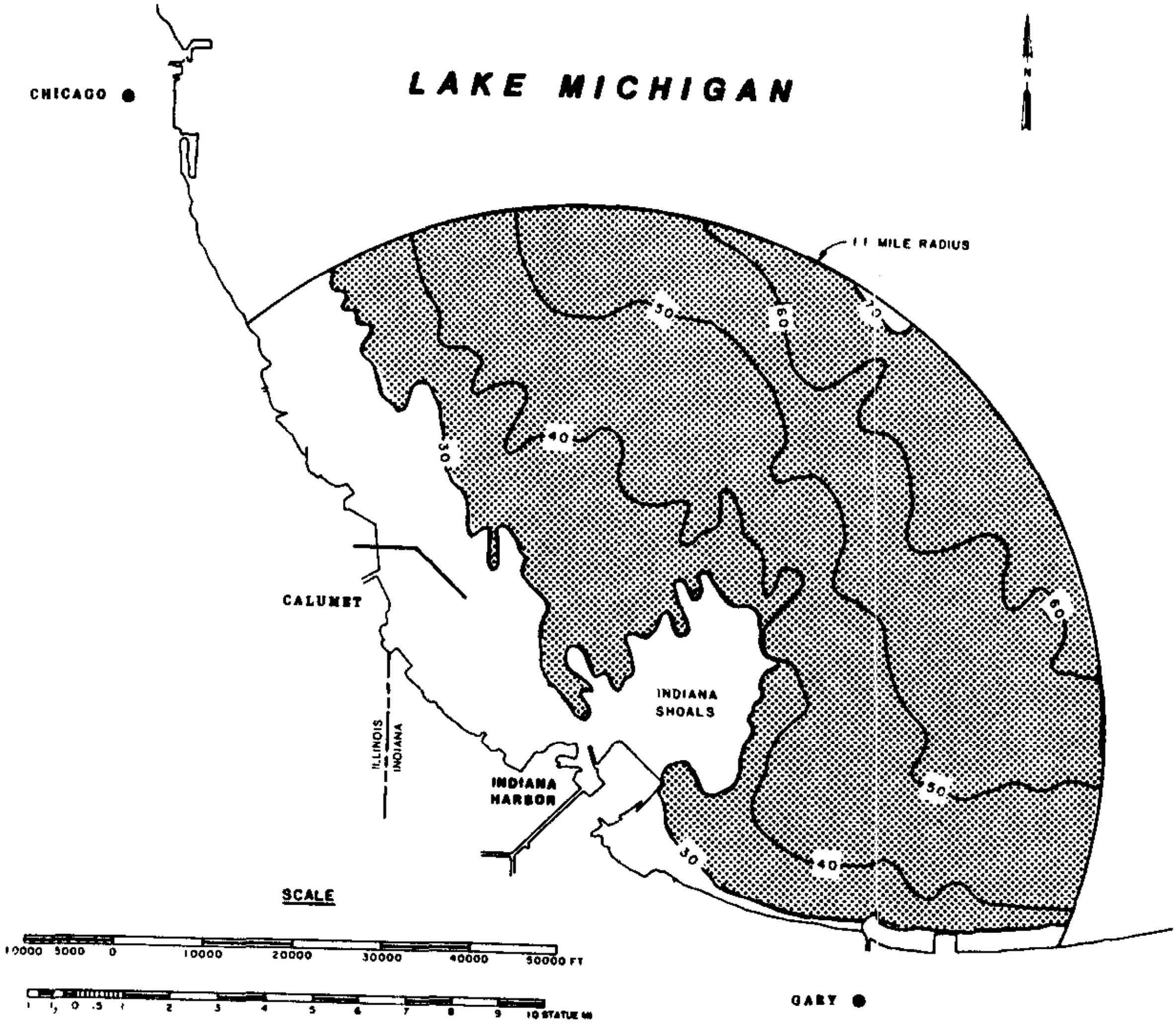


Figure 13. Area of potential CAD sites (shaded) in southern Lake Michigan

203. Although wave forecasts were extended into the outer portions of the harbor, the suitability of sites in both the outer and inner harbor areas was found to be influenced primarily by navigation requirements and/or geometry and obstructions. The outer turning basin has sufficient area to accommodate the entire required volume (Figure 14). The entrance channel into the inner harbor has a capacity on the order of 100,000 yd, or half the projected requirement. In both cases this presumes that the surface of the completed cap would coincide with the existing project depth. Two major problems arise with that assumption. First, the CAD would preclude any future deepening and may hamper routine maintenance of the project. Second, ships using the harbor routinely pass at depths equal to the project depth, essentially in contact with the bottom. Armoring of the bottom could affect that practice and certainly the practice would adversely affect the cap.

Cap materials

204. As stated above, the selection of a cap material must satisfy the dual requirements of providing contaminant isolation and resistance to resuspension and transport. The two studies leading to specification of a cap design are containment isolation studies, and resuspension and transport studies. The sediment used in the contaminant isolation studies was a native silty sand sampled from Lake Michigan. Figure 15 presents the grain-size distribution of a composite sample of the proposed cap material.

205. Contaminant isolation studies. Contaminant isolation studies were run using small column tests and large column tests.

a. The effectiveness of capping in chemically isolating Indiana Harbor sediment from the overlying water column was investigated using small- (22.6 ℓ) scale laboratory reactor units. The depth of cap material needed to accomplish this was evaluated by following changes in dissolved oxygen and ammonium-N for a period of 30 days in the overlying water column.

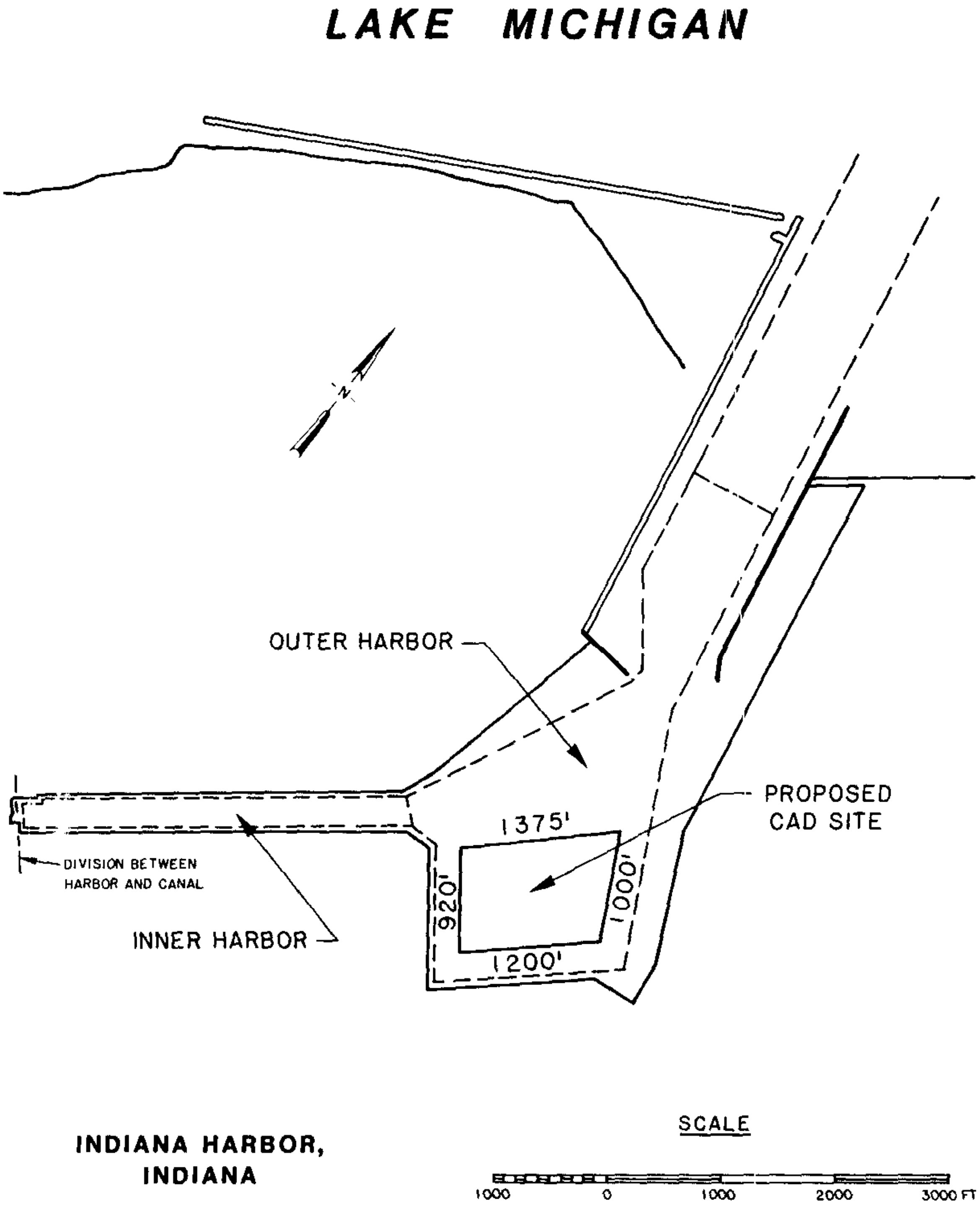
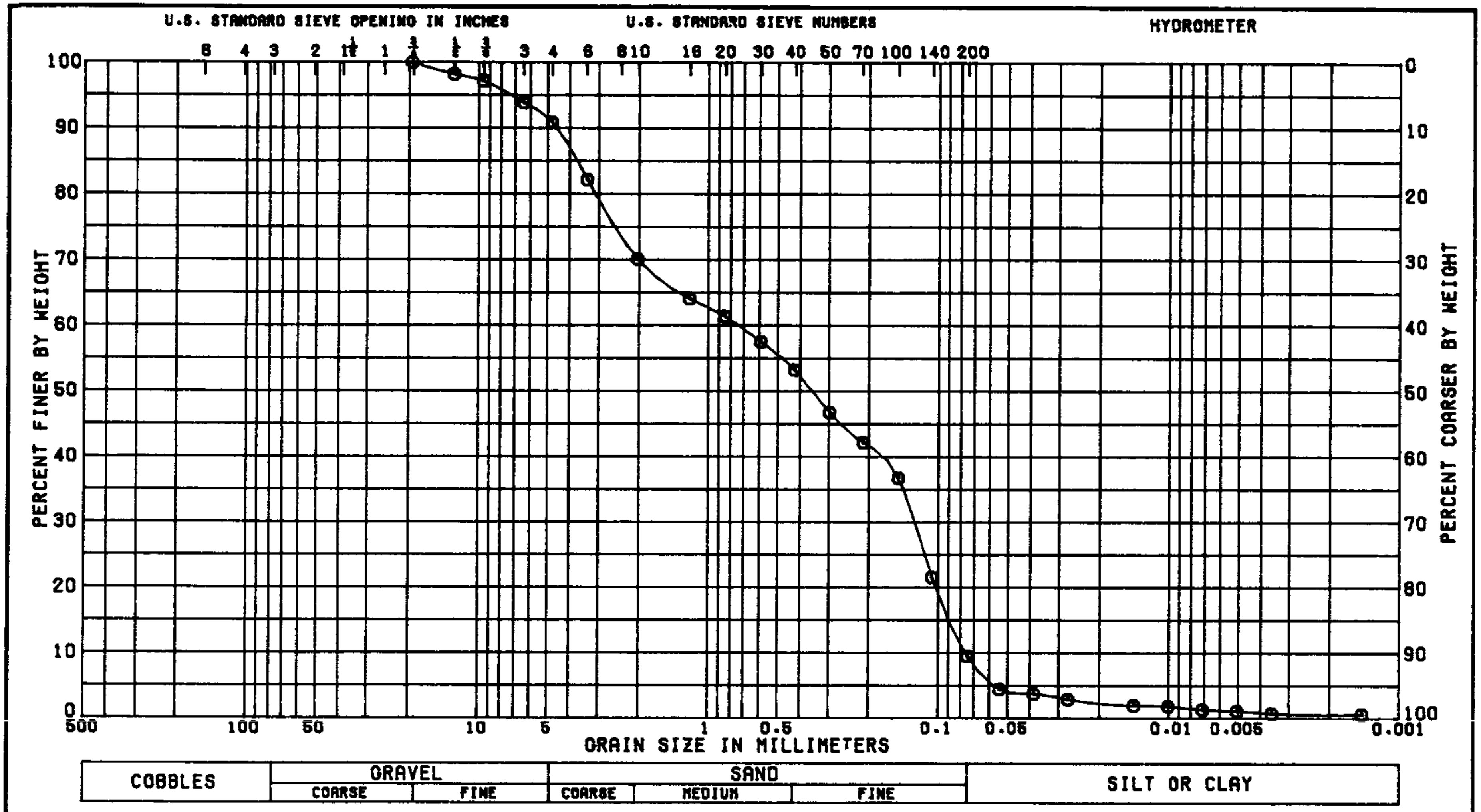


Figure 14. Proposed CAD site in outer portion of Indiana Harbor



LL NP	PL	PI	GS 2.65 EST	NAT W.%

CLASSIFICATION

SILTY SAND (SP-SM), GRAY: WITH GRAVEL

GRADATION CURVE

PROJECT INDIANA HARBOR CAP SEDIMENT

BORING NO. 0 SAMPLE NO. 1

DEPTH/ELEV 0 DATE 13 AUG 85

Figure 15. Grain-size curve for proposed cap material

b. Large column capping tests are conducted to verify the results obtained in the small column tests. The volume of the small predictive tests is too small to permit introduction of aquatic biota. However, the presence of members of the aquatic biota is required to substantiate the effectiveness of capping for reasons detailed in the following paragraphs.

206. Organisms that burrow into and/or feed upon benthic surface deposits are normally present in the aquatic environment. The activities of these organisms can cause disturbance of the sediment surface (bioturbation) and possible breaching of a cap at a contained aquatic disposal site. If breeching occurs, cap integrity may be lost, enabling benthic organisms to have direct access to the contaminated sediment; this process may also expose the underlying contaminated sediment to the water column, with possible resuspension of PCB-contaminated particles.

207. Many aquatic organisms are able to "process" much of the water in a given location, passing the water either over their gills or through their digestive tract. During this activity, the organisms are exposed to large volumes of water, and any contaminants having a high affinity for biological tissues can be extracted and concentrated by the organism. For this reason, organisms can be used in the capping studies to trace the movement of any contaminant initially present in the test sediment, but not in the cap material or the water column. In addition, because organisms have the ability to concentrate materials from their ambient environment, they can be used to keep track of the history of the presence of contaminants in the cap material or water column over a period of time. Thus, a number of individuals of a test species are placed into the large columns at the beginning of the test. Samples of the test species are removed at 10 and 40 days, and the levels of the contaminant of interest are compared with the levels of this substance present at time 0. The resulting change in tissue level of the contaminant

can then be used to indicate if the contaminant is able to move through the cap material and whether there is a change in the release pattern of the contaminant with time.

208. The use of aquatic organisms in the large column tests differs from the usual previous use of organisms in bioassay/bioaccumulation tests because the organisms were used here as a source of bioturbation and to monitor the possible movement of contaminants through the cap material.

209. The effectiveness of a cap of Lake Michigan sediment in chemically and biologically isolating Indiana Harbor sediment from the overlying water column and aquatic biota was verified using 250 liter laboratory reactor units. The organisms used in these studies were red swamp crayfish (*Procambarus clarkii*), yellow perch fingerlings (*Perca flavescens*), and the clam *Anondonta grandis*. A comparison was made of Lake Michigan sediment only (control), Indiana Harbor sediment only, and Indiana Harbor sediment capped with 30 cm of Lake Michigan sediment (the 30 cm depth suggested from the results of the small column tests).

210. The large column studies were run for 40 days. Samples of clams were taken at 10 and 40 days. Samples of other animals were taken at 40 days only. Samples of animal tissue taken prior to exposure to the various treatments were compared with tissue samples taken during and posttreatment for contents of heavy metals and organic contaminants. Water samples were also taken from each of the treatments at 40 days and compared with inflow water with regard to heavy metals and organic contaminants present. Heavy metals and organic contaminants examined included: mercury, lead, zinc, cadmium, chromium, arsenic, PAHs, PCBs, and phenol.

211. The results of contaminant isolation studies were as follows:

a. Uncapped Indiana Harbor sediment was extremely toxic to the test animals. Crayfish were used because they are both surface dwellers and bioturbators. However, uncapped Indiana Harbor sediment killed all added crayfish within three days after the large column studies were initiated. In addition, large numbers of the fish and clams in the same units also died during and shortly after the period when the crayfish were alive. It was postulated that the mortalities observed in the fish and clams were the direct result of crayfish bioturbational activity causing Indiana Harbor sediment to be suspended in the water column, directly exposing fish and clams to the sediment although these organisms were well above the sediment surface. Death of the crayfish resulted in cessation of bioturbation, and sediments previously held in suspension either settled or were swept out of the system by flow-through waters; this was evident from a visible decline in turbidity within the reaction columns. The decrease in the level of Indiana Harbor sediment in the water column then resulted in a decrease in die-off of the fish and clams in the water column. In contrast, all crayfish survived the full 40-day exposure in the large column units containing either Lake Michigan sediment only or Indiana Harbor sediment capped with 30 cm of Lake Michigan sediment. Unfortunately, an insufficient number of fish survived in the Indiana Harbor sediment only treatment to provide statistically significant results for comparison with the other treatments.

b. The 30-cm cap of native Lake Michigan sediment prevented the movement from the underlying Indiana Harbor sediment into the water column and aquatic biota of statistically significant levels of any of the metals or organic contaminants tested, with the exception of arsenic. This metal was found in significantly greater levels in crayfish from the Indiana Harbor sediment with cap treatment than in crayfish from the Lake Michigan sediment control treatment or in the pretreatment crayfish samples. The clams in the Indiana Harbor sediment treatment accumulated statistically significant levels of the PAH compounds anthracene, benzo(a)pyrene, chrysene, and fluoranthene. These compounds were not accumulated by clams or any other animals in the Lake Michigan sediment or the Indiana Harbor sediment with the capping treatment. Clam tissue samples from the Indiana Harbor (only) showed significantly higher levels of total PCBs at both 10 and 40 days than did samples from either of the other two treatments or the pretreatment tissue samples.

212. Resuspension and transport studies. Bottom stresses in Lake Michigan and outer harbor portions of the study area result from a combination of water motion caused by wave action and currents produced by wind stress acting directly on the water surface. Both the waves and the wind stress are probabilistic events and must be evaluated for a particular

external occurrence. In order to provide comparative values and to allow for economic evaluation, events having return periods of 20, 50 and 100 years were investigated. Deep water wave heights and periods for each return interval were determined using hindcasting techniques and WES' Coastal Engineering Research Center Wave Information Study (WIS). These deep water wave characteristics were then mathematically transformed, i.e. refracted and diffracted, into the actual study area using the Regional Coastal Processes Wave Refraction-Diffraction (RCPWAVE) model. The resulting local wave heights can be equated (using linear wave theory) to a maximum water particle velocity as a function of water depth.

213. In a similar approach, the probabilistic wind speeds in the study area were converted to direct stresses on the water surface, and finally to the (vector) velocity components of a bottom current in the area. The resultant maximum water velocities due to wind and slope currents and due to wave action were then taken as additive to produce a conservative, but reasonable estimate of maximum water particle velocities across the study area. The minimum size/weight of a sediment grain that would be stable under the influence of these predicted velocities was then calculated using initiation of motion theory and empirical relationships.

214. In the inner reaches of the harbor, wave action was expected to have a less pronounced effect on the bottom water particle motion. (However, the RCPWAVE data were carried into the harbor entrance where a finite element response model was run to verify the magnitude of wave-induced currents in the area.) Bottom current velocities resulting from direct wind stress and from the flow of water in the channel were evaluated in a manner similar to that described above. However, there remains some uncertainty in the treatment and prediction of bottom stresses due to ship motion in the harbor. Evidence

suggests that ship traffic in the area routinely uses all (and more) of the available draft in the channel and direct shear between vessel hulls or props and the bottom is common.

215. Results of resuspension and transport studies were as follows:

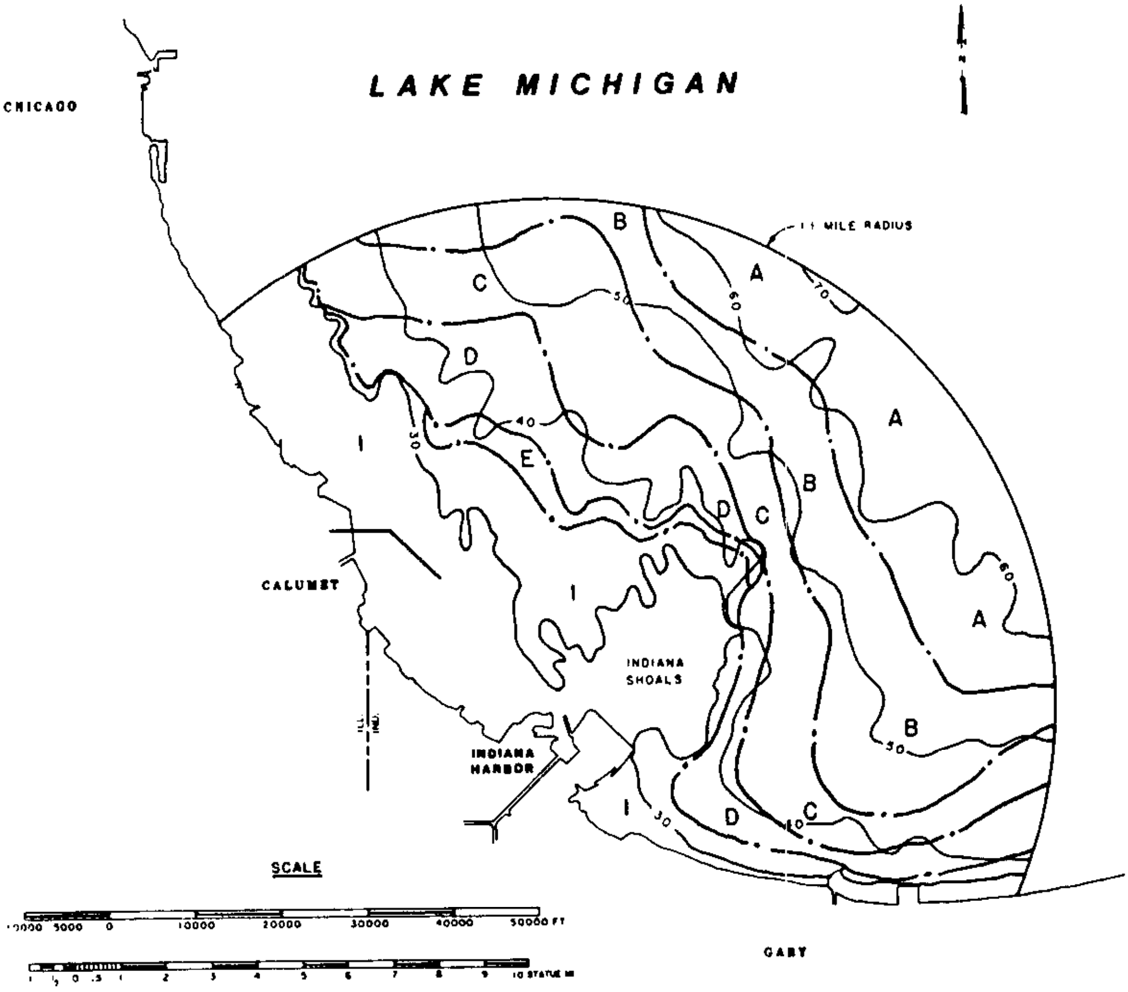
- _a._ Studies indicated that the deep water wave heights in Lake Michigan can approach 23 ft. Transforming these waves across the study area produced a design wave at the harbor entrance on the order of 13 ft. This prediction agrees well with historical observations of 18 ft storm waves off the Calumet breakwater. Wave heights inside the harbor itself are on the order of 3 to 4 ft.

- _b._ The maximum bottom currents due to the local wave conditions and to wind-induced motion were combined to give a conservative estimate of the total maximum bottom velocity at a specific point. These computed velocities ranged from 6.0 to 12.9 fps.

- _c._ As expected, bottom stresses in the lake generally increase as the water depth decreases and the minimum size/weight necessary for a particle to remain stable on the bottom becomes greater. Predicted minimum weights necessary for stability under each return period event in the lake ranged from 1 or 2 lb to as high as 100 lb. The weights as a function of location are shown as contour bands in Figures 16-18. A comparison of these particle weights (sizes) with the grain-size distribution curve for native Lake Michigan sediments presented earlier leads to the conclusion that a cap constructed only of the existing lake bottom sands would not act as a stable armor structure under the combined effects of a conservative design storm. This does not imply that native lake sands cannot be successfully used as a cap or that an armor layer is a necessity. As discussed in design recommendations below, a number of alternatives are available for consideration by the District.

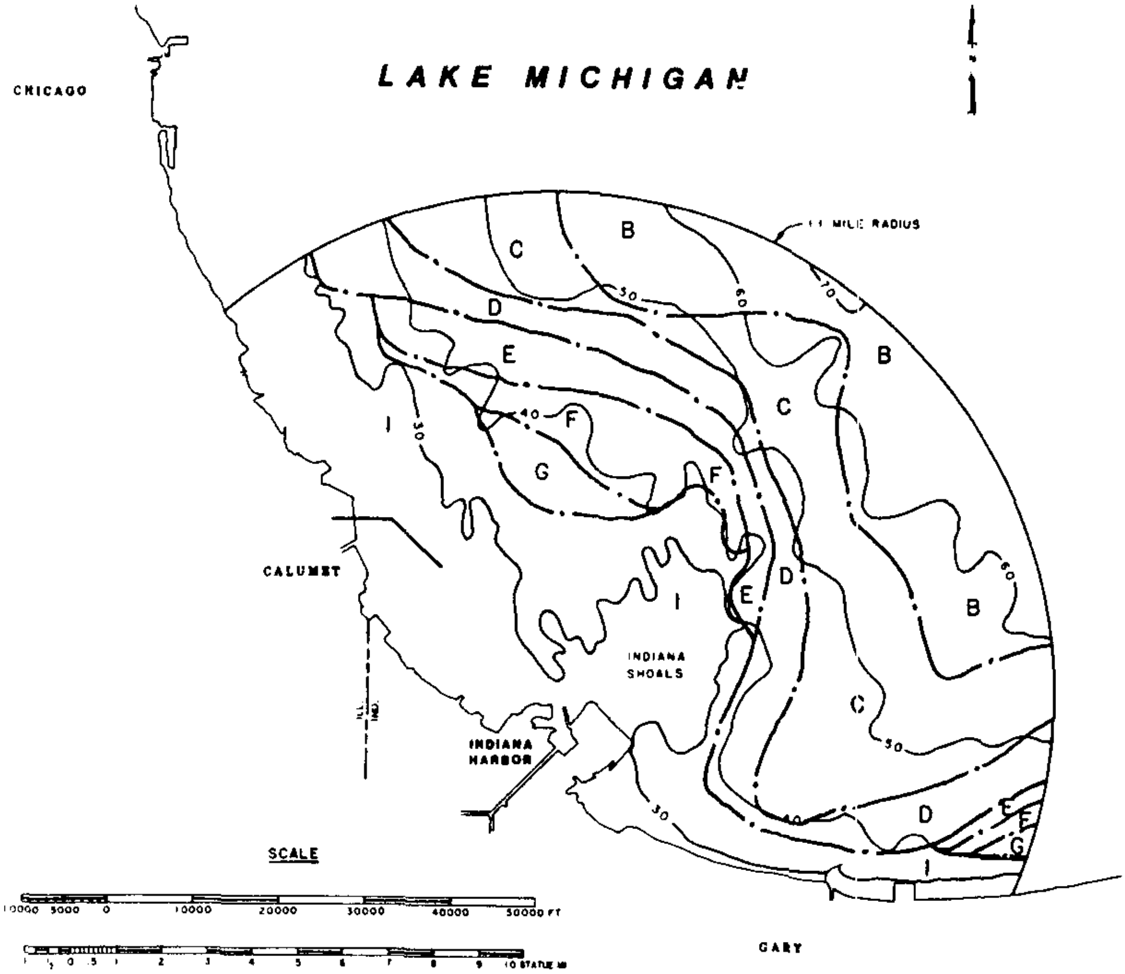
- _d._ The sheltered environment in the harbor results in reduced bottom stresses due to water motion, and in significantly smaller grain sizes required at that location for stability. Application of the Ackers-White method indicated that material in the range of very coarse sand to fine gravel would not be transported by ambient currents. However, as described above, ships using the channel frequently come into direct shear with the bottom sediment, and/or their propellers are in such proximity that shear stresses on the bottom are produced that are much larger than those of the "normal" water motions.

216. Recommendations for cap material. Lake Michigan sediment may be used as a cap material to effectively isolate Indiana Harbor sediments. The



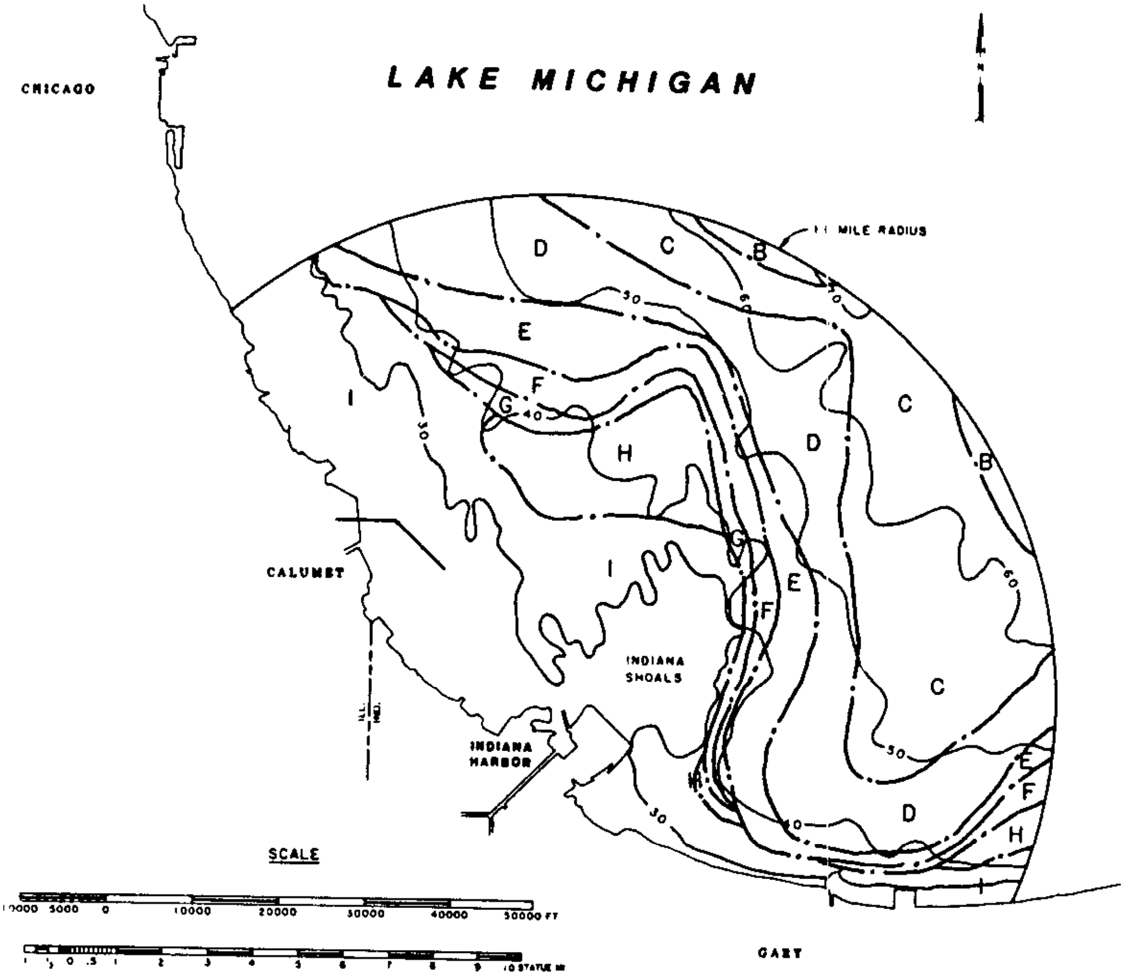
AREA	PARTICLE WEIGHT (LB)
A	1-2
B	2-5
C	5-10
D	10-20
E	20-30
I	AREAS OF BREAKING WAVES, SHOALS, AND SHALLOW WATER, NOT RECOMMENDED AS SITES FOR CAD

Figure 16. Armor cap material sizes based on 20-year design wave



AREA	PARTICLE WEIGHT (LB)
B	2-5
C	5-10
D	10-20
E	20-30
F	30-40
G	40-60
I	AREAS OF BREAKING WAVES, SHOALS, AND SHALLOW WATER, NOT RECOMMENDED AS SITES FOR CAD

Figure 17. Armor cap material sizes based on 50-year design wage



AREA	PARTICLE WEIGHT (LB)
B	2-5
C	5-10
D	10-20
E	20-30
F	30-40
G	40-50
H	50-112
I	AREAS OF BREAKING WAVES, SHOALS, AND SHALLOW WATER, NOT RECOMMENDED AS SITES FOR CAD

Figure 18. Armor cap material sizes based on 100-year design wave

minimum cap thickness recommended for isolation is 20 in. This thickness must be the minimum achieved at any point on the disposal site and must be maintained (i.e., after storm events, etc.). The 20-in. thickness is that measurement from the sediment-cap interface to the top of the cap and does not consider any mixed layer, sinking, cap consolidation, etc.

217. A cap constructed of only native sandy sediment will not act as a stable armor structure under the influence of predicted storm events, and material may be expected to be transported at the site. Even though sediment finer than the stable particle weights is likely to be transported, it is difficult to predict the effect such transport would actually have on the isolating capability of the cap. Sediment transport is generally a continuous process with most natural systems maintaining a rough equilibrium between particles entering and leaving an area, e.g. it would be very rare to find a site at which material was uniformly transported "away" in all directions. Certainly under storm conditions there can be a net loss of bottom sediment in an area, but actual profile lowering in these water depths would be relatively small for a single event. Alternatives for dealing with such losses are either armoring of the cap surface (above the 20 in. minimum thickness) with a layer of stone having particle weights such that they will not be resuspended, or advance nourishment of the cap with a volume of the lighter lake sediment material sufficient to allow for sacrifice under storm conditions while retaining the 20-in. minimum.

Site design and construction

218. Approach. As mentioned previously, any discussion of site design at this preliminary stage can only address conceptual features. The location of potential sites plays an especially crucial role in the design because of

variations in bottom stress. The locations will also influence required construction techniques which will in turn drive many design features.

219. The volumetric requirements are such that to place the entire volume of contaminated sediment (with an appropriate bulking factor applied) in the inner harbor would require on the order of 1.5 miles of unobstructed channel length (see Appendix I). Such a length is not readily available; therefore, this discussion of design will focus principally on sites in southern Lake Michigan and in the outer harbor.

220. For preliminary discussion purposes the design will assume that the bulking factor of approximately 2, which is generally consistent with the testing supporting the CDF evaluation, can be applied to hydraulically dredged sediment placed in a CAD. Therefore, sites must have a capacity approaching 400,000 cu yd. (Actually, volumetric requirements will depend on the total time over which placement occurs since some initial consolidation will take place.) Because of storms and high bottom stresses it would be desirable to have the completed cap elevation at the same level as the existing lake bottom. Therefore, for this study, excavation of a CAD site appears to be indicated rather than capping of a mound of material above existing contours. The excavation provides additional lateral containment for hydraulically dredged slurry. More detailed bathymetry at potential sites may lead to identification of existing depressions that could be expanded. A typical site would require excavation approximately 15 ft below surrounding bottom elevations with side slopes of approximately 1V to 4 or 5H. The area required would then be very roughly 1 million sq ft, or 1,000 ft by 1,000 ft.

221. A single, open excavation of that size is not a desirable approach. Rather, the site should be configured so as to contain the required volume in a series of smaller "compartments" or possibly parallel trenches.

Compartmentalization is necessary to provide the maximum degree of confinement for the soft sediment during capping; to allow for sequential, staged placement of material and cap (reducing the surface area of contaminated material exposed at any one time); and to reduce the effects of erosion/breaching by storm action during or after construction.

222. Lake Michigan sites. The most likely area in the lake itself for sites of the required size is 4 to 8 miles east of Indiana Harbor in water depths of 40 to 60 ft. To produce a site with the recommended depth of approximately 15 ft would then require a digging depth of 55 to 75 ft. This would exceed the construction capability of a conventionally configured (without ladder pump) hydraulic cutterhead dredge. In addition, the normal wind and wave climate in the open lake is such that a cutterhead dredge could not safely operate in these areas. A mechanical dredge could perform the excavation, although it would be operating at the limits of its practical depth, positioning/stability requirements, and economical time. The logical choice to construct a site in the lake would be a hopper dredge. It is capable of operating in the lake environment and can complete the required excavation to the necessary depths in a feasible time.

223. A reasonable construction sequence might be as follows (Figure 19). Begin excavation with the hopper dredge of a trench approximately 2,000 ft long and 15 ft below existing bottom. The trench would have a nominal width of 150 to 200 ft and would be oriented with the long axis perpendicular to the direction of wave propagation at the site (typically parallel to the bottom contours). This is a normal "channel" dredging operation and would require no unusual techniques except perhaps leaving three short "plugs" or cross dikes so that the trench was segmented into four 500-ft sections. The material from this first excavation could be stockpiled in the same area, creating a low

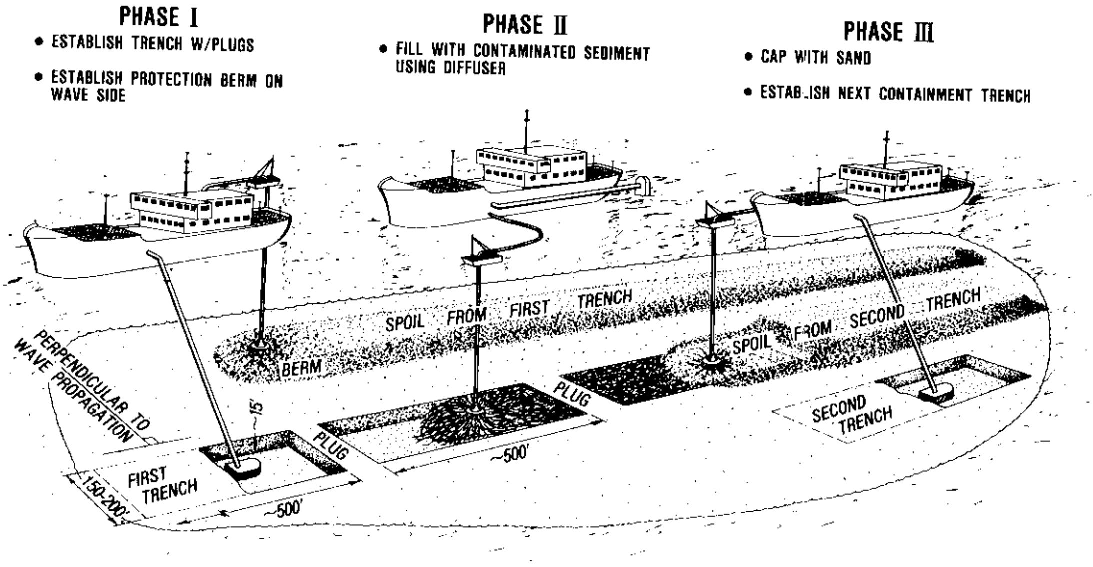


Figure 19. Sequence of construction for CAD site in lake area

berm of material along the trench and some distance seaward. As soon as the dredge completed the first trench, disposal of contaminated sediment could begin in the first 500-ft section. Placement of the material would likely involve the use of a pump-out barge and the submerged diffuser to reduce resuspension and to ensure accurate placement and accounting of the contaminated sediment.

224. Some additional testing will need to be accomplished prior to final design of a CAD option to establish the optimum method for placing the cap material. Certainly, the cap material will need to be placed in a manner that minimizes impact or point loading on the surface of the semifluid contaminated sediment. Options include the use of the submerged diffuser; direct pump down from the hopper dredge to the bottom through the diagram; slow sprinkling of the material through the water column by controlled discharge from the hopper doors; or, even sidecasting, or similar sand spreading equipment tested by the Japanese. In each case, the unknowns to be addressed are not so much the equipment, but the time before the initial lift of cap can be placed and the rate at which additional lifts can be added. Waiting to place the cap increases the internal shear strength of the contaminated sediment and reduces the chance of displacement during capping, but leaves the contaminated surface exposed to the overlying biota and to transport by sudden storm action. Additives or other forms of stabilization are possible if investigation indicates such a need.

225. Whatever final method is used, the operation lends itself well to sequential construction. Cap material for the first trench can come from excavation for a second trench, parallel and shoreward of the first. (Of course, volumes do not balance and there will be considerable excess produced by the excavations.) Placement of a continuous lift of capping down an entire

2,000-ft length may be the first cap on the last 500-ft section, and at the same time, the fourth and final lift on the initial 500-ft section (Figure 20). Positioning, timing, and traffic control at the site will be critical; otherwise, the operation of the equipment is conventional and the staging is a logical process. Four such trenches would contain the entire volume.

226. The design of the cap section will require input from the District on economic requirements and risk analysis. The 20-in. thickness for isolation is a minimum. An armor layer sized for the 100-year return interval storm and placed on a graded filter bed above the cap may be an extreme approach that is warranted only as the most conservative approach. Incipient motion theory addresses only stability and not transport, especially not transport rates. A thickness of much smaller (gravel) material could be placed through a diffuser or similar technique and have some potential for motion although infrequently. Advanced nourishment with a greater thickness of the native material is also a possibility. Some motion will occur on a regular basis, but material will move onto the site as well as leave it. Net loss might take place over time, but maintenance may be more economical than armoring. The berm of material left in place could provide a source for movement onto the site that would slow loss rates.

227. Outer harbor site. Design considerations for a site in the outer harbor (and possible smaller demonstration sites in the inner harbor) are similar to those described above. The primary difference is in the equipment used for the excavation. In the harbor areas, under favorable weather conditions, a cutterhead dredge could be used to excavate the disposal area. Digging depths (approximately 40 ft) may still require ladder pumps or similar equipment, but the size would be reasonable.

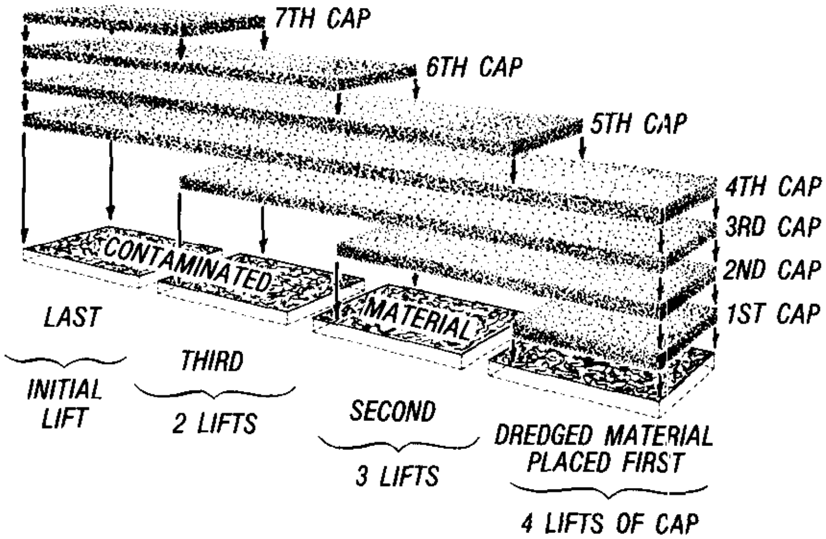


Figure 20. Section showing incremental loading resulting from sequential application of cap material

228. The configuration of the turning basin dictates a site that is rectangular rather than the linear trenches. Compartmentalization is still important, but could be achieved by subdividing the site into six to nine smaller sections in a "checkerboard" arrangement. The construction sequence previously described could still be productively employed with the added benefit in handling that the excavating dredge could discharge cap material on completed sections directly through a pipeline with an integral diffuser. Figure 21 shows this sequence applied in the harbor area. Among other assumptions, this option presumes that the native material at the outer harbor site is suitable as a capping material. Only lake bottom sediments have been tested. The contaminated sediment could also be placed directly by pipeline and diffuser if a hydraulic dredge is used for the actual removal.

229. Cap design in the harbor requires consideration of the effects of ship transit on the bottom as well as the potential effects of any armoring on those ships. These issues have been discussed in previous sections and in detail in the appendixes. The effect of a CAD site on the future maintenance and/or improvement of the harbor is also an issue that can only be addressed by the District in considering this alternative.

Monitoring

230. Monitoring at the site must address both contaminant migration and physical condition of the site and do so over time. Three basic categories of monitoring are suggested based on their time frames and intent.

231. Construction. Considerable monitoring must take place before, during, and immediately following the construction operation. Background chemical characterization of the site will be necessary to serve as a baseline for comparisons. Water samples should be taken during the placement and capping primarily for monitoring resuspension in the area. However, the focus

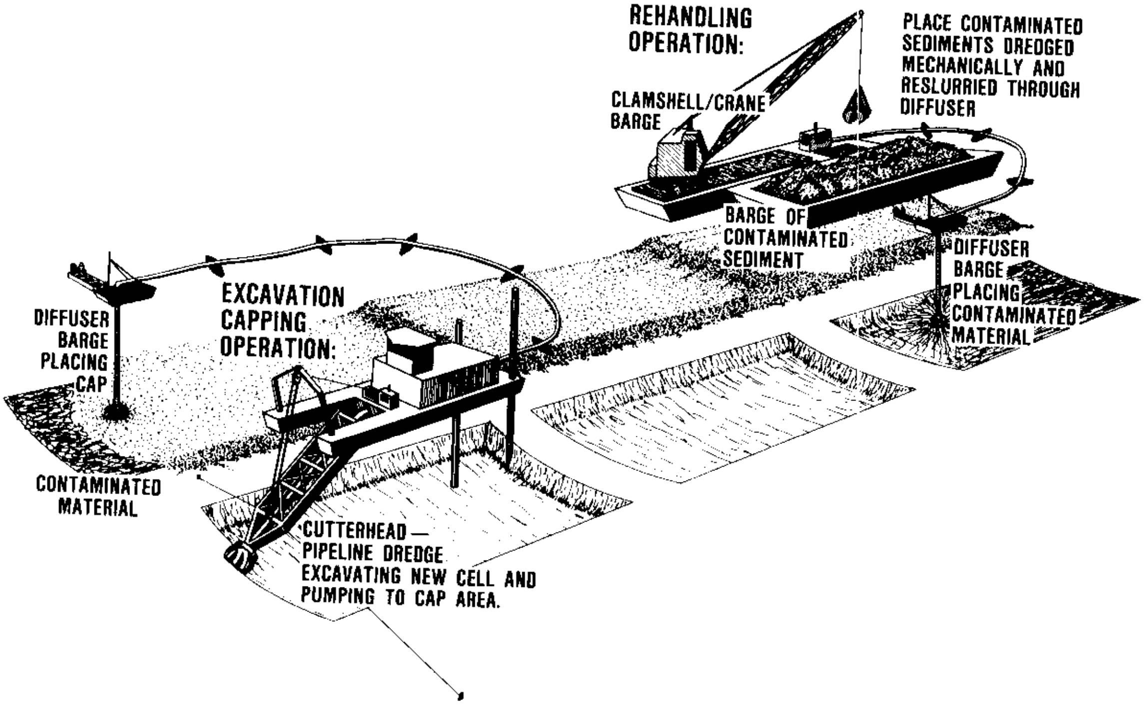


Figure 21. Sequence of construction for CAD site in harbor areas

of the construction monitoring should be on bathymetry, accurate positioning, and accounting for the volume/mass of sediment handled. Moored buoys will be required at the site together with a real time and recording positioning system. Replicate soundings must be taken frequently during placement of the sediment and the capping. Side-scan sonar and video equipment could also be used to verify conditions.

232. Cores must be taken through the completed cap to verify thickness and to determine sediment chemistry. Recommended indicators are metals, PAHs, and PCBs. Indicators for the water column analysis should include one to two metals (probably arsenic), phenol, one to two PAHs, total PCBs, and total suspended solids. A complete series should be taken on completion of the construction, and again after 1, 3, and 6 months. Bathymetry should also be repeated at these intervals.

233. Long term. Similar water column and sediment series should be completed at 1, 3, 5, and 10 years after construction. Bathymetry and consolidation should also be measured at these intervals.

234. Contingency. In addition to the above regular monitoring, specific contingency plans should be developed to complete a similar monitoring series after a prespecified threshold storm event or ship incident.

Confined Disposal Alternatives

Background

235. A confined disposal facility is an upland or in-water structure constructed for the disposal of dredged materials. About 60 percent of all dredged materials in the United States are confined in one type of facility or another. Upland confined disposal facilities may be formed by the

construction of earthen dikes or use of existing pits or depressions. In-water CDF's are typically made of stone-filled dikes, similar in appearance to a breakwater. Confined disposal facilities are often constructed in Europe and Japan for special purposes, such as the creation of "fast" land for port development.

236. The Corps has constructed some 30 confined disposal facilities around the Great Lakes since the 1960's. These facilities were authorized under the diked disposal program (PL 91-611). Facilities were constructed to confine polluted dredged materials deemed unsuitable for open-water disposal. Of the facilities built around the Great Lakes, eight have been upland CDF's and 22 are in-water facilities. Sizes have ranged from a few acres to several hundred. A number of these facilities have supported purposes other than disposal of dredged materials, such as marina development, shoreline protection, and creation or expansion of parks and wildlife areas.

237. The evaluation of a site for a confined disposal facility must consider many factors: capacity; site characteristics such as groundwater table, geometry, layout, and foundation conditions; compatible methods of dredging and disposal; costs; public acceptance; potential environmental impacts on groundwater, surface water, and aquatic and terrestrial animals and plants; potential impacts on ultimate site usage; and archaeological and historical resources. The selection of a site for a CDF can be a very lengthy process, requiring extensive coordination with local, state, and Federal government agencies. The site selection for a CDF for Indiana Harbor has lasted over 14 years.

238. The design of a CDF centers around engineering and environmental analysis. The engineering of a diked structure is similar to that of a dam or

levee. Geotechnical and structural evaluations of dike foundation and materials for construction are used in the analysis of dike stability. Hydraulic evaluations of the wave climate and coastal forces are used in the analysis of dike size, configuration, and materials for an in-water CDF. Environmental evaluations consider the containment of contaminated dredged materials, routes of contaminant loss, and exposure of the environment to the contaminated sediments in the analysis of control measures. Control measures are design or operational features which limit the movement of contaminants or the exposure to the environment.

239. Through the application of the Management Strategy, the potential routes of contaminant migration (effluent, leachate, and surface runoff) and environmental exposure (plant and animal uptake) have been examined. The potential routes of contaminant migration and the corresponding testing protocols and control measures as called for by the Management Strategy are indicated in the lower portion of Figure 4.

240. The appropriate laboratory tests have been completed and the results will be used to evaluate control measures for the confined disposal of PCB-contaminated sediments from Indiana Harbor. Two confined disposal alternatives will be considered, an in-water CDF and an upland CDF.

<u>In-Lake CDF</u>

241. The in-lake CDF considered in this part is a site and corresponding design proposed by the Chicago District to confine 1,300,000 cu yd of moderately to heavily polluted dredged materials from Indiana Harbor and Canal (USACE 1986). This analysis will assume that this site was enlarged to provide capacity for the 200,000 cubic yards of PCB-contaminated material. This evaluation also would also apply to a similarly-designed CDF at another site.

242. Engineering evaluation. Engineering evaluation is divided into the four areas of concern for confined disposal: effluent quality, runoff quality, leachate quality, and plant and animal uptake and volatilization. These contaminant pathways are shown conceptually for an in-lake CDF in Figure 22. Possible contaminant control measures for the in-lake CDF are summarized below and discussed in the following paragraphs.

Possible Control Measures for In-Lake CDF

Contaminant Pathway	Control
Effluent	Settling Filter Dike Chemical Clarification
Surface Runoff	Encapsulation Place Below Lake Level
Plant/Animal Uptake	Encapsulation
Leachate (Through Dikes)	Filter Dikes Operational Controls Encapsulation
Volatilization	Encapsulation Place Below Lake Level

243. The evaluation of effluent quality examines the sedimentation design for storage and water quality; the chemical clarification concept for additional solids removal; the filter design for filtering rate, clogging potential, removal efficiency, and design concept; the disposal operation concept; and the probable effluent quality based on results of laboratory testing and other information. Additional restrictions are presented to improve the effluent quality for both mechanical and hydraulic dredging. The evaluation of surface runoff quality summarizes the results of laboratory testing, proposes restrictions on the disposal operation, and presents control

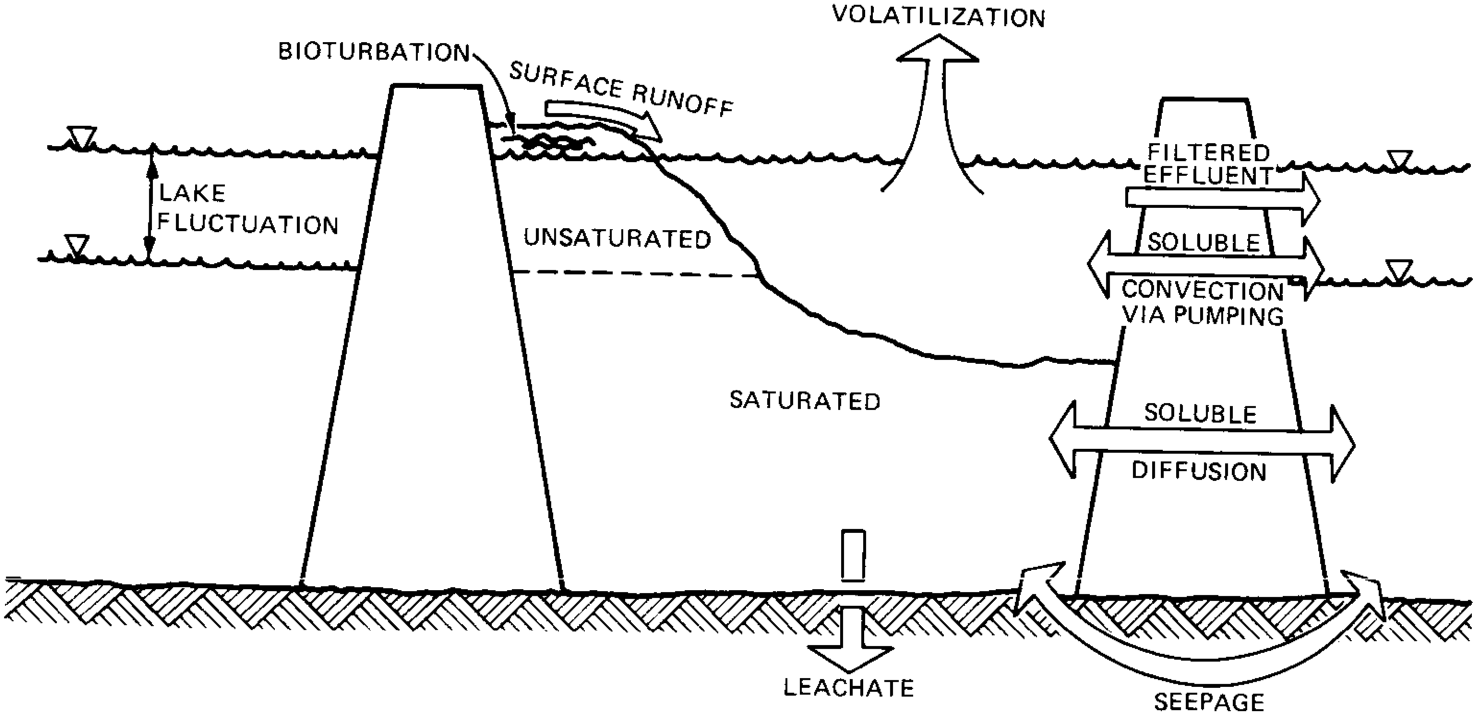


Figure 22. Contaminant pathways for an in-lake confined disposal facility

measures to reduce contaminant release by runoff. The evaluation of leachate quality presents the results of leaching tests indicating leachate quality as a function of volume of leachate produced and assesses the potential attenuation in contaminant concentration before reaching the groundwater or the lake water. Potential restrictions in the disposal operations to reduce the rate and contaminant concentration leaching from the site are discussed. The evaluation of plant and animal uptake summarizes the potential uptake of contaminants in both an aerobic and anaerobic environment and presents the restrictions required for both environments. The evaluation of volatilization presents the potential for losses by volatilization and gives control measures to reduce it during and after dredging.

244. Proposed operation and design. The proposed CDF is located in Lake Michigan at East Chicago, Indiana, and is referred to as site 12 in US Army Engineer District, Chicago (1983). A sketch of the CDF is shown in Figure 23. The proposed CDF design includes stone-filled dikes. The dikes will be permeable with a core of prepared limestone or quarry-run stone and a 10-ft layer of lake sand to act as a filter for discharging the clarified supernatant water. The proposed cross section of the dike is shown in Figure 24. The CDF dikes will be constructed to a crest height sufficient to withstand overtopping by most frequent storm events.

245. The proposed CDF is about 35 to 40 acres and has a depth of about 35 ft. The capacity of the CDF is expected to be 1,400,000 cu yd of sediments. It is anticipated that about 200,000 cu yd of sediments will be deposited during each of seven dredging projects spread throughout a 10-year period. Each project will last about two months (US Army Engineer District, Chicago 1985).

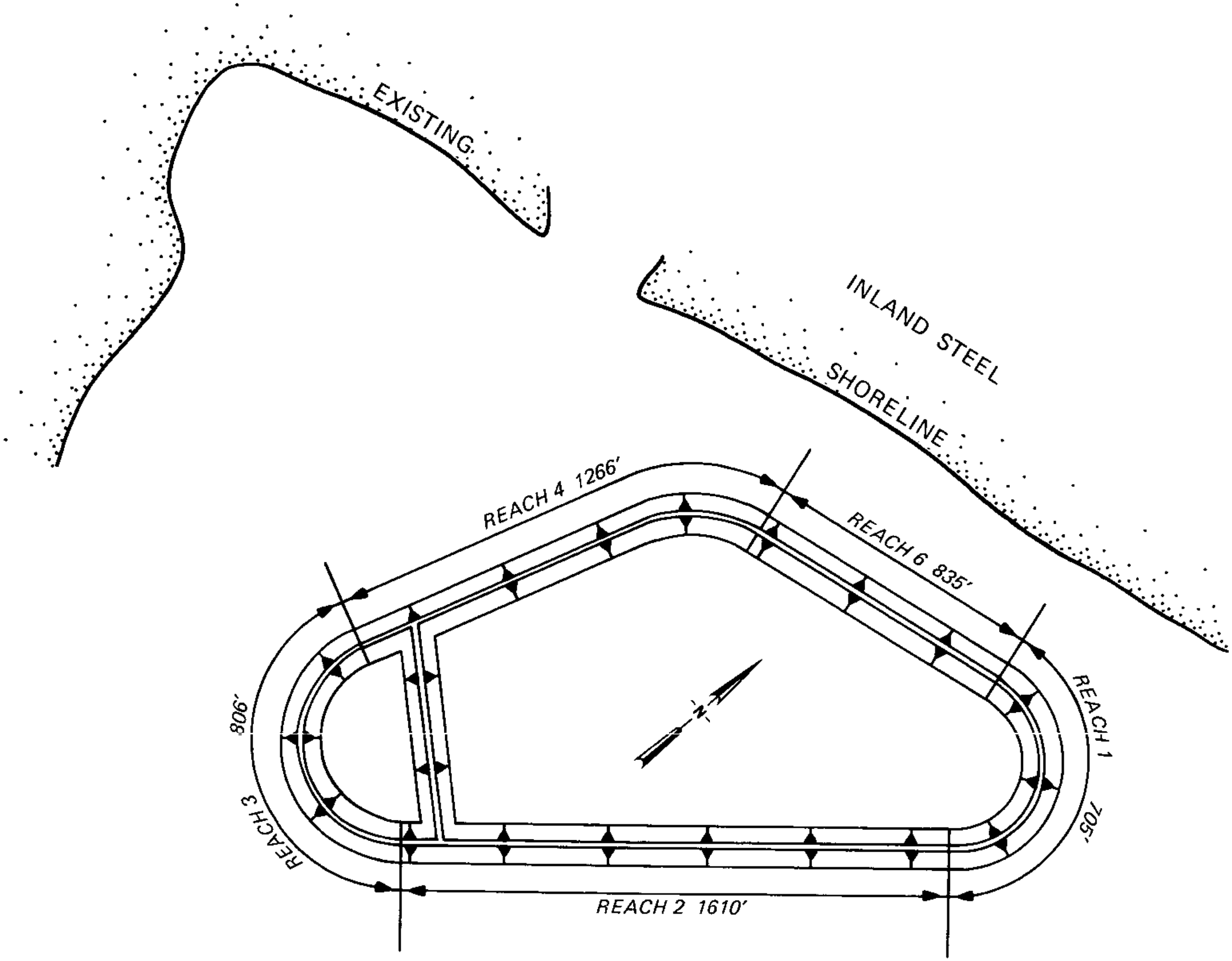


Figure 23. Site plan of proposed in-lake CDF

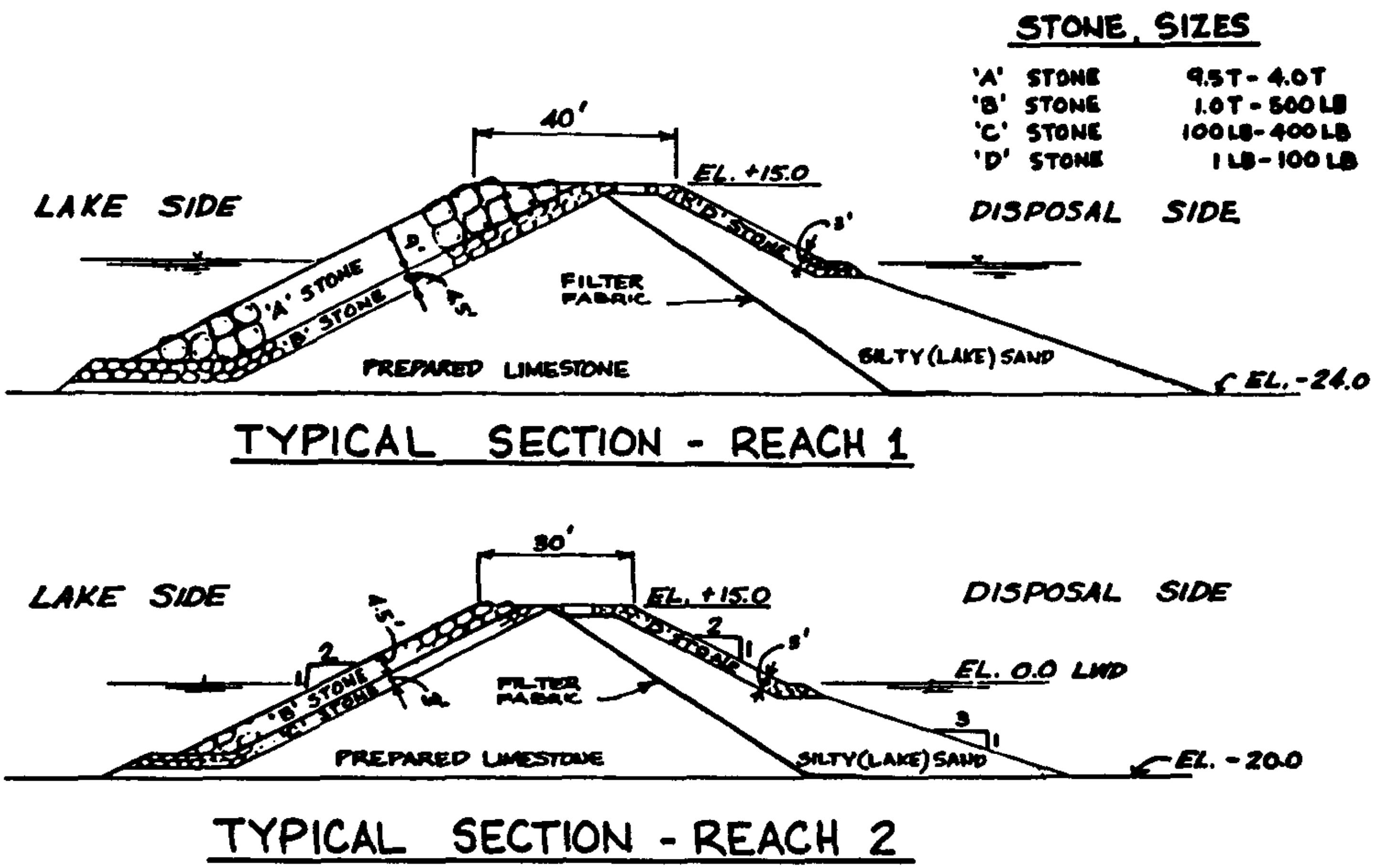


Figure 24. Typical dike cross section of proposed in-lake CDF

246. The CDF will be divided into two settling basins separated by a cross dike. The large primary basin will receive all of the dredged material and will be used for plain sedimentation and storage. The small secondary basin will be for chemical clarification and will receive only clarified supernatant water or filtered water from the primary basin. The CDF will be constructed of previous dikes and all water leaving the CDF will either filter through the dike or evaporate. Supernatant water from the primary basin will be pumped into the secondary basin from a pumpout tank after the primary basin dikes clog. Polymeric flocculants will be added to the pumped water to enhance clarification.

247. The proposed CDF disposal operation consists of mechanically dredging sediments into barges and scows using a clamshell dredge. The material is then either mechanically or hydraulically transferred from the scows to the primary basin of the CDF. Water from the CDF will be used to transport material from the scows when necessary, minimizing the flow rate of water passing through the CDF. In essence, the volumetric flow rate will equal approximately the dredge production rate in cubic yards of sediments per day since this should approximate the rate that the disposed sediments displace water in the CDF. Another alternative is to use a hydraulic dredge (such as the matchbox or cutterhead) for dredging and disposal. Its flow rate would be greater than that of a mechanical dredge.

248. The proposed CDF could be expanded to store the PCB-contaminated sediments from Indiana Harbor Canal as well as the other, less contaminated material. The PCB-contaminated sediments may be dredged either mechanically by a clamshell dredge or hydraulically by a matchbox dredge.

249. Sedimentation. A detailed evaluation of sedimentation and filtration is presented in Appendix A and the findings are summarized here. The

effluent quality of the supernatant and the loading on the filter dikes are highly dependent on the dredging and disposal methods and stage of CDF filling. As presented in Appendix A the suspended solids loading on the filter dikes, that is the supernatant solids concentration following settling is summarized as follows:

Dredging and Disposal Method	Predominant Settling Behavior in CDF	Suspended Solids Loadings to Filter Dikes Following Settling
Hydraulic Dredging with Direct Pumping	Flocculent Zone	2.1 g/ℓ 0.4 g/ℓ
Mechanical Dredging with Hydraulic Off-Loading	Flocculent Zone	1.3 g/ℓ 0.25 g/ℓ
Mechanical Dredging with Mechanical Off-Loading	-	0.020 g/ℓ

As shown in the summary, the loading for hydraulic disposal may be much lower if the influent concentration is kept high and the settling is controlled by zone settling instead of flocculent settling. Detailed discussion is found in Appendix A.

250. Filter dike. The dikes (shown in Figure 24) appear to be sufficiently high to prevent overtopping by waves. Waves in the region under severe winds could be as large as 20 ft but with the breakwater the design should be adequate. The gradations and order of placement of the dike material should prevent erosion. Loss of sand by migration into the layers of larger stones should be prevented by the filter fabric. If lake sand is used in the dike section as proposed the grain size and permeability are too small to prevent clogging and to ensure adequate seepage throughout the disposal life of the CDF except for mechanical disposal. This could be remedied by selection of sands with higher permeability and effective size. The filter

material and depth of filter sand is sufficient to remove virtually all suspended solids from the effluent.

251. Disposal operation and control measures. A plan view of the CDF showing a possible arrangement of contaminant control measures for the PCB-contaminated sediments is shown in Figure 25. Sediments will be dredged either mechanically by a clamshell dredge or hydraulically by a matchbox dredge. If dredged hydraulically, the material will be pumped directly into the primary cell of the CDF. If dredged mechanically, the material will be placed in scows which will transport the material to the CDF. The scows will be emptied into the primary cell of the CDF either mechanically or hydraulically using water from the CDF to aid the transfer. The CDF will be divided into two cells--a primary cell of about 40 acres and a secondary cell of about 2 acres as shown in Figure 25. The primary cell is for plain sedimentation and storage, and the secondary cell is for additional filtration and chemical clarification of supernatant water. The CDF will be constructed of previous dikes and all water leaving the CDF will either filter through the dike or evaporate. Water will pass into the secondary cell from the primary cell by filtering through the cross dike separating the cells (prior to clogging) and by being pumped from an intake structure in the cross dike. Water passing through the pump intake structure will be treated prior to discharge with a polymeric flocculant to coagulate emulsified oil and rapidly settle most of the remaining suspended solids. The treated supernatant will then exit the secondary cell by either evaporation or seepage through the dikes.

252. This disposal concept of the proposed in-water CDF appears to minimize the potential detrimental effects to the environment while still performing the dredging and disposal with conventional equipment and

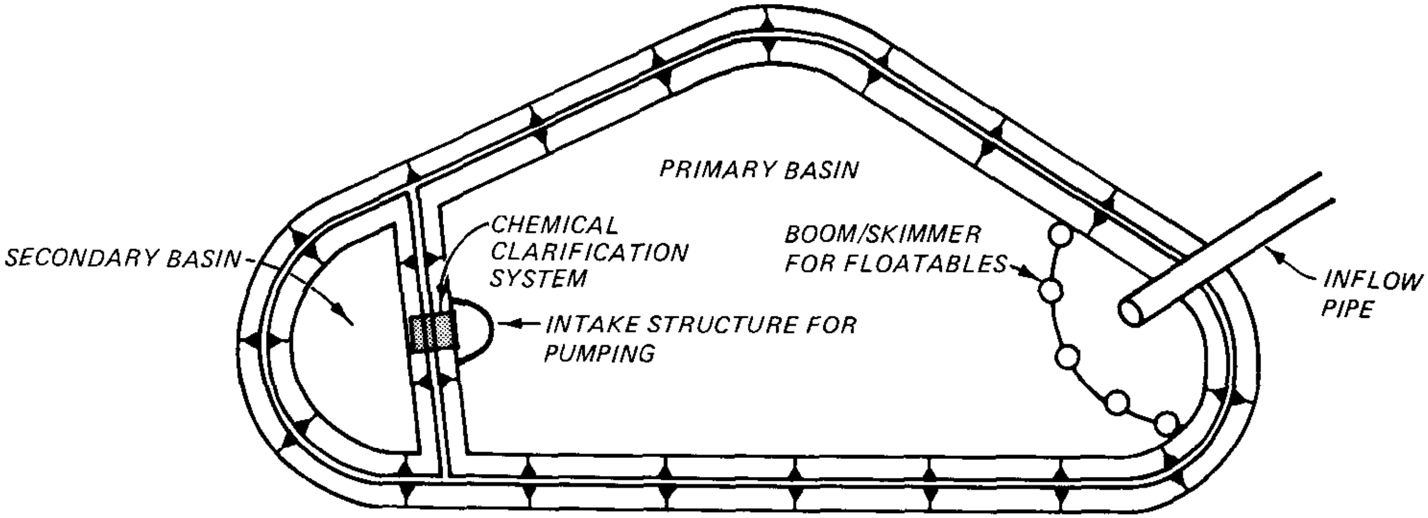


Figure 25. Plan view of confined disposal facility showing arrangement of contaminant control features

procedures. However, several operational problems may exist in the execution of this concept.

253. The supernatant from the primary cell may contain oil and grease which have the potential to clog the previous dikes. Oil and grease can clog filter sands having large effective grain sizes. Therefore, a device such as an oil boom with a skimmer or an oil absorbent should be installed as shown in Figure 25 to skim the oil and grease around the inlet before the oil reaches the dikes or is emulsified by turbulence. A similar device should also be placed in the primary cell where the supernatant passes through the pumpout structure to the secondary cell. For additional oil removal, the polymeric flocculant used for chemical clarification should be selected in part for its ability to remove oil and grease. Oil removal is very important since PCB is commonly associated with the oil.

254. Leakage through the weir structure during periods of operational difficulties with the treatment system could seriously deteriorate the quality of the supernatant in the secondary cell. This would lead to clogging of the secondary cell's dikes. This problem as well as the problem of producing enough mixing for effective treatment could be eliminated in the proposed disposal operation by pumping the supernatant from the primary cell into a rapid mixing tank that discharges into the secondary cell. This method requires more equipment, labor and energy but provides much better controls.

255. Treated material tends to settle into a low density mass. Consequently, the secondary cell may fill fairly soon for the hydraulic disposal alternatives. This would drastically reduce the surface area of the sand available for filtering. Therefore, settled material from the secondary cell should be periodically pumped back to the primary cell.

256. The chronological order of the dredging projects should be arranged in a manner to seal the PCB-contaminated material subaqueously between layers of less contaminated clays and silts as shown in Figure 26. The moderately polluted sands should be deposited in the CDF last. In this manner less contaminated clays and silts would seal the bottom and sides of the primary cell before PCB-contaminated materials are introduced into the CDF. Less contaminated clays and silts are then placed above the PCB-contaminated material in the CDF. The clays and silts have low permeability which will slow any potential migration of contaminants from the CDF by leaching. The less contaminated clays and silts also have the potential to adsorb some of the contaminants which will attenuate the impact of any potential release.

257. Keeping the PCB-contaminated material encapsulated in a subaqueous environment and covered by cleaner material serves several functions. It prevents contaminants from being released by erosion and plant and animal uptake. It reduces the release of volatiles. Subaqueous confinement also reduces the release of contaminants by oxidation.

258. Disposal of contaminants early in the life of the CDF also allows more time to be available for settling during disposal and less resuspension of settled material by wind. Dredging clean sands last would minimize the loading of fine-grained solids into the CDF when the available volume for settling is the smallest. This will improve the supernatant quality at the end of the disposal operation. The sand cover would also minimize the potential for erosion.

259. Effluent quality. Estimation of the likely effluent quality is based on the results of the settling, filtering, and modified elutriate tests. Effluent quality for the in-lake CDF refers only to that supernatant water that filters through the dikes (see Figure 22); the quality of water leaching

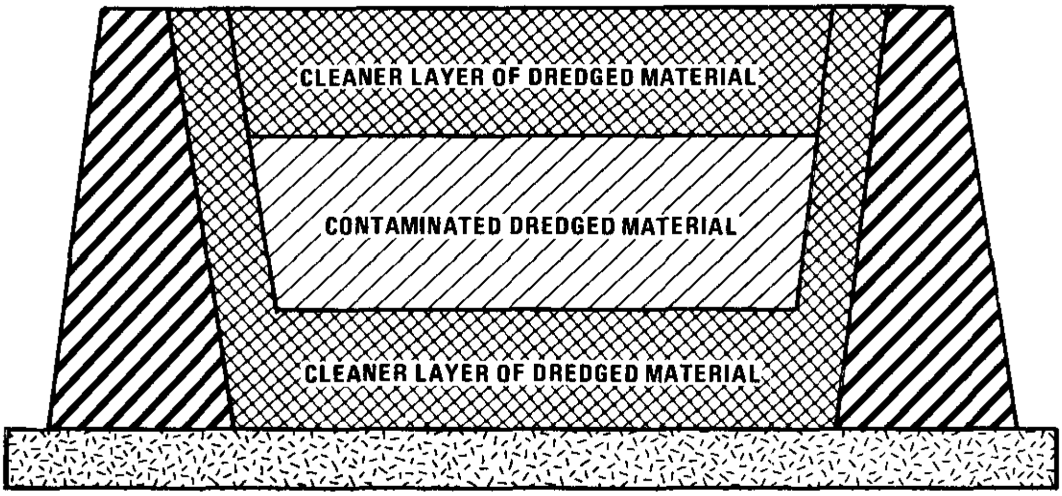


Figure 26. Disposal concept for encapsulation of PCB-contaminated dredged material within alternating layers of cleaner dredged material

from the settled material may be drastically different. The D_{10} for the secondary cell dikes will be about 0.5 mm based on projected permeability of the sand; therefore, using Krizek's (1976) relationships, the effluent suspended solids concentration will be less than 0.5 mg/ℓ.

260. The modified elutriate results are discussed in Part II and in Appendix B. Filtering is expected to remove all of the contaminants adsorbed on solid particles. Only dissolved contaminants are expected to be released. The modified elutriate test predicts dissolved contaminant concentrations in the supernatant following disposal by hydraulic means and plain sedimentation. The modified elutriate test was run using an initial concentration of 100 g/ℓ which is characteristic of the influent for disposal by hydraulic means from scows. Laboratory tests are not available for directly evaluating effluent quality from clamshell disposal into CDF's or from disposal using a matchbox dredge with a submerged diffuser.

261. The effects of chemical clarification by polymer addition and of filtration are not modeled by the modified elutriate test or any other standard test protocol. Chemical clarification jar tests and filter tests could be used to determine whether any effects on the dissolved contaminant concentrations should be expected. Significant effects are not expected for most contaminants; therefore, the effluent is likely to contain only the dissolved contaminants predicted by the modified elutriate test. However, the concentration of very hydrophobic, easily adsorbed contaminants such as PCBs may be reduced significantly by adsorption to the fine-grained material in the dikes.

262. The Indiana water quality standards are listed on Table 1. Comparisons of probable effluent quality from the in-lake CDF under different methods of dredging/disposal are shown on Table 3, and discussed in

Appendix B. The CDF effluent with hydraulic transfer would exceed Indiana Lake Michigan standards for cadmium, lead, iron, phosphorus, phenol, and PCB. This assumes the sediments are reslurried and hydraulically transferred to the CDF using water from within the CDF. The effluent with hydraulic dredging using a matchbox dredge exceeded standards for iron, phosphorus, phenol, and PCB. With mechanical disposal, the CDF effluent should meet Indiana Lake Michigan standards for all parameters with the possible exception of PCB's, which should approach ambient Lake concentrations (approximately 0.02 μg/ℓ). The concentrations of most contaminants would be lowest for mechanical disposal and highest for hydraulic transfer from scows. If a small mixing zone were considered (less than 100 feet), the concentrations associated with matchbox dredging would fall within the standards. No mixing zone, other than the stone-filled dike, would be required if the sediments were disposed mechanically.

263. Leachate quality. The potential for leaching from the proposed CDF is very small. As dredged material is placed in the CDF, the material gradually spreads and settles across the bottom of the entire CDF and in time consolidates to form a layer that can virtually seal the CDF. Consolidated dredged material can have a permeability as low as 10^{-9} cm/sec. In addition to the low permeability, the driving force for seepage is very small since the difference in head between the lake and the CDF is likely to be small. Consequently, if the contaminated materials were placed in the CDF after previous disposal operations had deposited enough material to seal the CDF, the potential for leaching to release contaminants is very small.

264. Leaching tests have been run to estimate the water quality of the leachate from the contaminated sediments. The tests indicate that the sediments have a tendency to retain heavy metals and PCBs, releasing only trace

quantities in the leachate. The results of the leaching tests are presented in Part III and Appendix G. The concentration of contaminants would be further attenuated by adsorption on clean materials that the leachate will pass through prior to reaching the lake or groundwater. Consequently, if the CDF is managed properly, leaching is not expected to be a significant problem due to the small quantity of leachate expected and the low concentrations of contaminants.

265. Use of mechanical dredging and disposal instead of hydraulic dredging would further reduce the quantity of leachate and release of contaminants since the quantity of water in the deposited material that will be released during consolidation is much smaller. The water content of recently settled hydraulically dredged material would be about 300 percent while mechanically deposited material would be about 130 percent. In addition, the permeability of the mechanically deposited material is smaller since the material is more consolidated. The only drawback of mechanical disposal is that the material does not spread as well and, consequently, may not seal the CDF as well as hydraulically placed material. Therefore, it may be prudent to use hydraulic disposal in at least one of the disposal operations prior to disposal of the PCB-contaminated material. Alternatively, the area including the dikes where the PCB-contaminated sediments are to be disposed by either mechanical means or with a submerged diffuser should be lined to be relatively impermeable.

266. Runoff quality. Runoff should not pose a problem since the PCB-contaminated material should be placed below the water level and no runoff should occur. Additional less contaminated material should be placed above the PCB-contaminated material to encapsulate the contaminants and prevent

runoff from contacting PCB-contaminated materials. In addition, all runoff will be filtered by the dikes before leaving the CDF and entering the lake.

267. Contaminant uptake. Encapsulating the PCB-contaminated dredged material should prevent any long-term plant and animal uptake. The short-term uptake should also be small since the PCB-contaminated material will be placed under water in an enclosed area offshore. Consequently, plant and animal uptake should not pose a significant problem. Plant uptake of contaminants was insignificant for sediments under water. The same sediment was toxic in the animal uptake test until sufficiently oxidized; consequently, there was no short-term uptake.

268. Volatilization. The PCB-contaminated materials, if hydraulically disposed, should be pumped into the CDF through a submerged inlet to minimize splashing and turbulence at the surface thereby minimizing stripping of volatiles. In addition, the PCB-contaminated material should be disposed below the lake level to keep the material saturated. Drying and subsequent wetting would significantly release volatiles from the dredged material (Thibodeaux 1979, and Chiou and Shoup 1985). Therefore, it is important to design the cap to keep the dredged material saturated and to provide a capillary break between the dredged material and the cap. A layer of sand placed above the lake level provides a good capillary break and promotes drainage.

269. Summary. The proposed in-water CDF appears to mitigate the potential detrimental effects to the environment when operated properly. The settling and storage designs appear adequate. The filter design is good except for the effective particle size of the filter layer for the secondary cell. Several design and operational considerations need to be made regarding chemical clarification, oil removal, and sequencing the disposal projects. The effluent quality nearly meets the Lake Michigan water quality standards,

particularly if a small mixing zone is permitted. The concentrations of iron, lead, phenol, PCBs, ammonia, and total phosphorus are likely to be somewhat higher than the standards if hydraulic disposal is used. Only the concentration of PCBs is expected to exceed the water quality standards when mechanical disposal is used.

Upland CDF

270. No specific upland CDF site or design was specified by the Chicago District for consideration, but it was assumed that such a site could be designed which would satisfy the intent of TSCA regulations and guidelines. Therefore, an upland CDF design which performs like a TSCA landfill will be assumed for the purpose of evaluation later in this part. This site would be used solely for the approximately 200,000 cubic yards of PCB-contaminated dredged material.

271. Engineering evaluation. This evaluation examines several control measures for disposal of PCB-contaminated sediments in a conventional upland dredged material containment area. Each control measure is evaluated for its ability to fulfill the intent of TSCA land disposal regulations. As in the evaluation of the proposed in-lake CDF, effluent quality, leachate quality, surface runoff quality, plant and animal uptake, and other factors are considered in the determination of the adequacy of the controls. These contaminant pathways for a typical upland site are shown in Figure 27. The control options considered include no controls, several methods of effluent treatment, several types of caps or covers, several types of liners, and several methods of leachate collection and treatment. The impacts of the dredging and disposal methods are also included in the evaluation. Possible contaminant control measures for the upland site are summarized below and discussed in the following paragraphs.

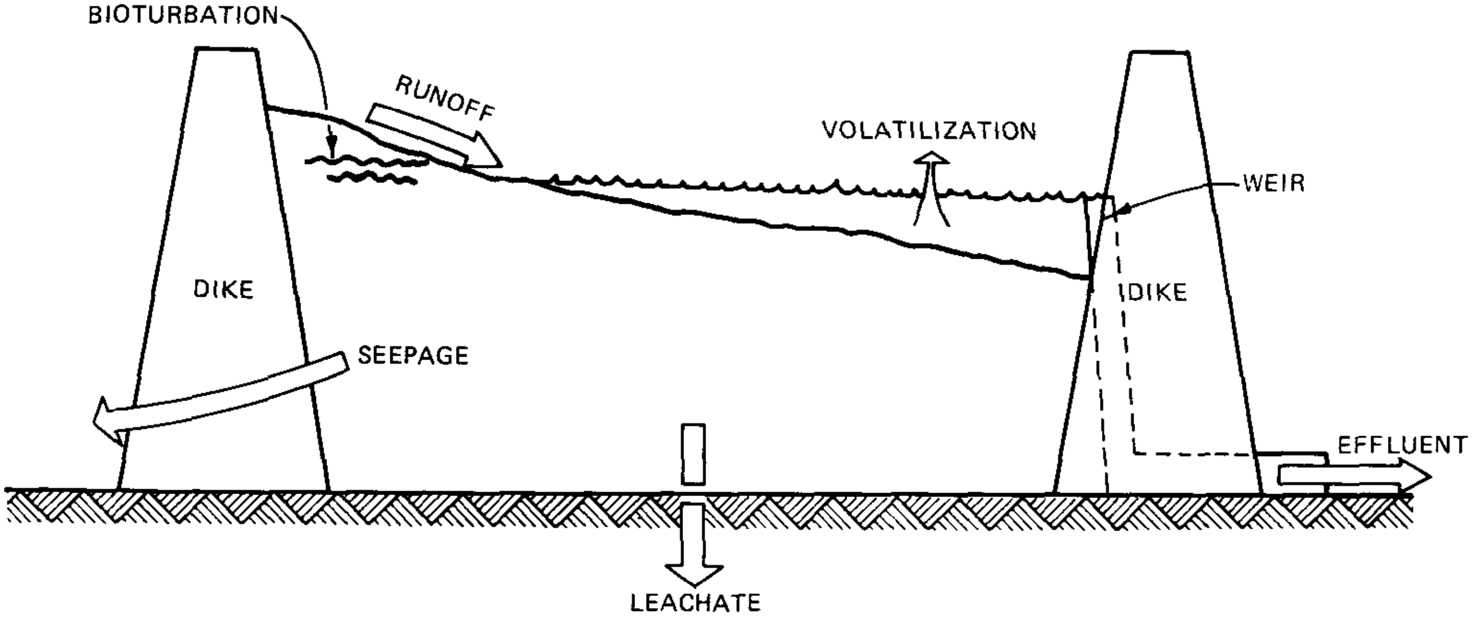


Figure 27. Contaminant pathways for an upland confined disposal facility

Possible Control Measures for Upland CDF

Contaminant Pathway	Control
Effluent (Hydraulic Filling)	Settling Chemical Clarification Filtration Carbon Adsorption
Runoff	Filtration Carbon Adsorption Surface Cover
Volatilization	Surface Cover
Plant/Animal Uptake	Surface Cover
Leachate	Surface Cover Liner Leachate Collection and Treatment

272. Disposal in an upland site differs from disposal in the proposed in-lake CDF in numerous ways. Material in an upland site becomes aerobic and oxidized upon drying, while material placed below the lake level in an in-lake CDF remains anaerobic and reduced. Contaminants (particularly heavy metals) tend to be more mobile and are released at higher concentrations in an aerobic, oxidized environment. During dewatering and drying at an upland site, volatile contaminants are released with the evaporation of site water. Volatilization increases with cyclic wetting such as the infiltration following rainfall events (see discussion of volatilization in Appendix G). Surface runoff of precipitation also gathers contaminants from exposed contaminated dredged material. Similarly, wind can scour exposed material and transport contaminated dust. The quantity of seepage or leachate released from an upland site is greater than from an in-lake CDF of similar design because the pressure head differential between the saturated material and the surrounding environment is greater. In the in-lake CDF, it is proposed that

the PCB-contaminated sediments are codisposed with and encapsulated in other sediments while disposal of only PCB-contaminated sediments was considered for the upland CDF. Codisposal can isolate the contaminants and attenuate the concentration of contaminants leaching from the material.

273. Results of tests performed both on the original anaerobic sediment and on dried, aerobic, oxidized sediment indicated that effluent quality, surface runoff quality, leachate quality, and plant and animal uptake are all unacceptable without controls. The quantity of contaminants associated with suspended material in the effluent and surface runoff greatly exceeded water quality standards for many parameters. The quantity of dissolved contaminants in the effluent, surface runoff, and leachate exceeds the water quality standards for several parameters. The anaerobic sediment was quite toxic to animals while the aerobic, oxidized sediment was able to support life, permitting unacceptable bioaccumulation of contaminants. Plants grown on the aerobic sediment in an upland disposal condition accumulated unacceptable quantities of lead and cadmium.

274. Operation and design. No specific site has been identified for an upland CDF. However, it was assumed that dikes for an upland site would be constructed either from on-site materials or imported materials. Materials used for dike construction would necessarily be relatively impervious. The site design would incorporate covers and/or liners as discussed in the following paragraphs. The size of the site would depend on the method of placement of the material (either mechanical or hydraulic).

275. The PCB-contaminated material could either be placed in the site hydraulically by direct pipeline discharge or mechanically by trucks, depending on the site location. If hydraulic placement is used, the control

measures for maintaining effluent quality would be a major part of the design. If mechanical filling were used, effluent would be only a minor concern.

276. Effluent treatment. Most of the contaminants in dredged material are primarily associated with the sediment particles and the suspended solids. Therefore, the chief goal of effluent treatment for hydraulic filling is the removal of suspended solids. The treatment method employed to remove suspended solids is dependent on the concentration of these solids. When disposed in an upland site, the dredged material undergoes primary settling and consolidation, generating supernatant to be discharged. The suspended solids concentration in the supernatant is dependent on the method of dredging and disposal, being much higher for sediments hydraulically dredged or disposed.

277. Based on settling test results, chemical clarification (addition of polymeric flocculant followed by secondary settling) is required for hydraulically handled sediments. Chemical clarification can reliably reduce the suspended solids concentration to about 20 mg/ℓ in a dredged material containment area. Based on sampling of the supernatant in the Chicago area CDF at Calumet Harbor during mechanical dredging and disposal, chemical clarification is probably not needed to further reduce the suspended solids concentration for mechanical disposal. The concentration of contaminants associated with solids in the supernatant following primary settling and chemical clarification (hydraulic dredging), or primary settling (mechanical dredging) would still exceed Indiana water quality standards (Table 1).

278. Filtration is required to remove additional suspended solids and produce an effluent essentially free of suspended solids. To employ filtration effectively, the influent to the filters should have a suspended solids concentration of less than 50 mg/ℓ to ensure a high quality effluent and to lessen maintenance and operational problems. The effluent quality following

filtration is dependent on the methods of dredging and disposal. Filtrate for sediments hydraulically dredged or disposed is expected to have the characteristics of the filtered modified elutriate sample as listed in Table 3. Filtrate for sediments mechanically dredged and disposed is expected to have the quality of the dissolved or filtered fraction of the interstitial pore water or the initial leachate from the anaerobic sediment as given in Tables G5, G38, and G39 of Appendix G. The volume of filtrate for mechanically dredged and disposed sediments is about 10 percent of that for hydraulically handled sediments. Consequently, the mass of contaminant loss in the effluent is much smaller for mechanically handled sediments.

279. The effluent quality from the upland CDF, using hydraulic dredging/disposal would exceed most of the Indiana water quality standards for the Indiana Harbor/Grand Calumet River (iron, phosphorus, ammonia, phenol, and PCB). A small mixing zone would be required for most of these parameters to meet the standards. The concentration of PCB's exceeds the water quality standards by a factor of about 4000. However, the concentration of the filtered modified elutriate water is only about 10 times the PCB concentration of site water collected from Indiana Harbor Canal for the analysis (0.3 μg/ℓ).

280. Carbon adsorption may be used to provide additional removal of the trace organics, PCBs, and to a much lesser extent, heavy metals. Specific tests were not run to evaluate this control measure, but based on the results reported in the literature, significant reductions in concentration are to be expected. Reductions of soluble, hydrophobic organics such as PCBs and phenol can exceed 95 percent while as little as 10 percent of the small, polar, hydrophilic organics such as sugars and alcohols may be removed by carbon adsorption. Additional tests are needed to determine the probable effluent

concentration for this measure and to evaluate the cost effectiveness of this control measure.

281. In summary, effluent treatment is required to produce an acceptable effluent. As a minimum, filtration should be employed to produce an effluent nearly free of suspended solids which would yield an effluent that approaches acceptable water quality with a small mixing zone for all contaminants except PCBs. The concentration of PCBs in the site water greatly exceeds the Indiana water quality standard of one part per trillion and therefore the small incremental increase in PCBs returning to the site via the effluent may not have a significant impact.

282. Surface runoff. The quality of surface runoff from an upland CDF was evaluated using testing protocols described in Part III and in Appendix E. Runoff from the upland CDF following disposal of PCB-contaminated sediments would have high concentrations of suspended solids and attached contaminants (Table 6). After the sediments have dried and became oxidized, surface runoff would contain reduced levels of suspended solids (Table 7). Control measures for surface runoff from the upland CDF include treatment and surface cover. It is assumed that the runoff would be contained within the diked area of the CDF, and that this runoff could be drained or pumped to a treatment system before discharge. Filtration, as used for the CDF effluent, can remove most suspended solids from surface runoff, producing a discharge water quality as shown in Tables 6 and 7 (filtered runoff).

283. Filtered surface runoff from wet, anaerobic sediments has a quality very similar to the filtered modified elutriate. Filtered surface runoff from wet sediments should therefore be similar to the CDF effluent during hydraulic dredging/disposal. A small mixing zone would be required for most contaminants. Carbon adsorption may be used to reduce the concentrations of

PCB's. The filtered surface runoff from the dry, oxidized sediments would contain lower concentrations of dissolved organic contaminants, but increased levels of most heavy metals.

284. Treatment is a practical control of surface runoff until a surface cover can be applied. A graded, low permeability cover can only be installed after the sediments have been dewatered and consolidated sufficiently to allow access by heavy equipment. The time required for drying and consolidation of dredged material will depend on sediment characteristics, the method of dredging and disposal, the thickness of the dredged material lift, and meteorological conditions. An interim control for surface runoff would be codisposal with less contaminated sediments, which could be placed on top of the PCB-contaminated sediments hydraulically. This would require an increase in the size (capacity) of the upland CDF.

285. Volatilization. Testing procedures during surface runoff and plant and animal uptake studies have demonstrated that significant amounts of organic contaminants can be released from Indiana Harbor sediments during aging or drying. The concentrations of volatile organic contaminants in the sediments air dried for 6 months were reduced by 50-80 percent. PCB's were reduced by more than 50 percent in sediments aged 6 months in a moist condition. These reflect a "worst-case" of the potential contaminant loss through volatilization (see discussion in Appendix G).

286. Controls for volatile loss from an upland CDF are more limited than for the in-lake CDF. Controls must reduce the exposure of PCB-contaminated sediments to drying and rewetting. This is best done by keeping the sediments permanently saturated, which in the upland CDF would promote leachate movement and prohibit the application of a graded, low-permeability surface cover.

Codisposal, with less contaminated sediments (as suggested for runoff control) should reduce the volatile loss from the upland CDF.

287. Caps or covers. Three types of covers were evaluated for their potential to reduce infiltration into the dredged material and thereby reduce the potential leachate production. Covers also effectively eliminate problems associated with surface runoff and contaminant uptake by plants and animals utilizing the CDF. The three types of covers are illustrated in Figure 28. Cover 1 consisted of only an 18-in. layer of clay loam topsoil on top of the graded surface of the partially dewatered dredged material. Cover 2 contained the same topsoil layer but it was underlain by a 24-in. compacted clay liner having a hydraulic conductivity of 1 X 10**(-7) cm/sec. The topsoil and dredged material were assumed to have a hydraulic conductivity of 1.38 X 10**(-4) cm/sec and 2.25 X 10**(-5) cm/sec, respectively. Cover 3 consisted of an 18-in. layer of topsoil covering a 12-in. drain layer of sand overlying the 24-in. clay liner described above. The sand had a hydraulic conductivity of 8.43 X 10**(-3) cm/sec and was placed on a 2-percent slope. All three covers will help to restrict plant and animal uptake by physically isolating the PCB-contaminated material from plants and animals. The thicker covers obviously provide better isolation and the hard, compacted, clay liner restricts root penetration and animal burrowing.

288. Infiltration through the cover and into the dredged material was estimated using the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al. 1984a and Schroeder et al. 1984b). Several assumptions were made to apply the model to the containment area design conditions. The HELP model's default climatic data base for Chicago, Illinois was assumed to be representative of climatic conditions at the upland site. The physical properties of the cover materials and the dredged material such as their

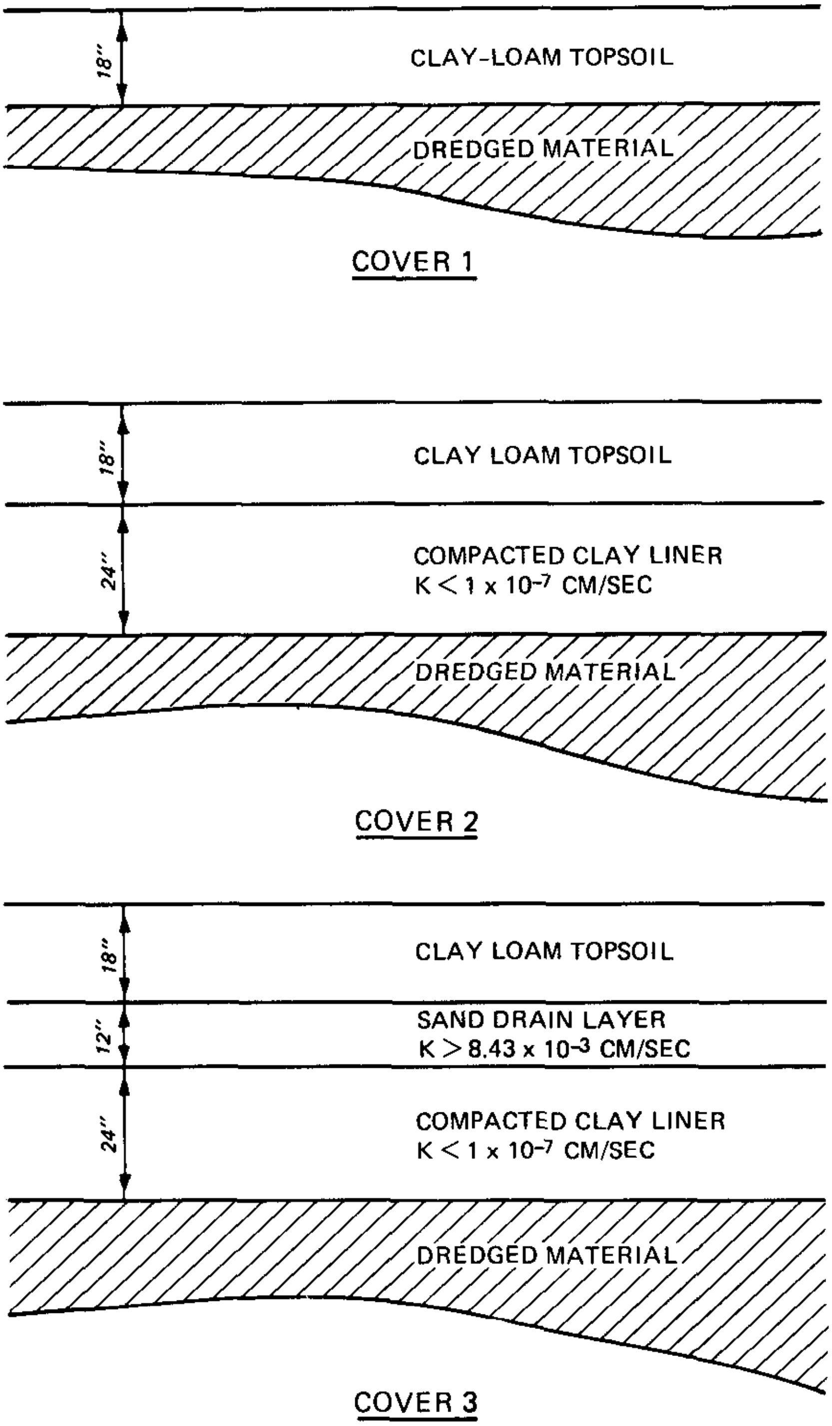


Figure 28. Typical surface cover designs

porosities and saturated hydraulic conductivities were assumed to remain essentially unchanged during the five year modeling period. This assumption is not very good since significant consolidation of the dredged material is expected during this period. Nevertheless, this assumption is acceptable because it represents a worst case analysis since consolidation will restrict infiltration. The in-place dredged material during capping was assumed to have properties similar to that of the in-situ sediment. The topsoil was assumed to be vegetative with a fair stand of grass.

289. The precipitation averaged 34.08 in. per year during the modeling period. The percolation through the cover into the PCB-contaminated material is tabulated below for the various covers.

	Percolation	
Cover Type	(in./year)	(Percent of Precipitation)
Cover 1	7.55	22.15
Cover 2	1.65	4.84
Cover 3	1.36	3.98

These results suggest that a drain layer in the cover does not substantially improve the performance of the cover and is probably unnecessary. The clay liner provides a very substantial reduction in the percolation besides additional protection against plant and animal uptake.

290. Additional reductions in percolation are practicably attainable only by the installation of a synthetic flexible membrane liner on the surface of the clay liner. These additional reductions may not be justifiable due to the saturated condition of the dredged material. The dredged material after primary consolidation and initial dewatering, assuming that the material returns to the soil moisture content of the in-situ sediment, contains about 30 in. of drainable water for approximately an 11-ft depth of dredged

material. This corresponds to the volume of percolation through Cover 2 generated in 18 years. Therefore, the percolation through the clay liner constitutes a small portion of initial leachate production. After consolidation occurs, the leachate production rate will decrease. In the leaching permeameters, the hydraulic conductivity decreased drastically as the pore water leached out the bottom and the material consolidated. The hydraulic conductivity decreased to less than 1 X 10**(-8) cm/sec, a tenth of the hydraulic conductivity value assumed for the clay liner. In summary, the potential for leachate production is largely controlled by the water content and consolidation of the dredged material, and the impact of percolation through the cover is small when a clay liner is used.

291. The performance of the cover may improve if the clay liner is underlain by a sand layer. This layer could drain pore water from consolidating dredged material and initial percolation through the clay liner. The top portion of the dredged material consolidates as a result of the surcharge placed on the material by the weight of the cover. The drainage from this sand layer must be handled in the same manner as leachate since it will contain contaminated pore water from the PCB-contaminated dredged material.

292. In summary, a cover composed of an 18-in. topsoil layer overlying a 24-in. clay liner provides excellent protection against release of contaminants by surface runoff, and uptake by plants and animals. The cover also significantly reduces the contribution of rainfall to leachate production. A sand layer underlying the clay liner may aid the consolidation of the dredged material which decreases the hydraulic conductivity and the rate of leachate production. The cover should be maintained with vegetation to control erosion. Cover maintenance should include a program to cut out woody species

whose roots may penetrate the liner and release contaminants, predominantly cadmium.

293. Liners and leachate collection. Three types of liners for the bottom of the upland dredged material containment area were evaluated for their potential to restrict percolation of leachate from the site. The liner types are illustrated in Figure 29. Liner 1 consisted only of an assumed natural foundation of 60 in. of undisturbed, moderately compacted silty clay loam having a hydraulic conductivity of 1.45 X 10**(-6) cm/sec. Liner 2 consisted of a 24-in. compacted clay liner that was identical to that used in the cover design. The hydraulic conductivity was 1 X 10**(-7) cm/sec. Liner 3 contained the same clay liner but it was overlain by a 12-in. sand layer. The sand layer was identical to that used in Cover 3 and had a hydraulic conductivity of 8.43 X 10**(-3) cm/sec. The sand layer was assumed to be placed on a 3-percent slope with parallel drain pipes spaced 100 ft apart. Underdrainage systems have been studied for dredged material disposal sites (Hammer, 1981). The low permeability of the consolidated sediments and clogging of the sand drainage layer may limit the effectiveness of a leachate collection system. A filter fabric (geotextile) should be placed on top of the sand layer to inhibit clogging.

294. The liners were evaluated using the HELP model to estimate percolation through the liner for a 20-year modeling period (Schroeder et al. 1984a and Schroeder et al. 1984b). Several assumptions were made to apply the model. The 20 years of climatic data were prepared by using the 5 years of default climatic data four times. It was assumed that this procedure would be sufficient to observe the leachate production from draining the initially saturated dredged material besides from infiltration through the cover. The evaluation was performed for each liner overlain by 10 ft of saturated dredged

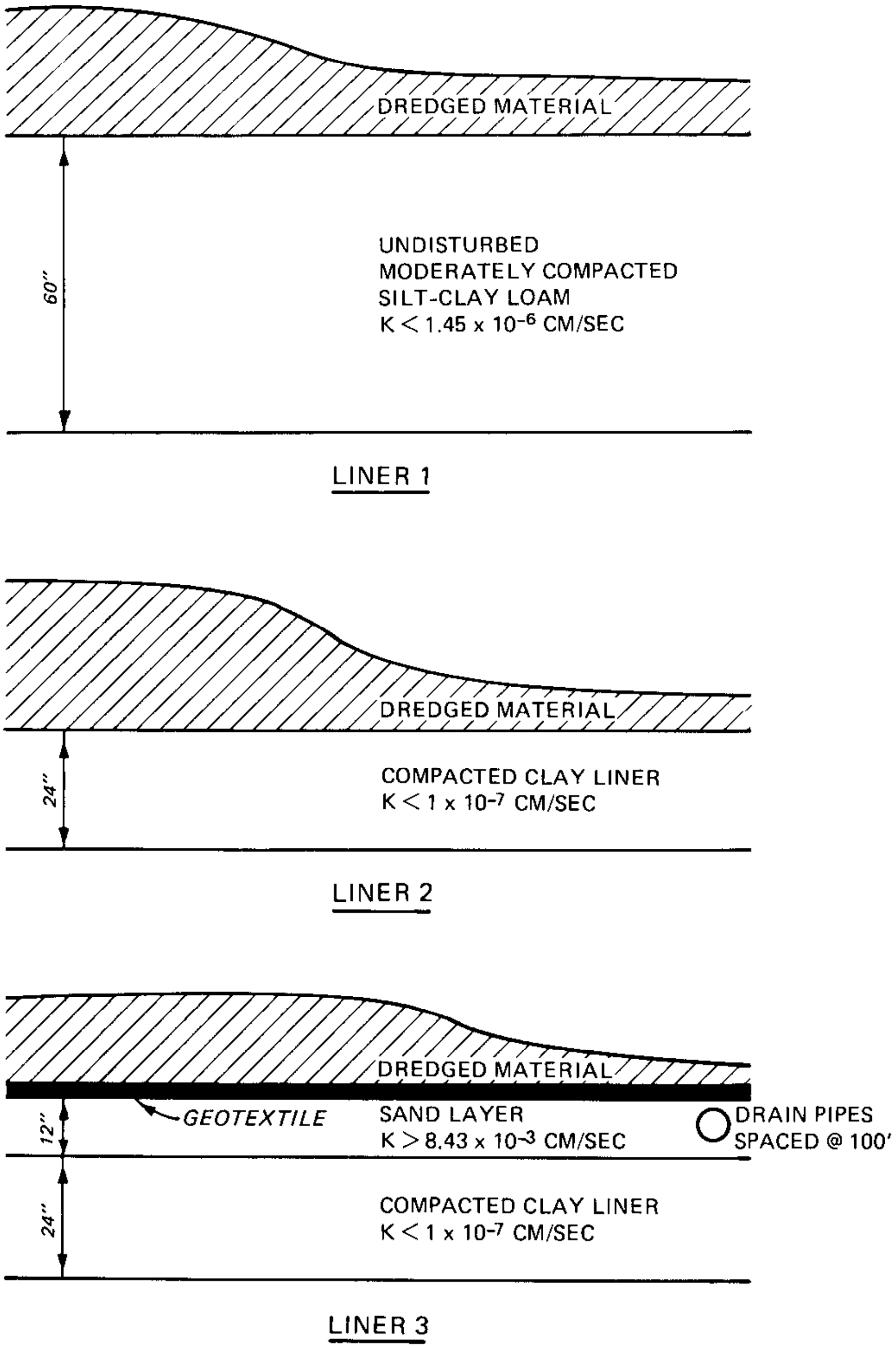


Figure 29. Typical liner designs

material capped by Cover 1 in one case and by Cover 2 in another case. The porosity and drainable porosity of the dredged material was assumed to be 0.72 in./in. and 0.42 in./in., respectively. Its saturated hydraulic conductivity was assumed to be 2.25 X 10**(-5) cm/sec. The physical properties of the materials in the containment area were assumed to remain essentially unchanged during the 20-year modeling period. As stated in the section on covers, this assumption is not very good since significant consolidation of the dredged material is expected as pore water leaches from the dredged material. Consolidation and sealing is most likely to occur when the rate that water is drawn from the material to the leachate collection layer or liner is greater than the rate at which water can move through the dredged material to replace the leached water. Quick consolidation and sealing is expected when a sand drainage layer for leachate collection is used. Consequently, the leachate production rate is expected to decrease and be substantially lower than the estimates produced in this evaluation. Nevertheless, this assumption is acceptable because it provides a worst case analysis that can demonstrate the relative merits of the various liners. The in-place dredged material was assumed to have properties similar to that of the in-situ sediment.

295. The precipitation averaged 34.08 in. per year during the 20-year modeling period. Results of the model runs are summarized in Table 9. For Cover 1 the percolation into the dredged material was on average 7.55 in. per year and 1.65 in. per year for Cover 2. The percolation of leachate through the natural soil foundation (Liner 1) with Cover 1 averaged 10.20 in. per year and 4.23 in. per year with Cover 2. The loss of leachate exceeds the infiltration due to drainage of excess pore water from the dredged material. The leachate production rate decreased rapidly in the first year since the

Table 9

Summary of Liner Performance

	Percolation through Liner, in. (Average per year)*		Leachate Collection, in. (Average per year)*	
	Cover 1	Cover 2	Cover 1	Cover 2
Liner 1	10.20	4.23	-	-
Liner 2	7.19	3.84	-	-
Liner 3	1.28	1.26	8.88	2.94

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* Values for each year decreased exponentially during the 20 year period modeled.

saturated hydraulic conductivity is assumed to remain constant. The percolation of leachate through the compacted clay liner (Liner 2) was on average 7.19 in. per year with Cover 1 and 3.84 in. per year with Cover 2. The percolation rate for this liner is less than the infiltration rate for the design with Cover 1; therefore, consolidation is expected to be slower. With Cover 2 the percolation rate is greater than the infiltration rate and only slightly less than the natural foundation liner. However, the percolation rate is slower and more uniform than it was for Liner 1 which drained the dredged material substantially in the first year. The percolation of leachate through the compacted clay liner with leachate collection (Liner 3) averaged 1.28 in. per year with Cover 1 and 1.26 in. per year with Cover 2. The effectiveness of this liner is essentially independent of the cover design but the cover design severely affects the quantity of leachate collected and to be treated. The leachate collection averaged 8.88 in. per year with Cover 1 and 2.94 in. per year with Cover 2. The drainage rate for leachate collection is initially large and therefore substantial consolidation is expected. Consequently, the saturated hydraulic conductivity will decrease considerably and the leachate production will be significantly lower. Liner 3 performs significantly better than the other liners. Leachate collection is important to reduce the impact of leachate on groundwater.

296. Additional reductions in percolation are practicably attainable only by the installation of a synthetic flexible membrane liner on the surface of the clay liner. The value of these additional reductions may not be significant in light of the potential impacts on the groundwater. The impact is presently difficult to assess without additional laboratory testing but significant attenuation of contaminant concentration is expected as the leachate passes through the clay liner and the foundation soils. The estimated maximum

concentration of contaminants in the leachate exceeds water quality standards for only cadmium, lead, PCBs, and possibly dissolved organic carbon (DOC) under aerobic, oxidizing conditions and for only chromium, lead, PCBs, and possibly DOC. Only the concentrations of PCBs and DOC are high in comparison to water quality standards. PCBs have a high affinity for soils and virtually all of it is likely to adsorb to the clay liner as evident by the high partitioning coefficient between the soil and water. This affinity was found both in this study and in the literature. The behavior of DOC in passing through the clay liner and foundation soils is unknown since its composition is unknown. It is expected that the DOC will have some affinity for soil since it must have had an affinity for the sediment to have stayed with the sediment in the channel rather than escaping to the water column in the channel. However, the affinity cannot be too strong to be present at its high concentration in the leachate. The impact on the groundwater also depends on specific site conditions such as flow pattern, groundwater quality, and groundwater use. In conclusion, additional testing and analysis are required to evaluate the impact of leachate on groundwater. Only the DOC readily poses concern when Liner 3 is employed without a flexible membrane liner.

297. In summary, a leachate collection system consisting of a 12-in. sand layer to collect leachate and a 24-in. clay liner to restrict percolation of leachate to the groundwater provides good protection against release of contaminants by leaching. The system can reduce leachate losses by as much as 90 percent prior to covering the site with a clay liner and as much as 70 percent after capping with a clay liner. Further testing and analysis are required to assess the impact of the leachate quality on potential contamination of the groundwater.

298. Leachate treatment. As stated above, only DOC and PCBs are present in the leachate at concentrations requiring treatment. The treatment process of choice for DOC is dependent on the nature of the chemicals composing the DOC. Stripping may be used to remove and concentrate volatiles. Carbon adsorption is particularly effective for many organic species, especially compounds like PCBs that have low solubility in water and are large, nonpolar, and hydrophobic. The carbon adsorption process is flexible and can be adapted to dredging projects where the leachate quality and quantity are likely to vary considerably. In addition, the process also removes small quantities of heavy metals. Additional treatment may be desired to remove more DOC after carbon adsorption if low removals are achieved. Under that circumstance a biological treatment process should be considered. As an alternative, discharge to a sewage treatment plant for additional treatment should be considered since biological processes perform best under conditions of uniform inflow rate and quality. In summary, treatment is probably required prior to discharge of the leachate because of high concentrations of DOC and PCBs. Additional testing and analysis is required but carbon adsorption appears to be the process of choice.

299. Summary. Disposal in an upland dredged material containment area requires control measures to reduce the release of contaminants by plant and animal uptake and discharge of effluent, surface runoff, volatilization, and leachate. The control measures include effluent treatment, capping, lining, and leachate treatment. Since the contaminants are predominantly associated with the suspended solids in the effluent, filtration is the minimum treatment to produce an acceptable effluent of supernatant and surface runoff. The PCB-contaminated material should be capped by a layer of topsoil underlain by a 24-in. compacted clay liner to restrict infiltration, reduce potential

leachate production, provide a physical barrier between plants and animals and the contaminants, and prevent scouring of contaminated material by surface runoff and wind. Volatilization from an upland CDF can only be controlled by codisposal with less contaminated sediments. The upland site should be lined by a 24-in. compacted clay liner to restrict seepage of leachate out of the site and to decrease the seepage rate. In addition, the performance of the clay liner on the bottom of the area could be improved by overlaying it with a 12-in. sand drainage layer and a leachate collection system. The effectiveness of a leachate collection system will be limited by the low permeability of the consolidated sediments and clogging of the drainage layer. Carbon adsorption appears to be the best treatment process for leachate treatment because of its efficiency and flexibility. These control measures should reduce the loss of contaminants to acceptable levels.

PART V: DREDGING EQUIPMENT EVALUATIONS

300. The two proposed dredging reaches, totaling 200,000 cu yd, of contaminated material in Indiana Harbor have high concentrations of PCBs and other contaminants. When these sediments are disturbed, as in dredging operations, contaminants may be transferred for a short period of time to the water column either through resuspension of the sediment solids, dispersal of interstitial water, or desorption from the resuspended solids. In an investigation of PCB-laden sediments, Fulk, Gruber, and Wullschleger (1975), have shown that almost all the contaminants transferred to the water column were due to the resuspension of solids. The release of contaminants can therefore be reduced by reducing the resuspension of sediment during the dredging and disposal operations.

301. WES has been developing and evaluating innovative dredging equipment and methods to reduce sediment resuspension through the Dredged Material Research Program (DMRP) and the IOMT program. This part is a review of the innovative techniques and equipment and their applicability to the dredging to be done in Indiana Harbor. Also presented in this part is a description of demonstration projects of innovative equipment performed by the Chicago District.

Dredging Equipment

302. Selection of the proper dredging equipment for any project includes analysis of the characteristics and quantity of material, distance to and type of disposal, dredging depth, level of contamination, and several other factors. There are several different alternative types of dredges that may be

suitable for removing the contaminated Indiana Harbor sediments; these dredges fall into three broad categories: Hydraulic, Mechanical and Special Purpose Dredges.

Hydraulic dredges

303. Characteristics. Research under the IOMT program has shown that hydraulic dredges tend to generate less turbidity than mechanical dredges (Hayes, Raymond, and McLellan 1984). This is particularly true for conventional cutterhead dredges and for hopper dredges not allowing overflow. However, lack of maneuverability in a restricted area precludes using a hopper dredge at Indiana Harbor.

304. A cutterhead suction dredge (Figure 30), using the proper operating techniques, limits sediment resuspension to the lower portion of the water column. Indeed, the cutterhead may be the most sensitive of any dredge type to changes in operating techniques. The sediment resuspended by a cutterhead dredge is dependent on thickness of cut, rate of swing, and cutter rotation rate (Barnard 1978). Proper balance of these operational parameters can decrease sediment resuspension while having little or no adverse effect on production (Hayes, Raymond, and McLellan 1984).

305. Operational controls. Operational controls will reduce the amount of material disturbed by the cutterhead but not entrained by the suction (Huston and Huston 1976). Based on the impact of the factors described above, the following operational controls to reduce levels of sediment resuspension are recommended:

a. Large sets, very thick cuts, and very shallow cuts should be avoided. Thick cuts tend to bury the cutterhead and may cause high levels of resuspension if the suction cannot pick up all of the dislodged material, while in shallow cuts the cutter tends to "throw" the sediments beyond the intake of the dredge (Hayes, Raymond, and McLellan 1984).

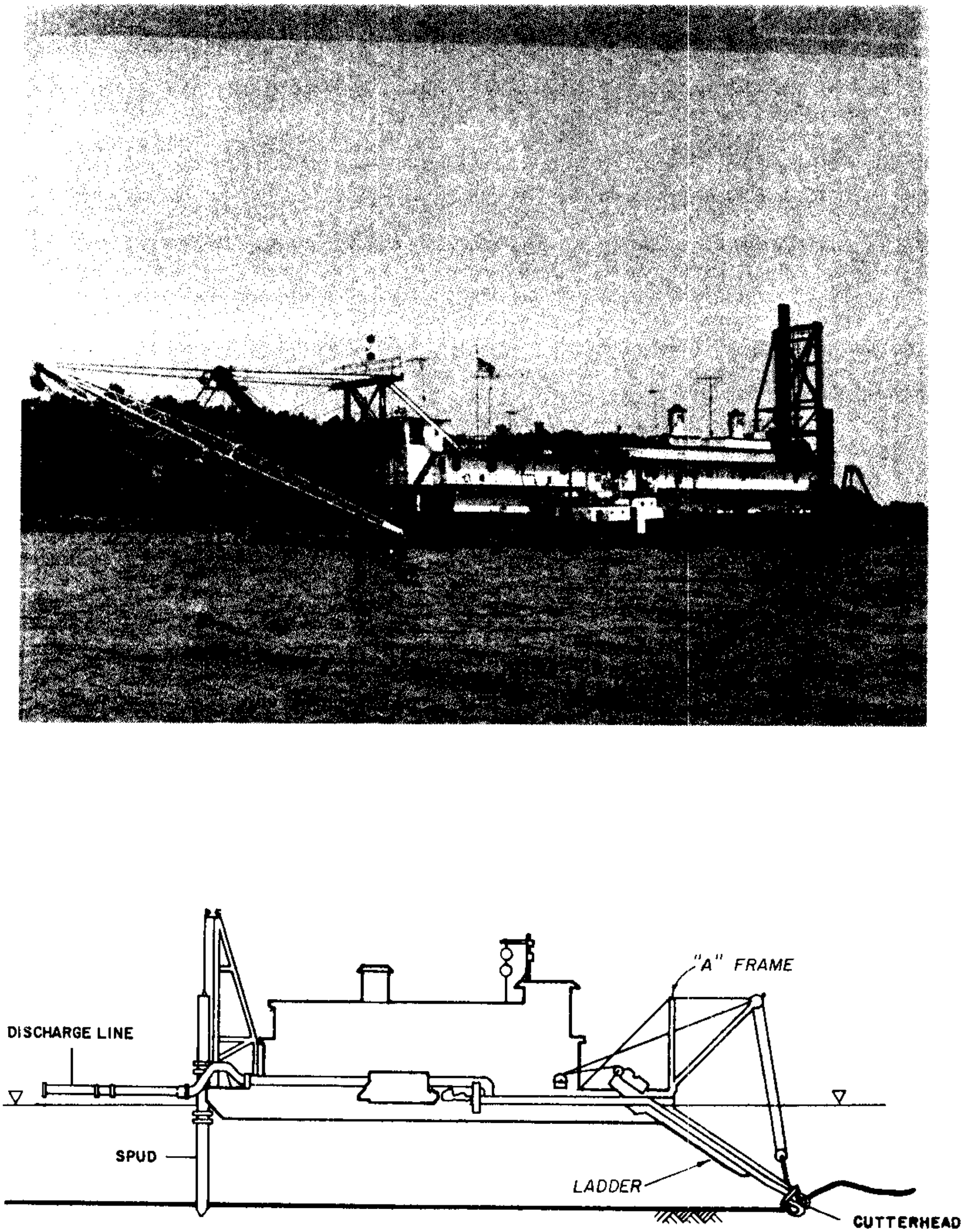


Figure 30. Cutterhead suction dredge

b. The leverman should swing the dredge so that the cutterhead will cover as much of the bottom as possible. This minimizes the formation of windrows or ridges of partially disturbed material between the cuts; these windrows tend to slough into the cuts, and the material in the windrows may be susceptible to resuspension by ambient currents and turbulence caused by the cutterhead. Windrow formation can be eliminated by swinging the dredge in close concentric arcs over the dredging area. This may involve either modifying the basic stepping methods used to advance the dredge or using a Wagger or spud carriage system.

c. Side slopes of channels are usually dredged by making a vertical box cut; the material on the upper half of the cut then sloughs to the specified slope. To minimize resuspension, the specified slope should be cut by making a series of smaller boxes. This method, called "stepping the slope," will reduce but not eliminate all sloughing.

d. On some dredging projects, it may be more economical to roughly cut and remove most of the material, leaving a relatively thin layer for final cleanup after the project has been roughed out. However, this remaining material may be subject to resuspension by ambient currents or prop wash from passing ship traffic; therefore, this method should not be used in Indiana Harbor.

306. The above operating techniques, properly implemented, will reduce the above-ambient concentration of suspended sediments and the overall size of the plume at Indiana Harbor. Previous studies (Hayes et al. 1984, Barnard 1978, and others) have indicated that the above-ambient concentration of suspended solids should be no greater than 500 mg/ℓ near the dredgehead, and the overall length limited to 800 ft down current from the dredge.

Mechanical dredges

307. Characteristics. The IOMT program has shown that mechanical dredges produce larger suspended sediment levels than hydraulic dredges (Hayes, Raymond, McLellan 1984) (other than a hopper dredge allowing overflow). The only mechanical dredge that was considered for removal of the highly contaminated Indiana Harbor sediments is the clamshell bucket (Figure 31). It has been used during previous dredging projects in the harbor and is in common use in the Great Lakes region.

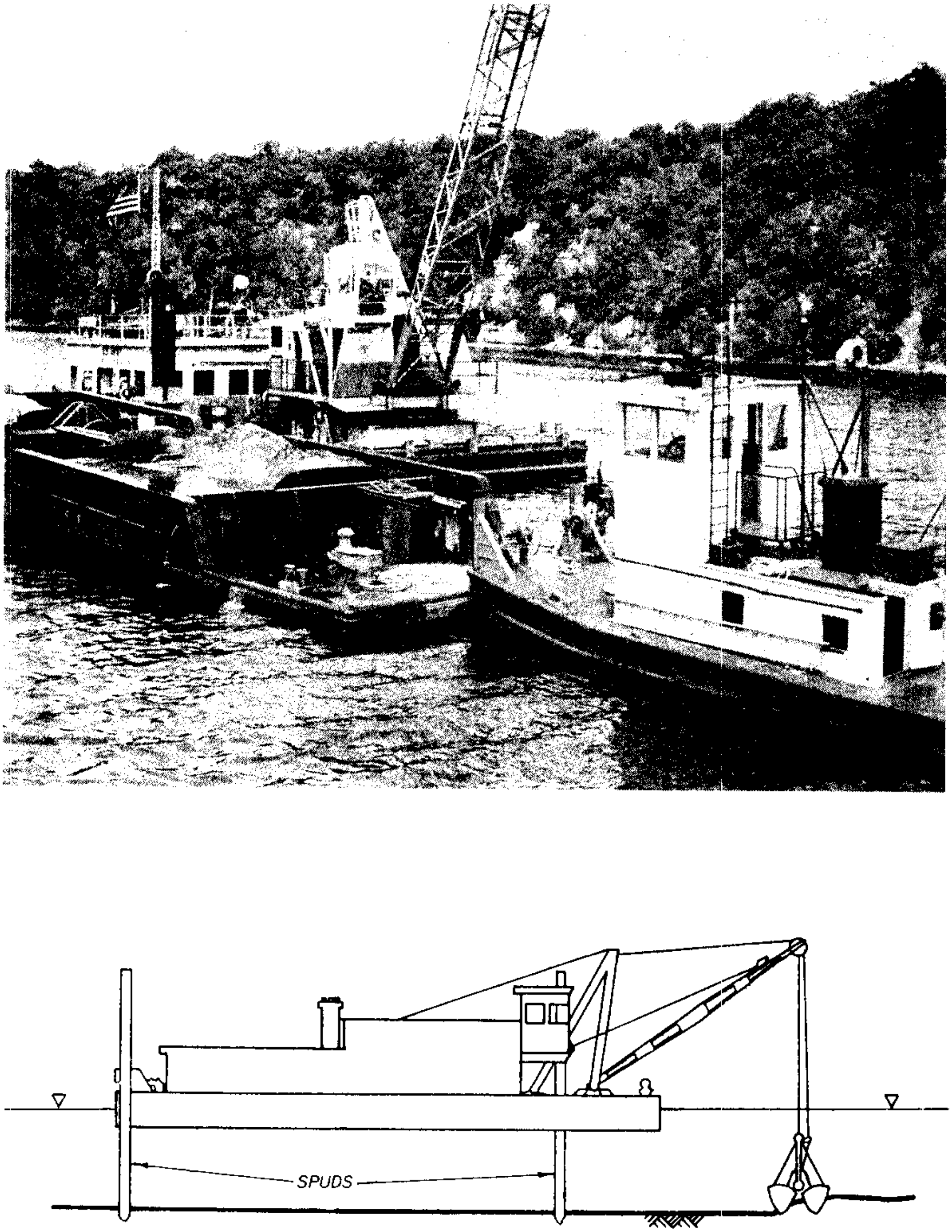


Figure 31. Clamshell dredge

308. Operational controls. Resuspension of sediments during clamshell dredging operations can be reduced by implementing operational controls and/or altering the bucket design. Operational controls can be applied to hoist speed, placement of the dredged material in the hopper barge, loading the hopper past overflow, and dragging the bucket along the bottom. Equipment design includes the seal of the bucket and the use of enclosed clamshell buckets. The sediment resuspension associated with a clamshell bucket dredging operation is largely dependent on the type of bucket, sediment type and condition, and condition of the dredging equipment; however, a substantial amount of resuspension reduction can be accomplished through operational controls.

309. During clamshell dredging projects, operational controls can be implemented to help reduce sediment resuspension. Controlling the speed of the bucket through the water column is one method of control. The hoist speed of the bucket should be kept below 2.0 fps to keep from washing sediment out of the bucket. The hoisting process should also be as smooth as possible so as not to jerk the bucket. When the bucket has been brought about to empty the load into the hopper dredge, care should be taken in the placement of the material. The dredged material should be deliberately placed in the hopper, as opposed to dropping or free-fall from several feet above. It should also be placed in such a manner so that it is evenly distributed throughout the hopper, minimizing the risk of spillage. The hopper barge should not be allowed to overflow when dredging at Indiana Harbor. When a clamshell dredge has finished dredging a certain reach, the operator will often drag the bucket along the bottom to create a smoother bottom. This practice should not be used at Indiana Harbor if the clamshell dredge is used.

310. Equipment design. Recent monitoring conducted during dredging at the Calumet River using a clamshell bucket showed a plume of suspended solids approximately 2 times background levels extending 25 feet from the dredge. An enclosed bucket (Figure 32) has been developed in which the top is enclosed so that the dredged material is contained within the bucket (Barnard 1978). Comparisons between standard open clamshell bucket and an enclosed clamshell bucket indicate that enclosed buckets generate 30 to 70 percent less resuspension in the water column than the open buckets. If a mechanical dredge is used at Indiana Harbor, it should be an enclosed clamshell.

Special-purpose dredges

311. Special-purpose dredging systems have been developed during the last few years in the United States and overseas to pump dredged material slurry with a high solids content and/or to minimize the resuspension of sediments. Most of these systems are not intended for use on typical maintenance operations; however, they may provide alternative methods for dredging projects having highly contaminated sediments such as in Indiana Harbor. The major drawbacks of special-purpose dredges are their limited availability and their inability to be incorporated into conventional transport and disposal operations. The Dutch matchbox dredge (Figure 33) can, however, be incorporated into an operation similar to a cutterhead suction dredge.

312. The matchbox suction head is designed to dredge fine-grained material as close to in-situ density as possible, keep resuspension to a minimum while dredging layers of varying thickness, and operate with restricted maneuverability (d'Angremond, de Jong, and de Waard 1984). To keep resuspension to a minimum, all cutter and waterjet devices commonly found on dredgeheads were avoided in the matchbox design.

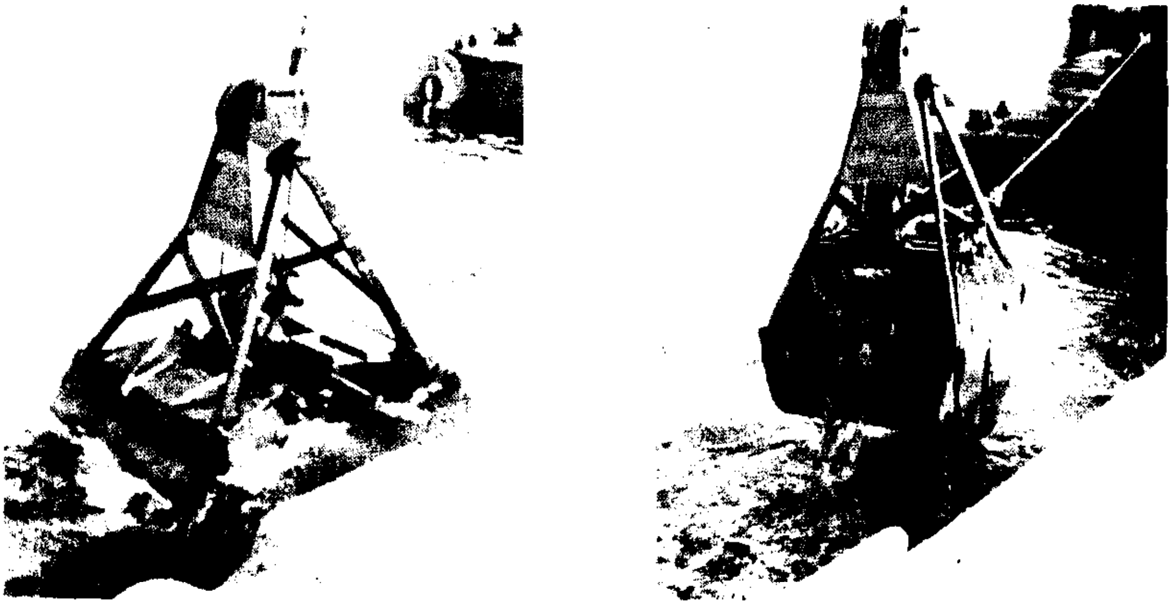
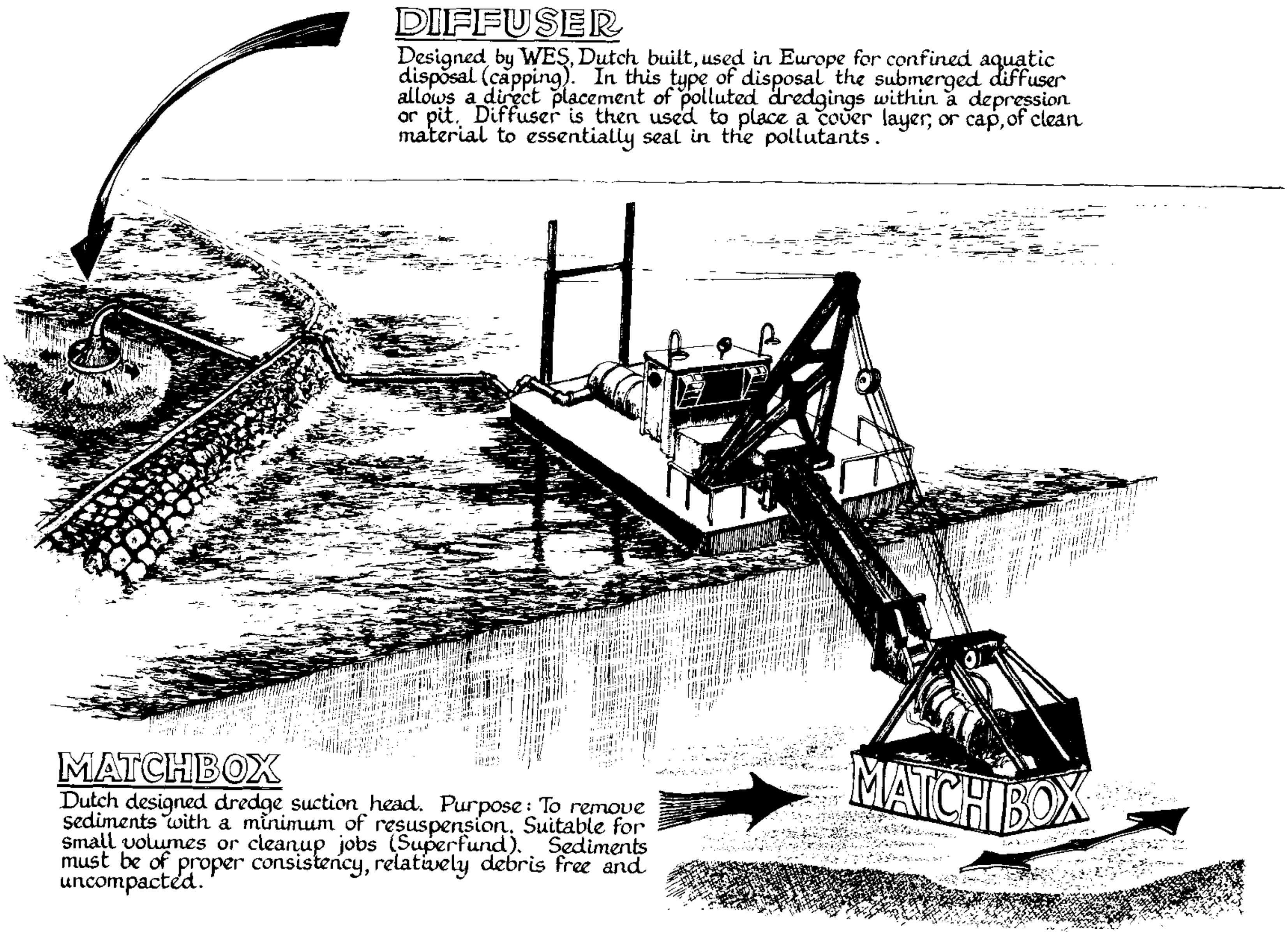


Figure 32. Enclosed clamshell dredge

313. Several innovative design features are incorporated into the matchbox dredgehead construction. These design features include:

- *a*. A plate covering the top of the dredgehead to contain escaping gas bubbles and avoid the influx of water.
- *b*. An adjustable angle constructed between the dredgehead and ladder to maintain the optimum dredging position regardless of dredging depth.
- *c*. Openings and valves installed on both sides of the suction head so that the leeward opening can be closed to avoid water and sediment release.
- *d*. Dimensions of the dredging plant which are carefully designed to account for the average flow rate and swing speed of the dredge.

314. The matchbox dredge may be suitable for dredging the contaminated sediments located in Indiana Harbor. Not only can the matchbox head be incorporated into a conventional cutterhead dredge operation, but this device has been shown to produce suspended solids concentrations of less than 135 mg/ℓ (d'Angremond, de Jong, and de Waard 1984). The matchbox head accomplishes this while dredging the sediments close to in-situ density.



DIFFUSER

Designed by WES, Dutch built, used in Europe for confined aquatic disposal (capping). In this type of disposal the submerged diffuser allows a direct placement of polluted dredgings within a depression or pit. Diffuser is then used to place a cover layer, or cap, of clean material to essentially seal in the pollutants.

MATCHBOX

Dutch designed dredge suction head. Purpose: To remove sediments with a minimum of resuspension. Suitable for small volumes or cleanup jobs (Superfund). Sediments must be of proper consistency, relatively debris free and uncompacted.

Figure 33. Dutch Matchbox dredge (provided by U.S. Army Engineer District, Chicago)

Dredged Material Transport and Placement

315. Dredged material is normally transported to a disposal site by towed or self-propelled barges or by pipeline. Both of these transport methods can be used in placement of the dredged material in a CDF or for open-water disposal. Disposal in a CDF would consist of a reslurry and pumpout operation or mechanical unloading with or without hydraulic assist for the barges or a direct pumpout for the pipeline operation. Open-water disposal normally uses split hull barges or direct pumpout from the pipeline. DMRP studies have shown (Neal et al. 1978) that an open-water pipeline discharge would produce large amounts of suspended material. Due to the contaminated nature of the Indiana Harbor sediment, this form of disposal is not recommended.

Pipelines

316. Some dredging operations, such as cutterhead, use floating pipelines to transport the dredged material from the dredge to the disposal site. These pipelines are usually jointed sections of steel pipe connected by ball joints. The pipelines, if properly maintained, have the ability to move high volumes of material quickly with no or short term environmental impacts. The pipelines can impose navigational problems or require booster pumps if, depending on the dredge, the distance to the disposal site is 2,500 to 3,000 ft from the dredging location.

317. If not properly maintained, floating pipelines used in Indiana Harbor could contribute to the release of contaminated sediments in several ways. During a dredging operation it is periodically necessary to add or take out sections of the floating line. If the pump is simply stopped and the line is not washed out, material in the line will settle to the bottom with possible future plugging consequences. In addition, if the line is broken before

it is thoroughly washed out, the material remaining in the line near the break will fall out into the surrounding water, releasing contaminated material. However, if the line is properly washed out, only clean water will escape when the break is made, and sediment suspension will be avoided.

318. Two types of pipelines are available for dredging discharge lines: steel and high density polyethylene (HDPE). HDPE is a lightweight, flexible material that, if used properly, can be used to advantage over steel. Connections between sections of steel line are usually made with ball joints to give flexibility to the line. If the joints are old and their gaskets worn, dredged material can leak out. HDPE connections are made by portable heat fusion machines which true, heat, and compress the ends of the pipe to create a joint which is stronger than the pipe itself. The material of HDPE is lighter than water and can therefore be towed in long lengths to the dredging site, and the pipe's flexibility allows it to be bent to radii approximately 25 times the pipe diameter, minimizing the need for ball joints or flexible connectors.

Barges

319. Barge transport is usually associated with clamshell dredging, but can sometimes be used in hydraulic dredge operations. Barges can be towed or self-propelled and can be scows, which must be pumped out, or split hull barges used in open-water disposal. If barges are selected for transport of dredged material in Indiana Harbor, certain operating procedures should be adopted. The dredged material should be deliberately placed in the hopper, as opposed to dropping or free-fall from several feet above. It should also be placed in such a manner so that it is evenly distributed throughout the hopper, minimizing the risk of spillage. The hopper barge should not be allowed to overflow when dredging in Indiana Harbor. When using a hopper

barge for disposing of the material, the hopper doors should open quickly and smoothly so as not to "sprinkle" the contaminated material over a long period of time.

Special equipment

320. The amount of water column turbidity generated by an open-water pipeline disposal operation or barge pumpout can probably be minimized most effectively by using a submerged diffuser system (Figure 34) that has been developed through extensive laboratory flume tests conducted under DMRP (Neal, Henry, and Greene 1978). This system has been designed to eliminate all interaction between the slurry and upper water column by radially discharging the slurry parallel to and just above the bottom at a low velocity. The entire discharge system is composed of a submerged diffuser and an anchored support barge attached to the end of the discharge pipeline that positions the diffuser relative to the bottom.

321. The primary purpose of the diffuser is to reduce the velocity and turbulence associated with the discharged slurry. In one DMRP design, this is accomplished by routing the flow through a vertically oriented, 15-deg conical diffuser with a cross-sectional area ratio of 4:1 followed by a combined turning and radial diffuser section that increases the overall area ratio to 16:1 compared to the pipeline. Therefore, the flow velocity of the slurry prior to discharge is reduced by a factor of 16, yet the dredge's discharge rate (i.e., slurry flow velocity X the pipeline cross-sectional area) is not affected in any way by the diffuser. The conical and turning/radial diffuser sections are joined to form the diffuser assembly, which is flange mounted to the discharge pipeline. An abrasion-resistant impingement plate is supported from the diffuser assembly by 4 to 6 struts. The parallel conical surface of the radial diffuser and impingement plate slope downward at an angle of 10 deg

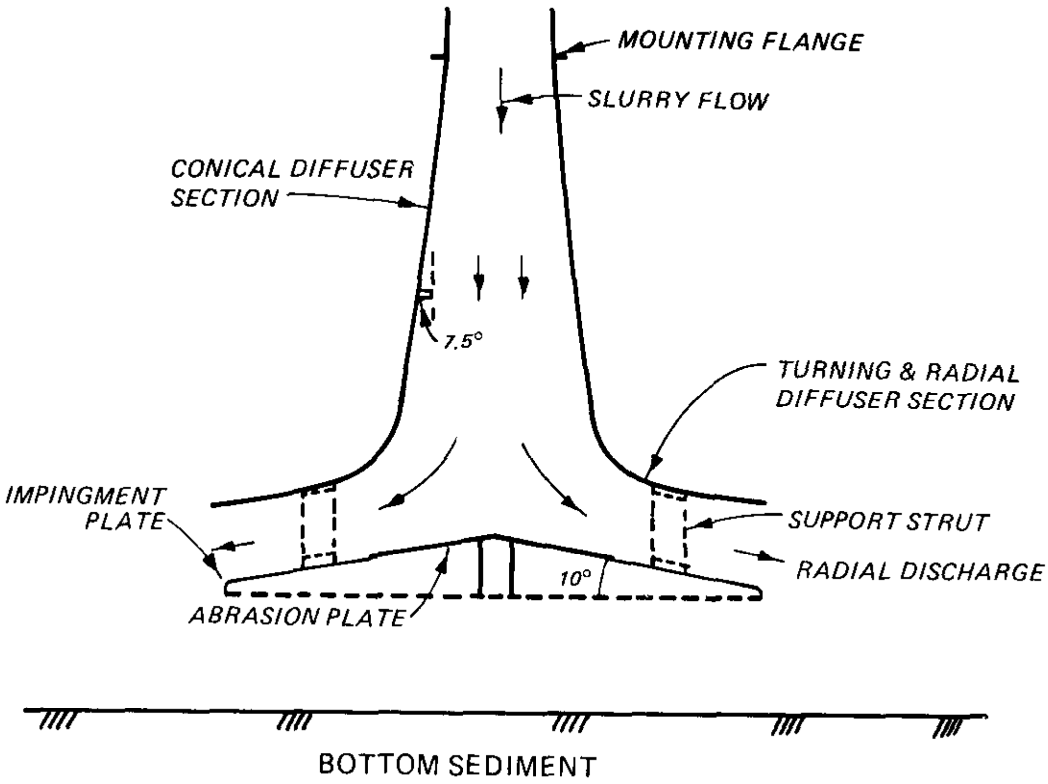


Figure 34. Submerged diffuser system

from the horizontal so that stones and debris can roll down the sloped surface and automatically clear the diffuser. The radial discharge area of the diffuser can be adjusted by changing the length of the struts supporting the impingement plant. In this manner both the thickness and velocity of the discharged slurry can be controlled. The strut length, which determines not only the slurry discharge velocity but also the maximum diameter of an object that will pass through the diffuser, should be approximately five-sixths of the pipe diameter.

322. A discharge barge (Figure 35) must be used in conjunction with the diffuser to provide both support and the capability for lowering the diffuser. The barge also provides a platform for the diffuser while it is being adjusted, serviced, or moved to a new site. Figure 35 also depicts the use of

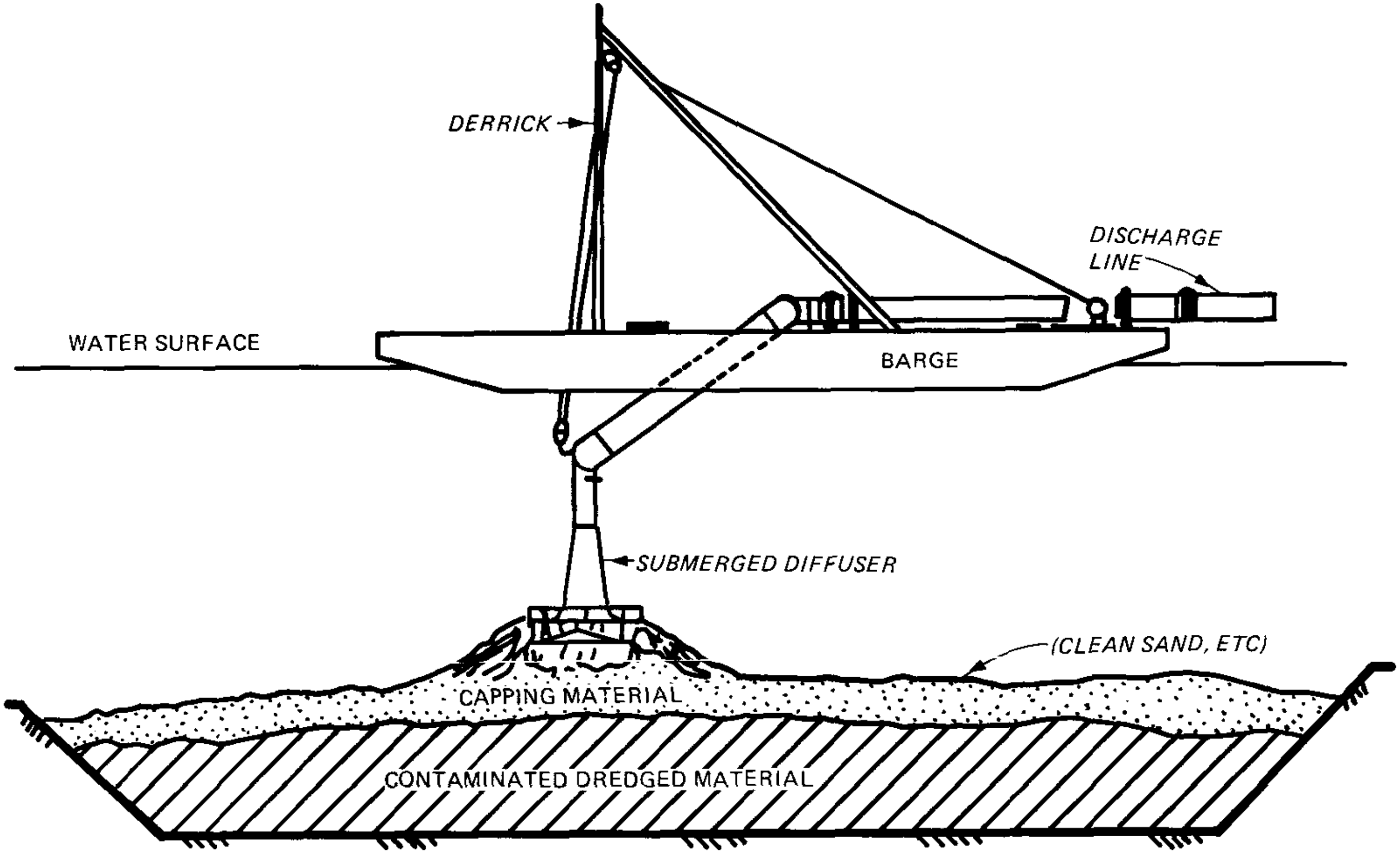


Figure 35. Submerged diffuser system, including the diffuser and discharge barge

the diffuser while constructing a CAD facility. The diffuser's ability to accurately place the dredged material and cap (see Part IV for details on CAD) would increase the overall efficiency of such an operation.

323. The diffuser has a great deal of potential for eliminating turbidity in the water column and maximizing the mounding tendency of the discharged dredged material. The slurry remains in the pipeline/diffuser until it is discharged at low velocity near the bottom, or below a zone of high current velocity, thus eliminating all interaction of the slurry with the water column above the diffuser.

Navigational and positioning equipment

324. Accurate navigation to a CAD site and precise positioning during material placement discharge are necessary for the capping work, if this option of disposal is selected. The type of navigational and positioning equipment used will depend on the location of the site selected for the CAD option. If the site is within the harbor or channel, shore-based line-of-site instruments should be accurate enough. These types of navigational aids lose their accuracy as the site moves offshore. Therefore, several different options for navigational equipment should be explored for the Indiana Harbor CAD site. These options include accurately placed taut-wire buoys, an array of acoustical positioning devices, or the construction of shore-based towers to fix positions offshore. The accuracy of positioning equipment depends on the site conditions, distance offshore, depth, etc., of the offshore CAD site. A more detailed analysis will be performed if the CAD disposal option is chosen.

Equipment Demonstration

325. Demonstrations of a clamshell dredge, a cutterhead suction dredge, the Dutch matchbox dredge, and a submerged diffuser were conducted in the Chicago District in August through October of 1985. The demonstrations were conducted in Calumet River and Harbor, which is just north of Indiana Harbor on Lake Michigan. Water depths at Calumet Harbor were approximately 25 to 30 ft. Sediment samples and current measurements collected at Calumet Harbor and Indiana Harbor indicate that the physical parameters at each site are similar. Therefore, the results obtained from the Calumet Harbor equipment demonstration can be directly applied to Indiana Harbor. The equipment demonstrations included field monitoring efforts developed under the IOMT Program to measure suspended solids, dredge production, and possible release of contaminants. The details and results of these equipment demonstrations will be submitted in a separate report entitled "Demonstrations of Innovative and Conventional Dredging Equipment at Calumet Harbor, IL" (Hayes, McLellan, and Truitt in preparation).

Clamshell field evaluation

326. The clamshell dredge demonstration was conducted during ongoing maintenance dredging occurring in Calumet River. This dredging was done using a standard (open) clamshell dredge (10 cubic yard bucket). The monitoring effort included water sampling to define the size and concentration of the suspended solids plume, observations of the dredge operating characteristics, collection of water samples for chemical water quality analyses, and sediment collection to be used for elutriate testing and bulk sediment analysis. The clamshell dredge field study incorporated one day of background sampling and two days of plume monitoring in the interior Calumet River. A total of

13 sampling stations at varying distances from the dredging operation were used and samples were collected at near-bottom, middepth, and near-surface. The field study identified a suspended sediment plume with a suspended sediment concentration at least 10 mg/ℓ above ambient of 3.5 acres near the bottom, 1.8 acres at middepth, and 1.7 acres near the surface. This 10 mg/ℓ level also corresponded to approximately twice the concentration of the ambient suspended sediment concentration. The rapid reduction in area of the plume from bottom to middepth indicates that the plume is generated primarily by the impact, penetration, and withdrawal of the bucket from the sediment. The highest concentrations and greatest variability of the plume were found near the bottom where samples collected within 50 ft of the dredge ranged from 540 mg/ℓ to 49 mg/ℓ.

Hydraulic dredge field evaluation

327. The cutterhead demonstration was conducted in Calumet Harbor near the Chicago Area CDF. The monitoring plan included observations of the cutterhead operation and collection of discrete water samples to measure suspended solids. The cutterhead operational parameters measured included production rate, swing speed, cutter rotational speed, and depth of each cut. The discrete water samples were collected from a specially designed head sampler attached to the dredge's ladder, which allowed collection of samples within 5 ft of the cutterhead. Additional water samples were collected at 6 to 10 stations located in and around the dredging operation at 5, 50, 80, and 95 percent of the total water depth. The field demonstration of the Dutch matchbox dredge was also conducted at Calumet Harbor. The dredge was the same one used in the cutterhead suction demonstration, except that the cutterhead was removed and the matchbox head installed. The monitoring plan was similar to that used for the cutterhead dredge. The dredge head sampler was modified

since the matchbox has no cutter, but the operation of both dredges was similar. The demonstration of the matchbox suction head dredge was the first use of the dredge in this country.

328. Two days of background sampling preceded the two days of matchbox testing which was followed by another day of background sampling and three days of cutterhead testing. A suspended sediment plume with a concentration of at least 10 mg/ℓ above ambient was identified for the matchbox operation over an area of 2.9 acres at 90 percent of the total depth and 0.4 acres at 80 percent of the total depth. No plume of this concentration was identified above this depth. Similarly, a suspended sediment plume with a concentration at least 10 mg/ℓ above ambient of 1.2 acres was identified for the cutterhead operation at 95 percent of the total depth. No plume of this concentration was identified above this depth for the cutterhead operation. The concentrations of suspended sediment in both plumes at distances of 100 ft or greater were all less than 20 mg/ℓ except for a few observations.

Submerged diffuser field evaluation

329. The submerged diffuser demonstration was conducted simultaneously with the matchbox dredge demonstration (Figure 36). The demonstration site was inside the Chicago Area CDF located at Calumet Harbor. The submerged diffuser demonstration was designed to evaluate the effectiveness of the diffuser in reducing the velocity of the dredged material and limiting the suspended solids plume to the lower portion of the water column. Velocity measurements were obtained at the exit of the diffuser and at a station located 7.5 ft from the diffuser exit. During the demonstration, pipeline velocities were reduced 75 to 80 percent at the diffuser exit and the diffuser's ability in containing the suspended solids plume to the lower portion of the water column was displayed. At a station 12.5 ft from the

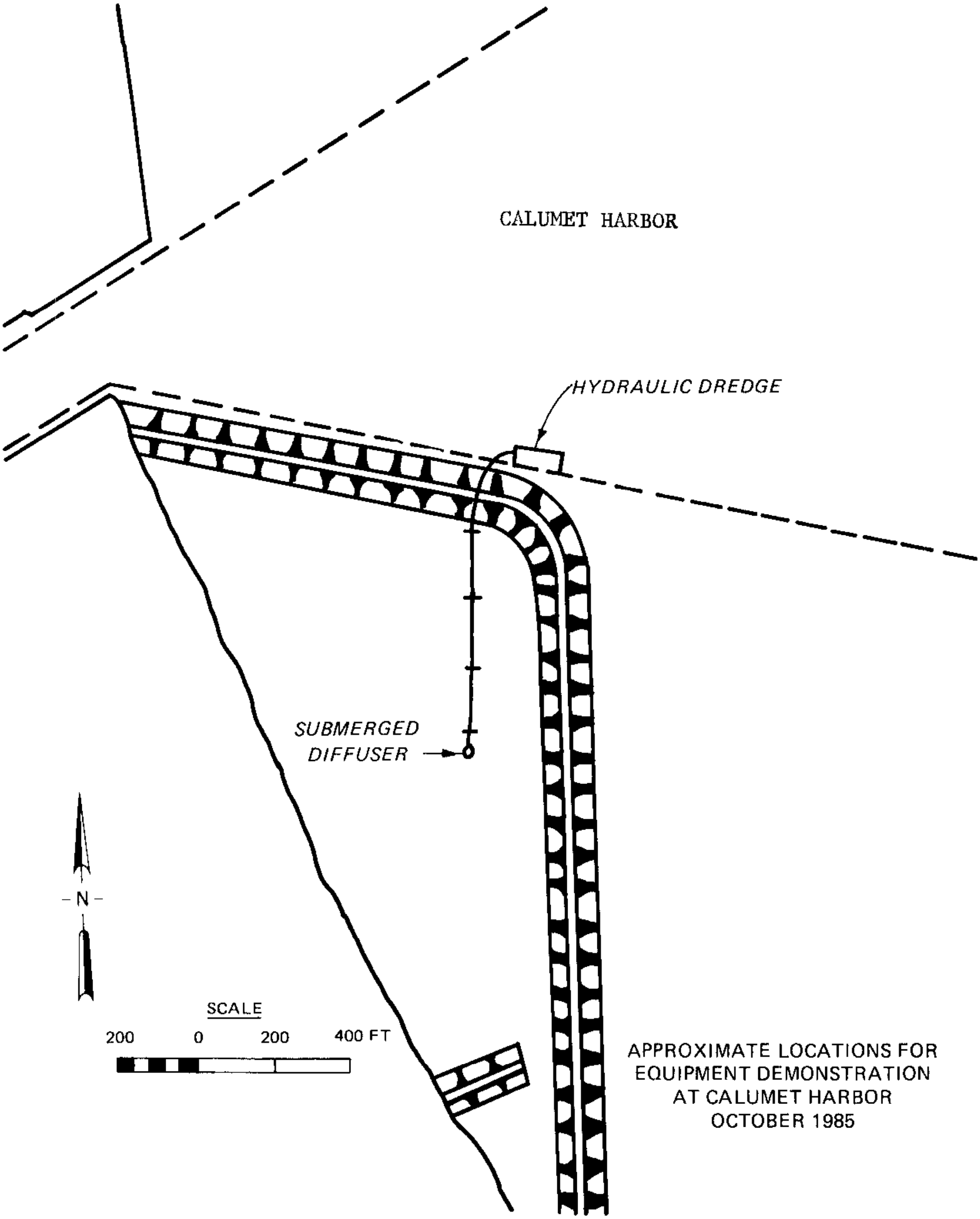


Figure 36. Submerged diffuser field demonstration location

diffuser exit in 20 ft of water, water column samples were collected at increments of 5, 50, 80, and 95 percent total depth, every 5 minutes throughout the dredging period. With ambient total suspended solids (TSS) concentrations ranging between 2 and 10 mg/ℓ, the average TSS level for the 5 and 50 percent samples was 9.6 mg/ℓ, while the average of the lower two in the discharge path was 3,266 mg/ℓ. The diffuser was able to significantly reduce the slurry velocity, confine the discharged material to the lower 20 to 30 percent of the water column, and reduce suspended sediment effects in the upper portion of the water.

Discussion and Potential Application

330. Based on the results of these demonstrations, both cutterhead and matchbox resulted in far less resuspension than the standard (open) clamshell dredge. The tests showed that the cutterhead can remove sediment with very little resuspension when operated properly. The data for the cutterhead operation shows very low levels of resuspension near the cutterhead. Additional analysis of the cutterhead data may provide insight to the impact of operational parameters on the resuspension process.

331. The matchbox dredgehead performed very well from the standpoint of production considering the operator's inexperience in using the dredgehead. The matchbox is also capable of removing sediment with very little resuspension. However, the data for the matchbox operation reflected precise positioning problems. The operator could not determine when the top of the matchbox was at the same level as the sediment nor could he properly match swing speed with flowrate. These are important for optimum operation of the matchbox. The data which did not appear to be so affected shows very low

levels of resuspension near the matchbox. Consequently, before the matchbox suction head could be recommended over the cutterhead for removing contaminated sediments, additional studies need to be conducted with better control of the matchbox position relative to the bottom. Additional improvements to the matchbox performance could be derived by incorporating density and pipeline velocity instrumentation to control the pump speed via computer. This equipment is available (Taylor 1986) and although a properly designed system may not increase production it would optimize the efficiency, density of dredged slurry, and effectiveness, precise removal of sediment layer, of the matchbox dredge.

332. The submerged diffuser was able to reduce the pipeline exit velocity by 75 to 80 percent. However, the exit velocities were 3 to 4 times greater than the theoretical predictions. Additional investigations may be needed to evaluate these variations. The demonstration clearly showed the diffusers ability to limit sediment resuspension to the lower portion of the water column. The diffuser was able to significantly reduce the slurry velocity, confine the discharged material to the lower 20 to 30 percent of the water column, and reduce suspended sediment effects in the upper portion of the water.

333. The dredging alternatives chosen for a particular project depend on, but are not limited to, availability of equipment, disposal site selected, dredged material contaminant levels, hydraulic characteristics of the area, and physical characteristics of sediment. Using the DMRP and IOMT research programs as background and the results of the demonstrations, several innovative dredging alternatives have been identified for the Indiana Harbor Project. The dredging alternatives include use of an enclosed clamshell bucket, a cutterhead dredge operated under specific guidelines, and a Dutch

matchbox suction head dredge. Transport techniques to reduce sediment resuspension include proper care when handling, replacing and extending pipelines for hydraulic dredge operations, and special loading and disposal techniques for barge transport. Disposal techniques that could be incorporated into the Indiana Harbor Project include the use of a submerged diffuser specially designed to reduce the velocity of the dredged material and reduce suspended sediment levels associated with disposal operations.

PART VI: SUMMARY AND CONCLUSIONS

Summary

334. This study evaluated dredging and dredged material disposal alternatives for approximately 200,000 cu yd of PCB-contaminated sediment from the Indiana Harbor Canal. Samples of sediments were obtained from two PCB-contaminated reaches for use in laboratory testing. A Management Strategy was applied which uses technically appropriate testing protocols designed especially for the unique nature of dredged material and the physicochemical conditions of various disposal alternatives. The Management Strategy was used to determine the potential for environmental harm from contamination, to examine the interrelationships of the problems and potential solutions, and to determine what restrictions are required for each disposal alternative under consideration. Effluent quality, surface runoff quality, leachate quality, settling, consolidation, plant contaminant uptake, and animal contaminant uptake tests were performed. Research to develop or improve leachate, surface runoff, and contaminant immobilization tests was also conducted.

335. Three dredged material disposal alternatives were evaluated: contained aquatic disposal, confined disposal in an in-lake CDF, and confined disposal in an upland CDF. The no-action alternative and the TSCA-approved disposal alternatives of incineration and placement in a chemical waste landfill were also evaluated for purposes of comparison. Application of the Management Strategy identified the required contaminant control measures for each of the dredged material disposal alternatives. New emerging technologies were evaluated for application to the PCB-contaminated sediments but these technologies were limited to contaminant containment and immobilization

techniques. No innovative contaminant destruction technologies were found to be appropriate for these sediments. Demonstrations of innovative and conventional equipment for dredging and disposal of the PCB-contaminated sediments were conducted to provide information for equipment selection. Specific conclusions for each aspect of the study are given in the following paragraphs.

Conclusions

Potential problems and testing results

336. Criteria for selection of controls. Results from effluent and runoff tests were compared with Indiana water quality standards and USEPA Federal water quality criteria for the protection of freshwater aquatic life. Results from plant and animal uptake tests were compared with the FDA allowable concentrations for foodstuffs. There were no appropriate criteria for comparison with leachate test results. The comparisons of test results and criteria were the basis of discussion of appropriate contaminant control measures for the disposal alternatives considered. The final design of the selected disposal alternative should be based on later comparisons of test results and specific criteria agreed upon by the concerned regulatory agencies.

337. Effluent quality. Based on the results of modified elutriate and settling tests, effluent quality for the in-lake CDF and upland disposal alternatives was directly related to the filling method used. Contaminants were found to be largely associated with suspended solids in the disposal area ponded waters. If mixing is considered, removal of suspended solids will reduce effluent contaminant concentrations to acceptable levels for the

in-lake CDF with the possible exception of PCB's. The removal of dissolved contaminants for the upland disposal alternative may be required to approach water quality standards.

338. Surface runoff. The results of the surface runoff studies indicated that excessive contaminant release could occur if the PCB- contaminated Indiana Harbor sediments were placed in the upland environment without surface capping or covering with a low permeability material. During the early, wet, anaerobic stages, contaminants were mostly bound to the suspended solids in the surface runoff and were mainly in the unfiltered samples. As the sediment dried, the SS concentrations decreased, thereby decreasing the unfiltered contaminant concentrations. Filtered concentrations during the wet, anaerobic stage were low compared with the unfiltered concentrations but would still be of concern when compared with the USEPA Maximum Criteria for the Protection of Aquatic Life. Until the sediment became oxidized and the pH decreased to about 6.5, the filtered concentrations of contaminants would also decrease significantly. Results of the tests represented the worst possible case that could occur during the wet, anaerobic stage. Control measures for surface runoff should concentrate on control of the SS in the runoff after considering an appropriate mixing zone outside of the disposal site. Placing the sediments below lake level for an in-lake CDF alternative would also be an appropriate control.

339. Leachate quality. Leachate tests were conducted for both the anaerobic/saturated and aerobic/unsaturated condition. The contaminant release characteristics determined in batch leaching tests indicate that even though the sediments are highly contaminated, the mobility of arsenic, cadmium, chromium, lead, and zinc is insignificant under either anaerobic or aerobic conditions. The data show that the majority of the metals in Indiana

Harbor sediments are tightly bound to the sediment solids. Metal concentrations measured did not exceed Drinking Water Standards during batch, column, or interstitial water testing of either anaerobic or aerobic Indiana Harbor sediment. The fraction of metals resistant to leaching was generally greater than 99 percent. Releases of metals during leaching from aerobic Indiana Harbor sediments should not be of major concern.

340. Batch testing of organic contaminant releases under anaerobic and aerobic conditions has also shown that the majority of these compounds are tightly bound to the sediment. The batch leaching data showed organic contaminant releases to be very low, and this was confirmed in the permeameter tests for the PAHs and most of the PCB cogeners.

341. Leachate tests indicate that contaminant release from sediments in compression settling is considerably lower than the results of the modified elutriate test. This indicates that mechanical dredging and placement of the contaminated sediments into a confined facility would minimize contaminant release at the disposal site.

342. Solidification/stabilization of contaminated sediments. Solidification/stabilization reduced the leachability of arsenic, cadmium, chromium, lead, and zinc. Cadmium and zinc were completely immobilized by some processes. Because some solidification/stabilization tend to increase the leachable metal concentration, careful process selection is needed to maximize chemical stabilization. The most effective processes for metal immobilization were Firmix with WEST-polymer and Firmix.

343. Solidification/stabilization did not significantly alter the sorption capacity of the sediment for total organic carbon. Data were not available to evaluate the potential of solidification/stabilization technology to reduce the leachability of specific organic compounds.

344. Plant contaminant uptake. Plant bioassays indicated high electrical conductivity, potentially low available nitrogen and phosphorus, as well as low concentrations of unknown organics that could limit plant growth. Plant growth on flooded sediments was greater than that on the upland sediments. Organic contaminants were not found in plant tissues. However, the content of heavy metals in plants grown on the upland sediments was greater than that of plants grown on the flooded sediment.

345. Plant cadmium and lead levels are high in the plants grown on the upland sediments. The cadmium level of 14.5 μg/g is above the FDA and indicates that control measures are needed if the material is disposed of in the upland environment.

346. Animal contaminant uptake. Animal bioassays, using sediment tested in its original state, found the sediments to be extremely toxic to earthworms. Earthworm survival was not observed until the sediment was aged for 6 months in sunlight and maintained in moist condition.

347. The results from the 6-month aging of the Indiana Harbor sediment indicate that, with time, Indiana Harbor sediment placed under confined upland conditions may become habitable and develop into a viable, productive ecosystem. This has occurred at the Times Beach disposal site at Buffalo, NY, as well as elsewhere in the Great Lakes area. Therefore, unless controls were implemented, upland disposal of Indiana Harbor sediment would require a monitoring and management strategy to address contaminant bioaccumulation as the site became biologically productive.

Disposal alternatives

348. No action. The contaminated bottom sediments present in the GCR/IHC limit the environmental quality of the waterway. The sediments are highly toxic and will inhibit recolonization of the waterway by diverse aquatic life.

The migration of sediment contaminants in any waterway is primarily the result of sediment resuspension and transport. Additional hydrodynamic information must be available to fully describe sediment transport processes in the GCR/IHC. Existing data indicates that the Indiana Harbor navigation channel had served as a sediment trap, retaining contaminated sediments which would otherwise have been transported to Lake Michigan. The siltation of the channel has reached a point of equilibrium, meaning it no longer functions as a sediment trap.

349. TSCA-approved alternatives. The estimated costs of TSCA approved disposal alternatives of incineration and placement in a chemical waste landfill for PCB-contaminated sediments are far beyond the limits which could be justified under the Corps' navigation maintenance authority. Alternate methods of disposal approved by the USEPA Regional Administrator appear to be the only feasible option available to the Corps under this funding authority.

350. Contained aquatic disposal. CAD was investigated in an effort to broaden the disposal options available to the Chicago District. In laboratory tests, a 12 in. layer of Lake Michigan sediment overlying Indiana Harbor sediment was effective in preventing the transfer of heavy metals, PAHs, phenol, and PCBs from the contaminated sediment into the overlying water and aquatic biota. However, to protect against the effects of deep burrowing animals, a minimum cap depth of 20 in. is needed to maintain an effective chemical seal.

351. The most likely area in Lake Michigan for CAD sites for disposal of the Indiana Harbor material is 4 to 8 miles east of Indiana Harbor in water depths of 40 to 60 ft. There were no feasible CAD sites identified in the entrance channel and canal areas of Indiana Harbor that were capable of handling the entire volumes of PCB contaminated sediment.

352. In-lake CDF. An in-lake CDF has been proposed to confine Indiana Harbor sediments that have been classified as moderately to heavily polluted. This CDF or one of similar design could also be considered for codisposal of the 200,000 cu yd of PCB-contaminated material.

353. Use of a two-celled CDF with filter dikes should remove virtually all suspended solids and associated contaminants from the filtered effluent. The effluent from the in-lake CDF would meet Indiana Lake Michigan water quality standards for all parameters, except PCB's which would approach ambient Lake concentrations. The effective particle size of sand used in the CDF filter dike section should be selected to prevent clogging during the life of the disposal area.

354. Design and operational controls for the CDF should also include chemical clarification, oil removal, and sequencing of dredged material disposal to provide maximum environmental protection.

355. The chronological order of the dredging projects should be arranged in a manner to seal the PCB-contaminated sediments subaqueously between layers of cleaner clays and silts. Encapsulation of the PCB-contaminated sediments should prevent any long-term plant and animal uptake and minimize leaching of contaminants from the CDF. Encapsulation would also prohibit surface runoff and contaminant loss through volatilization.

356. Upland CDF. No specific site has been identified for an upland confined disposal facility. A number of control alternatives were evaluated for their ability to limit contaminant loss. Effluent from an upland CDF during hydraulic dredging would require chemical clarification and filtration at a minimum. The effluent would exceed Indiana Harbor water quality standards for several contaminants, including PCB's. Carbon adsorption may be necessary to reduce dissolved contaminant levels.

357. Surface runoff from an upland CDF should be controlled. Filtration and carbon adsorption may be necessary for treatment of runoff until a surface cover can be applied. A surface cover (cap) of topsoil underlain by a 24-inch layer of compacted clay would restricted infiltration, reduce potential leachate, and prevent contaminant loss in surface runoff and by plant and animal uptake. Codisposal of the PCB-contaminated sediments with less contaminated sediments would reduce the contaminant loss by volatilization.

358. The upland CDF should be lined by a 24-inch compacted clay liner to restrict seepage of leachate. The performance of the clay liner may be improved by a leachate collection system.

Dredging and disposal equipment

359. Performance of a clamshell dredge, a conventional cutterhead hydraulic dredge, and an innovative matchbox hydraulic dredge were compared in field demonstrations to obtain data on sediment resuspension during dredging. Resuspension from cutterhead and matchbox operations was restricted to the lower water column and was lower than that for the standard (open) clamshell dredge. If a clamshell dredge is selected, the bucket should be enclosed.

360. Demonstrations of a submerged diffuser for placement of dredged material in open-water sites showed that the diffuser restricted material resuspension to the lower 20 to 30 percent of the water column and greatly reduced pipeline discharge velocities. The diffuser holds promise for use in the CAD alternative or for placing material subaqueously in an in-lake CDF.

Dredging and disposal alternatives

361. The feasible dredging and disposal alternatives identified for the PCB-contaminated sediments included CAD, in-lake CDF disposal, and upland confined disposal. With appropriate dredging equipment, disposal site designs, and contaminant control measures, any of the three disposal methods

could be used to provide environmentally sound disposal of the PCB-contaminated Indiana Harbor sediments.

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