CHAPTER 219

Extent of Contaminated Marine Sediments and Cleanup Methodology

John B. Herbich, Ph.D., P.E.[1]

Abstract

The problem of contaminated marine sediments has emerged as an environmental issue of national importance. Harbor areas in particular have been found to contain high levels of contaminants in bottom sediments due to wastes from municipal, industrial and riverine sources. The paper examines the extent and significance of marine sediment contamination in the United States; reviews the state-of-the-art of contaminated sediment cleanup and identifies research and development needs.

Introduction

Contamination of marine sediment in all areas of the world, particularly in the shallow water areas, poses a potential threat to marine resources and human health. Improving the capability to assess, manage and remediate these contaminated sediments is critical not only to the well-being of the marine environment but as well as to its use for navigation, commerce, fishing, and recreation.

This paper concentrates on the problem of contaminated marine sediments in U.S. waters which has emerged as an environmental issue of national importance. The summary is based on the results of the study conducted by a Committee on Contaminated Marine Sediments of the Marine Board, Commission on Engineering and Technical Systems, National Research Council. Members of the Committee were: Kenneth S. Kamlet (Chairman), A.T. Kearney, Inc., Williams J.

---

[1]Director, Center for Dredging Studies, Holder of W. H. Bauer Professorship, Civil Engineering Department, Texas A&M University, College Station, TX 77843-3136, USA.

Adams, Monsanto Company, A. Karim Ahmed, Environ Corporation, Henry J. Bokuniewicz, State University of New York, Thomas A. Grigalunas, University of Rhode Island, John B. Herbich, Texas A&M University, Robert J. Huggett, College of William and Mary, Howard L. Sanders, Woods Hole Oceanographic Institution, and James M. Thornton, Department of Ecology, State of Washington. Charles A. Bookman is the Director of the Marine Board.

The expertise of the members of the Committee spanned the fields of aquatic toxicology, dredging technology, resource economics, sediment dynamics and transport, benthic ecology, environmental law and public policy.

The nature of the problem has resulted from using coastal waters, intentionally or unintentionally, for waste disposal for many decades. Confined or partly confined areas where low wave and current energies are present (such as harbors) contain high levels of contaminants in bottom sediments due to wastes from urban, industrial and riverine sources. Such areas where flushing action is unlikely (except during hurricanes) have accumulated contaminants which may now be buried by fine sediment deposits of recent years that contain no, or low levels of contaminants.

Legislative authority for the management of contaminated marine sediments falls largely under three statutes: the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), the Marine Protection, Research, and Sanctuaries Act (MPRSA), and the Clean Water Act (CWA). The Comprehensive Environmental Response Compensation and Liability Act of 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986, is aimed at the cleanup and remediation of inactive or abandoned hazardous waste sites, regardless of location. Superfund sites are currently ranked by the Environmental Protection Agency (EPA) based on the hazard they may pose to human health and the environment via releases to groundwater, surface water, and air. Underwater accumulations of hazardous wastes in marine environments are unlikely to threaten human health except by way of food chain exposure, which is not currently addressed in EPA's hazard-ranking process. Under the 1986 Superfund amendments, however, EPA was required to modify its Hazard Ranking System to address "the damage to natural resources which may affect the human food chain and which is associated with any release (or a hazardous substance)" S(Section 105(a)(2)).

Meanwhile, the Clean Water Act of 1970, as amended by the Water Quality Act of 1987, gives EPA lead responsibility for safeguarding the quality of U.S. coastal and inland waters. This includes regulating the disposal of dredged and fill materials (shared with the U.S. Army Corps of Engineers, under Section 404), and removing in-place toxic pollutants in harbors and navigable waterways (under Section 115). The 1987 amendments added new authorities requiring EPA to study and conduct projects relating to the removal of toxic pollutants from Great Lakes Bottom sediments (Section 118(c)(3)); and to identify and implement individual control strategies to reduce toxic pollutant inputs into contaminated waterway segments (Section 304(1)).

In response to Title II of the Marine Protection, Research, and Sanctuaries Act of 1972 (PL 92-532) and the National Ocean Pollution Planning Act, the National Oceanic and Atmospheric Administration (NOAA) Office of Marine Pollution Assessment conducts comprehensive interdisciplinary assessments of the effects of human activities on estuarine and coastal environments. Among these assessment activities is the National Status and Trends Program (NST), which attempts to create, maintain, and assess a long-term record of contaminant concentrations and biological responses to contamination in the coastal and estuarine waters of the United States. This assessment provides some insight into the extent of contamination nationally.

As a result of legislative responsibility and programmatic interests, a wide variety of federal agencies have shown active interest in this subject. EPA's responsibilities under Superfund and the CWA are the source of its interests in water quality concerns and remediation of uncontrolled hazardous waste sites. The U.S. Army Corps of Engineers (COE) is involved because of its responsibility to dredge and maintain navigable rivers and harbors. The COE also assists in the design and implementation of remedial cleanup actions under Superfund. NOAA has responsibility for assessing the potential threat of Superfund sites to coastal marine resources as a natural resource trustee as well as under its NS&T program. The U.S. Fish and Wildlife Service has legal authority for various endangered coastal species, food chain relationships, and habitat considerations, all of which are potentially impacted by contaminated sediments. The Navy has had experience in assessing contaminated sediments and now must grapple with such problems in locating and maintaining homeports for Navy vessels.

Procedure

There are many definitions of contamination of sediments. The Committee defined the contaminated sediments for the purpose of the study as follows:

> "Contaminated sediments are those that contain chemical substances at concentrations which pose a known or suspected environmental or human health threat."

A symposium and a workshop was organized to examine the extent of contamination nationwide, the methods for classification of sediment contamination, risks to human health and the ecosystem, sediment resuspension and contaminant mobilization, remedial strategies and technologies for handling contaminated sediments. In addition, five case studies were examined of the different ways in which a variety of sediment contamination problems are being handled. They include the PCB problem in New Bedford Harbor, Massachusetts; PCBs in the upper Hudson River, New York; kepone contamination of the James River, Virginia; the variety of chemicals contaminating Commencement Bay, Washington; and the Navy Homeport Project in Everett Bay, Washington.

The main purposes of the study included a) examination of the extent and significance of marine sediment contamination, b) a review of the state-of-the-art of contaminated sediment removal and remediation technology, c) identification and appraisal of alternative sediment management strategies, and d) identification of research and development needs and issues for future technical assessments (Marine Board, 1989).

Extent of Contamination

Many contaminated marine sediments are found along all coasts of the contiguous U.S., both in local "hot spots" and distributed over large areas. There is a wide variety of contaminants including: heavy metals, polychlorinated biphenols (PCBs), DDT, and polynuclear aromatic hydrocarbons (PAHs). At present, there are no generally accepted sampling techniques or testing protocols.

Classification Methodologies for Determining Sediment Contamination

There have been some research efforts in classifying the extent of contamination and some States have collected data for special purposes. No uniform methods have been adopted by various State of Federal agencies.

A variety of classification methods are available:

a) Sediment bioassays - sediment toxicity on a crustacean, infaunal bivalve and infaunal polychaetes. Essentially marine life is subjected to various levels of toxicity and their survival noted.

b) Sediment quality triad:
   1) contamination quantified by chemical analysis,
   2) toxicity determined by laboratory bioassays, and
   3) benthos community structure determined by taxonomic analysis of biofauna.

c) Apparent effects threshold technique equilibrium partitioning (AET) - A tool for deriving sediment quality values for a range of biological indicators to assess contaminated sediments. The AET is the contaminant concentration in sediment above which adverse effects are always expected for a particular biological indicator.

Recommendations

To ensure that decision making is informed and scientifically based, continued research and use of assessment methodologies should provide information to determine:

- a range of concentrations of chemicals in sediments that will result in biological effects, and
- whether in-place sediments are causing biological impacts.

A tiered approach to the assessment of contaminated sediments should be used. The approach would progress from relatively easy and less expensive (but perhaps less definitive) tests to more sensitive methods as needed.

Contaminated Sediment Management Strategies

Although the dredged material management strategy developed by the Corps of Engineers may be relevant to severely contaminated sediments, it is important from a management standpoint to differentiate them from less contaminated sediments. In particular, most highly sophisticated remedial technologies (i.e, those involving treatment or destruction of associated contaminants) are likely to be cost-effective only in small areas and for sediments with relatively high contamination levels. Sediment contamination problems often involve large volumes of sediment with relatively low contamination levels. As a result, some highly sophisticated technologies may be inapplicable or inefficient for remediating contaminated sediments.

"No action" may be the preferred alternative in cases in which the remedy may be worse than the disease - e.g., where dredging or stabilizing contaminated sediments results in more biological damage than leaving the material in place. Contaminants generally accumulate in depositional zones, and, if the source is controlled, new clean sediments will deposit and cap the contaminated material over time. In effect, no action alternatives in such cases may result in natural capping.

1. No action may be an acceptable option if the contamination degrades or is buried by natural deposition of clean sediment in a short period of time.

2. In-place capping may be a useful option if the sediments are not in a navigation channel or if groundwater is not flowing through the site.

3. Removal and subaqueous burial off-site may be a viable option, although the experience with this technique is limited to relatively shallow water (less than 100 ft).

4. Incineration seems to be viable only for sites with relatively small amounts of sediments containing high concentrations of combustible contaminants.

5. Other techniques to assist in remediation of contaminated sediment may be appropriate in special cases. Examples include a variety of sediment stabilization or solidification techniques, and biological and/or chemical treatment.

Recommendations

- Additional evaluation should be conducted to determine the applicability of the Corps of Engineers' dredged material management strategy to more severely contaminated sediments.
- No action should always be considered as an alternative strategy for minimizing biological damage. In using the no-action strategy as a form of natural capping of contaminated material, consideration should be given to the length of time it takes for contaminants to be isolated from the food chain.

Remedial Technologies

From a remediation standpoint, the most important factors are likely to be a definition of the clean-up target, technical and cost feasibility, natural recovery estimates, and ability to distinguish and/or control continuing sources of contaminants.

Dredging technology exists that is capable of greatly reducing turbidity and resuspension in connection with dredging of bottom sediments in most applications (Herbich and Brahme, 1990).

The selection of proper dredging equipment is important to achieve an efficient removal of contaminated sediments, and to prevent additional contamination generated during dredging. The selection depends on a number of factors:

1) characteristics of sediments,
2) quantity of sediments to be removed,
3) degree of contamination,
4) toxicity of contaminants,
5) location,
6) environmental conditions at the site (waves, currents, tides, etc.),
7) distance to the disposal site,
8) type of disposal, and
9) availability of particular equipment.

Since conventional type of dredges designed for removal of large volumes of sediment are generally not suitable for small operations to remove pockets of contaminated sediments, special purpose dredges have been developed to dredge contaminated sediments while minimizing sediment resuspension and contaminant release. The specialty dredges may be placed in three categories:

1. mechanical - watertight clamshell,
2. mechanical-hydraulic - Mud Cat, remotely controlled Mud Cat, and clean-up system,
3. hydraulic - Refresher, waterless, matchbox, and wide sweeper, cutterless dredge, and
4. pneumatic - Pneuma and Oozer.

Watertight clamshell. A watertight clamshell was developed in Japan (Figure 1) and evaluated by the U.S. Army Engineer Waterways Experiment Station (Hayes et al., 1988). Experiments indicated that the watertight bucket significantly reduced water column turbidity.

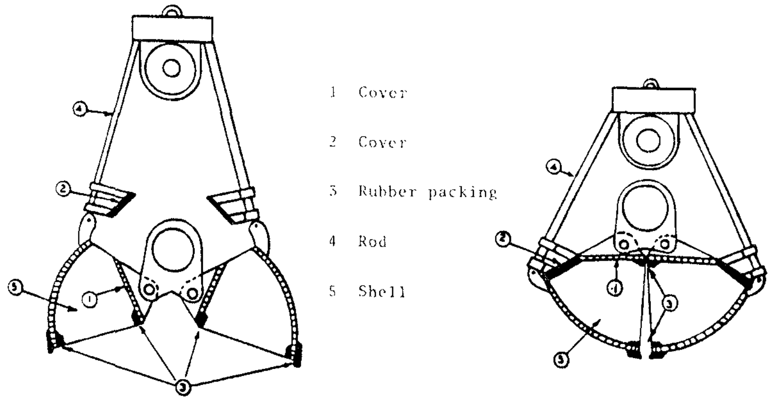

Figure 1. Open and closed positions of the watertight clamshell bucket

Mud Cat. The Mud Cat has a horizontal cutter-head equipped with knives and spiral augers that cut the material and move it laterally toward the center of the augers where it is picked up by the suction. The dredge can remove sediments in a 2.6-m width and in water depths up to 4.9 m. The dredge operates on anchor cables, and the manufacturer claims that it leaves the bottom of the dredged area flat. By covering the cutter-auger combination with a retractable mud shield the amount of turbidity generated by Mud Cat's operation can be minimized.

Remotely-controlled Mud Cat. A remotely-controlled unit has been developed in which the control cab is located on land and is remotely connected to the Mud Cat by an umbilical cord. This allows safe dredging of hazardous or toxic materials. The remote control provides the shore-based dredge master with a variable traversing winch control, a variable auger control, a variable dredge pump speed control, and a manually-controlled emergency shut down.

The "Clean-up" System. The clean-up head consists of a shielded auger that collects sediment as the dredge swings back and forth and guides it toward the suction of a centrifugal pump. The auger is shielded and a moveable wing covers the sediment as it is being collected by the auger. An underwater TV camera and sonar devices indicate the topography of the bottom (Figure 2). Fairly large volumes have been excavated by "Clean-up" dredges in soft muds and sand containing various contaminants such as mercury, cadmium, PCBs, oily and organic substances (Sato, 1984).

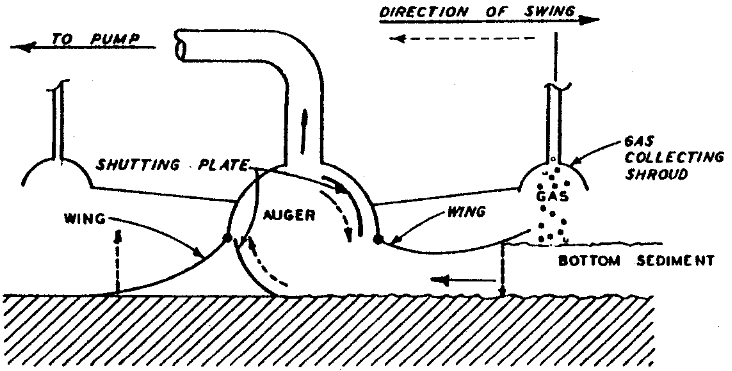

Figure 2. The "Clean-up" system (Sato, 1984)

Refresher. The material being dredged is confined by a specially-designed flexible enclosure that completely covers the cutter, preventing escape of sediments to the outside of the immediate dredging area (Figure 3). The working open section is always on the swing side of the cutterhead. A gas removal system is also installed and can be activated as needed to prevent gas moving up the suction pipe. The flexible enclosure of the cutterhead is automatically adjusted to bottom contours (Figure 4) (Shinsha, 1988).

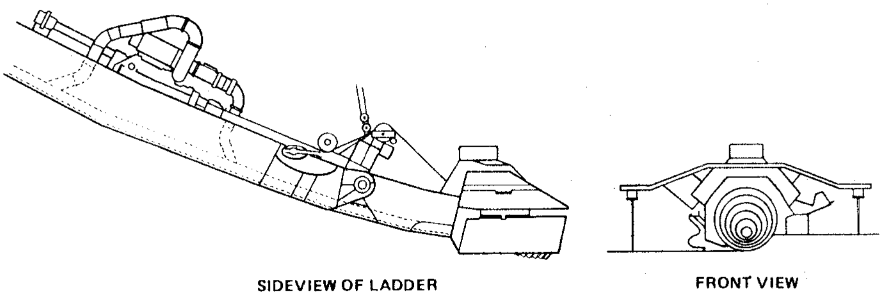

Figure 3. "Refresher" dredge (Shinsha, 1988)

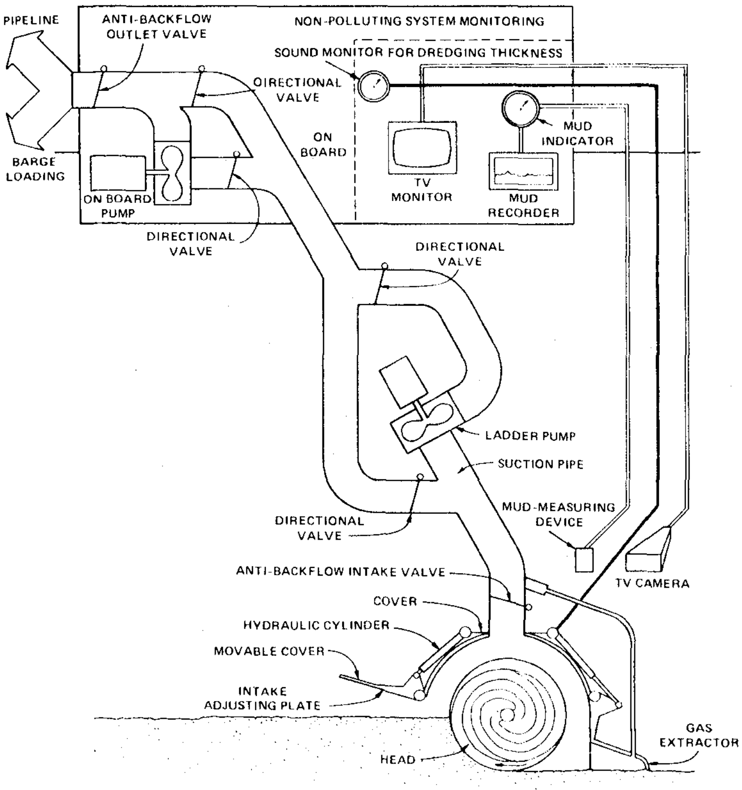

Figure 4. Description of a "Refresher" dredge (Shinsha, 1988)

Matchbox dredge. A special suction head was developed by a dredging contractor in the Netherlands to replace the traditional cutterhead (d'Angremond et al., 1984). The main design points are as follows:

1. A large plate covers the top of the dredge head to avoid inflow of water and escape of gas bubbles.
2. Adjustable angle between the drag head and the ladder to create an optimum position of the drag head independent of the dredging depth.
3. There are openings on both sides of the drag head to improve dredging efficiency. During swinging action the leeward side is closed to prevent water inflow.
4. Dimensions of the head must be carefully designed for the average flow rate and swing rate.

A direct comparison between a Matchbox suction head, a conventional cutterhead and a clamshell was made by the Waterways Experiment Station in Calumet Harbor (Hayes et al., 1988). The Calumet Harbor demonstration indicated that the clamshell dredge generated the largest suspended sediment plume affecting the entire water column. The cutterhead slightly outperformed the Matchbox dredge in this field experiment.

Pneuma pump. The Pneuma pump is a compressed-air-driven, displacement-type pump with several major components (Herbich, 1975). The pump body, the largest of these components in dimensions and weight, incorporates three large cylindrical pressure vessels, each having a material intake on the bottom and an air port and discharge outlet on top. Each intake and discharge outlet is fitted with a check valve, allowing flow in one direction only. Pipes leading from the three discharge outlets join in a single discharge directly above the pressure vessels. Different types of attachments may be fitted on the intakes for removal of varying types of bottom material. Pneuma pump was evaluated by the U.S. Army Engineer Waterways Experiment Station (Richardson et al., 1982).

Oozer dredge. The Oozer pump was developed by Toyo Construction, Japan. The pump operates in a manner similar to that of the Pneuma pump system; however, there are two cylinders (instead of three) and a vacuum is applied during the cylinder-filling stage when the hydrostatic pressure is not sufficient to rapidly fill the cylinders. The pump is usually mounted at the end of a ladder and equipped with special suction heads and cutter units depending on the type of material being dredged. The conditions around the dredging system, such as thickness, bottom elevation after dredging, and amount of resuspension, are monitored by high-frequency acoustic sensors and an underwater television camera. A large Oozer pump has a dredging capacity ranging from 300 to 500 m^3/hr. During one dredging operation, suspended solids levels within 3 m of the dredging head were all within background concentrations of less than 6 mg/liter.

Recommendations

- Source control measures must be considered in all cases, including no action. Federal and state regulatory agencies requiring remedial action should implement source control measures as a component of remedial action when applicable and appropriate. Use of financial incentives through strict liability for assessment cost, remedial actions, and damages also may play an important role in source control, provided that trustees make aggressive efforts to hold responsible parties liable for releases into the environment.

- Aggressive technology and information transfer mechanisms are needed to ensure that knowledge gained and lessons learned from all remedial actions are available and accessible to managers confronting new remediation problems at federal, regional and local levels. Knowledge gained should be systematically compiled in guidance documents. Lessons learned regarding the feasibility of sophisticated remedial technologies under varying conditions of contamination severity and extent should be documented and made widely available to facilitate future decision making. Lastly, experience gained through the use of screening procedures at large sites should be distilled and generalized into routine methodologies for economically assessing smaller sites.
- When possible, remediation projects should be designed to take advantage of existing navigational dredging activities that may already be authorized in conjunction with the Clean Water Act, Section 115 or Section 10/404.
- Research and development should be encouraged by the federal government to develop technology and equipment for efficiently removing contaminated sediments and to make it available in the United States. Foreign technologies should continue to be examined relative to their appropriateness in this country. Efforts to conduct and fund research and development as a partnership between government and industry should be encouraged.
- Although capping might not, in the strictest terms, be considered a remedial technology, it should not be ignored because it can play a valuable role in remediating contaminated sites.
- Monitoring programs should be well-focused on testing forecasts made during design of the remediation plan. To the extent possible, monitoring should be extended to remove uncertainties in the basic understanding of contaminated sediment behavior. For example, monitoring of capped areas might focus on changes of cap thickness, erosion around boundaries, and leakage of contaminant through the cap.

Remediation and Source Control: Economic Considerations

Remedial actions are costly and become more expensive as additional levels of clean-up or treatment are pursued. The role of tradeoffs between possible technologies at and among sites must be considered, given the scarcity of funds to clean up contaminated sites and the potentially great number of sites.

The use of the benefit-cost analysis as part of the remedial action decision process would provide perspective on the issues involved. It would place investments in this area on the same footing as other public investments. However, difficulty in quantifying benefits from remedial actions in monetary terms makes reliance on benefit-cost analysis infeasible in a number of cases. Nonetheless, in light of the high cost of remedial actions, it is important that implicit (if not explicit) consideration be given to potential benefits before remedial actions are undertaken.

Removal of contaminated sediments can be very expensive, varying widely from several hundred thousand dollars to tens of millions of dollars. Data on 15 clean-up sites indicate that total clean-up costs can reach $500,000 to $1,000,000 per acre* (U.S. Congress Office of Technology Assessment, 1988). This compares with an average unit cost of navigation dredging of $1 to $2 per cubic yard of sediment dredged. The average unit cost of all dredging, both government and private, is estimated in 1988 at $1.67 per cubic yard of material dredged. On site incineration, one of the remedial measures proposed at various sites, is also very expensive. The estimates quoted are from $186 to $750 per cubic yard.

<u>Recommendations</u>

- In view of the high cost of remedial actions in most cases, greater use should be made of benefit-cost comparisons over ecologically relevant time periods in order to place investments in this area on the same economic footing as investments in other public projects.

- Cost-effectiveness analysis of alternative remedial actions should consider both short- and long-term costs. Comparisons at and among sites should be based on costs estimated using a consistent approach.

- In evaluating the degree of remediation to be conducted at a site, it should be recognized that incremental costs typically will increase rapidly as additional levels of clean-up are sought.

- The decision as to whether or not remedial actions are undertaken should be based on a balanced

---

*For purposes of comparison, assume that a one-acre clean-up involved removing overburden to a depth of one yard, or a total of 43,560 yds^3 of contaminated material. In that event, total clean-up costs would range from $11.50 to $23.00 per yd^3.

comparison of the anticipated environmental and public health benefits of actions with their costs, including possible environmental and health risks.

• Clearly infeasible options should be eliminated at the outset, before alternative remedial actions are considered in depth.

References

d'Angremond, K., A.J. de Jong, C.P. de Waard. 1984. Dredging of polluted sediment in the first petroleum harbor, Rotterdam. Proc. 3rd U.S.-the Netherlands meeting on Dredging and Related Technology. Fort Belvoir, VA: U.S. Army Engineer Water Resources Support Center.

Hayes, D.F., T.N. McLellan and C.L. Truitt. 1988. Demonstration of innovative and conventional dredging equipment at Calumet Harbor, Illinois. MP EL-88-1. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Herbich, J.B. 1975. Coastal and Deep Ocean Dredging. Houston, TX: Gulf Publishing Company.

Herbich, J.B. and S.B. Brahme. 1990. A literature review and technical evaluation of sediment resuspension during dredging. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station (in press).

Marine Board, 1989. Contaminated marine sediments - assessment and remediation. Washington, DC: National Research Council, National Academy Press.

Pequegnat, W.E. 1987. Relationship between dredged material and toxicity. Terra et Aqua, 34.

Richardson, T.W., J.E. Hite, R.A. Shafer and J.D. Ethridge. 1982. Pumping performance and turbidity generation of model 600/100 Pneuma pump. TR HL-82-8,. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Sato, E. 1984. Bottom sediment dredge CLEAN UP. Principles and results, management of bottom sediments containing toxic substances. Proc. 8th U.S./Japan Experts Meeting, T.R. Patin, ed. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station, pp. 403-418.

Shinsha, H. 1988. Personal communication, Refresher dredge, Japan: Technical and Research Institute, Penta-Ocean Construction Company, Ltd.

U.S. Congress Office of Technology Assessment. 1988. Are we cleaning up? 10 Superfund case studies. Special Report OTA-ITE-362. Washington, DC: U.S. Government Printing Office.