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Dredging Research Technical Notes

Design Requirements for Capping

Purpose

This technical note describes design requirements and a design sequence for Level Bottom Capping (LBC) and Contained Aquatic Disposal (CAD) projects. The procedures and sequence include evaluation of capping and contaminated sediments, site selection, equipment and placement techniques, mixing and dispersion during placement, required capping sediment thickness, material spread and mounding during placement, cap stability, and monitoring.

Background

When dredged material is placed in open-water sites, there is potential for both water column and benthic effects. The release of contaminants into the water column is not generally viewed as a significant problem for dredged material from most navigation projects. The acceptability of a given material for unrestricted open-water disposal is therefore mostly dependent on an evaluation of the potential benthic effects. Capping is considered an appropriate contaminant control measure for benthic effects in the Corps' dredging regulations (33 CFR 335-338) and supporting technical guidelines (Francingues and others 1985), and is recognized by the London Dumping Convention as a management technique to rapidly render harmless otherwise unsuitable materials.

Guidelines are available for planning capping projects, and for selection of placement techniques for capping projects (Truitt 1987a and 1987b). This technical note supplements the available guidance by describing design requirements and design sequence for capping projects. Duplicative and unnecessary data collection and evaluations can be avoided by following the guidance in this technical note.

Additional Information or Questions

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Introduction

Capping is the controlled, accurate placement of contaminated material at an open-water disposal site, followed by a covering or cap of clean isolating material. For purposes of this note, the term "contaminated" refers to material found to be unacceptable for unrestricted open-water placement because of potential contaminant effects, while the term "clean" refers to material found to be acceptable for such placement. Level Bottom Capping (LBC) may be defined as the placement of a contaminated material on the bottom in a mounded configuration, and the subsequent covering of the mound with clean sediment. Contained Aquatic Disposal (CAD) is similar to LBC but with the additional provision of some form of lateral confinement (for example, placement in bottom depressions, or behind subaqueous berms) to minimize spread of the materials on the bottom. LBC and CAD are illustrated in Figures 1 and 2.

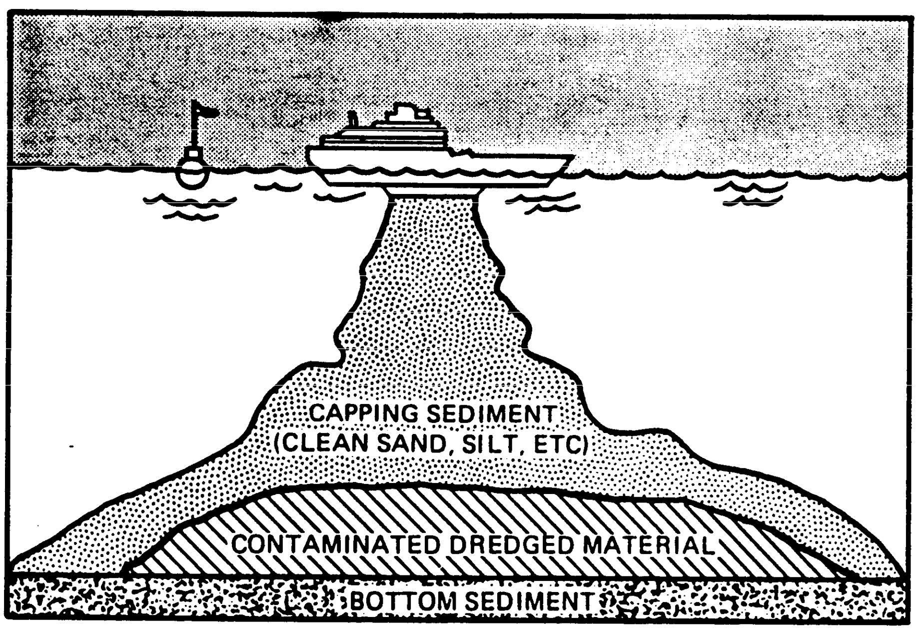

Figure 1. Level bottom capping operation (adapted from Shields and Montgomery 1984)

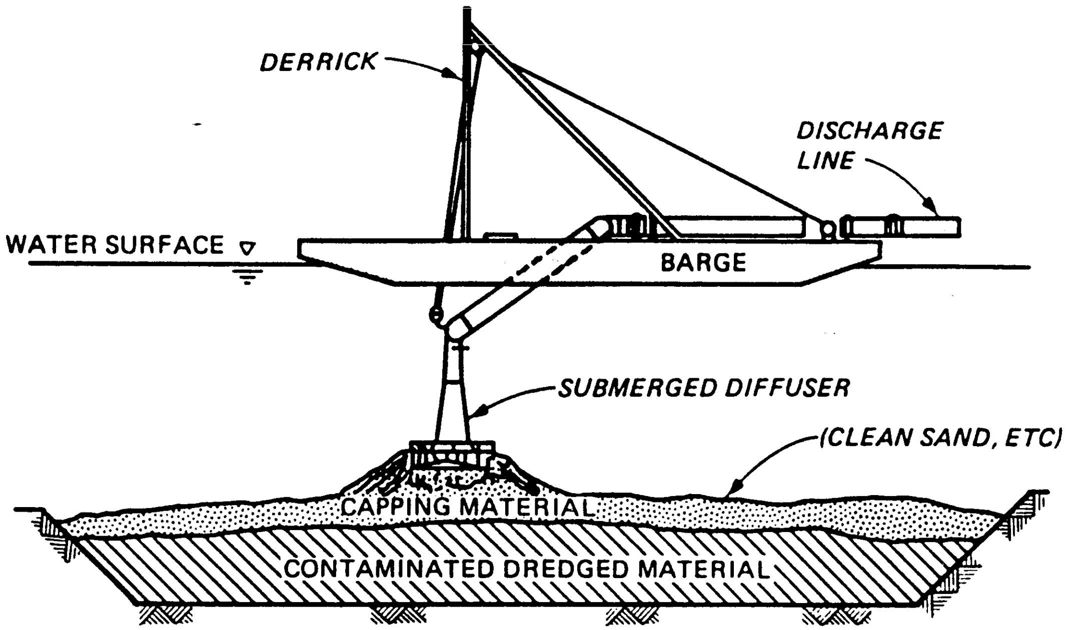

Figure 2. Contained aquatic disposal (adapted from Truitt 1987a)

Capping of contaminated material in open-water sites began in the late 1970s, and a number of capping operations under a variety of placement conditions have been accomplished. Conventional disposal equipment and techniques are frequently used for a capping project, but these practices must be controlled more precisely than for conventional placement.

Design Requirements for Capping

Capping should not be viewed merely as a form of unrestricted open-water placement. A capping operation should be treated as an engineered project with carefully considered design, construction, and monitoring to ensure that the design is adequate. The basic criteria for a successful capping operation is simply that the cap thickness required to isolate the contaminated material from the environment be successfully placed and maintained.

The flowchart shown in Figure 3 illustrates the major design requirements for a capping project and the sequence in which the design requirements should be considered. There is a strong interdependence among all components of design for a capping project. For example, the initial consideration of a capping site and placement techniques for both the contaminated and capping materials will strongly influence all subsequent evaluations, and these initial choices must also be compatible for a successful project (Shields and Montgomery 1984). When an efficient sequence of activities for design of a capping project is followed, unnecessary data collection and evaluations can be avoided. General descriptions of the

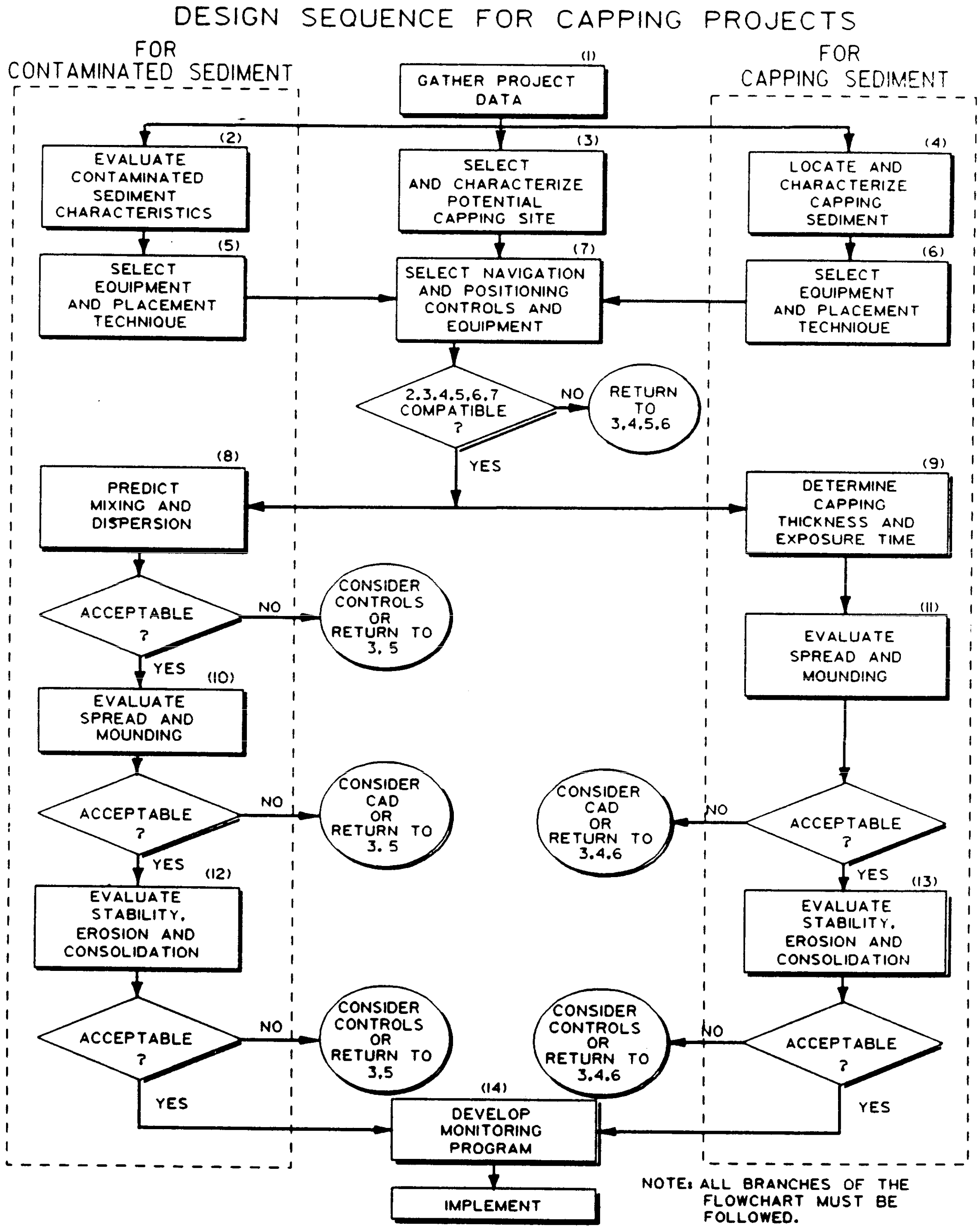

Figure 3. Flowchart illustrating design sequence for capping projects

various design requirements are given below in order corresponding to the recommended design sequence. The numbered blocks in the flowchart in Figure 3 are referenced in the text in parentheses.

Gather Project Data (1)

The first step in any project design is to gather and evaluate the existing data. For a capping project, such data would normally include surveys of the dredging area, existing data on the contaminated sediment, and data on potential placement sites. If capping is under consideration, data on the suitability of the material to be dredged for open-water placement may exist. These data may include results of physical, chemical, and biological tests required under Section 404 of the Clean Water Act or Section 103 of the Ocean Dumping Act. Data on potential placement sites may vary. Bathymetry, currents, and bottom sediment characterization data would normally be available for open-water sites under consideration.

Once the existing data have been gathered, three main aspects of capping design must be examined: aspects related to characterization and placement of the contaminated material, aspects related to the characterization and placement of the capping material, and aspects related to the capping site under consideration. Each of these aspects must be initially examined in a parallel fashion (2, 3, and 4). Further, the interrelationship and compatibility of these three aspects of the design are critical.

Characterize Contaminated Sediment (2)

The contaminated sediment must be characterized from physical, chemical, and biological standpoints. Physical characteristics are of importance in determining the behavior of the material during and following placement at a capping site. In-situ volume (to be dredged), in-situ density (or water content), cohesiveness, and grain-size distribution are needed for evaluations of dispersion and spread during placement, mounding characteristics, and long-term stability and resistance to erosion. These data should be developed using standard techniques.

Capping is a contaminant control measure for prevention of potential benthic effects (Francingues and others 1985), and capping as an alternative is usually considered only after determining that benthic effects resulting from unrestricted open-water placement would be unacceptable. Therefore, some chemical and biological characterization of the contaminated sediment will normally be performed as a part of the overall evaluation for suitability for open-water placement (US Environmental Protection Agency (EPA) and US Army Corps of Engineers (USACE) 1990). Chemical characterization of the contaminated sediment may include a sediment chemical inventory and standard elutriate test results. The chemical sediment inventory is useful in determining contaminants of concern and in development of appropriate chemical elements of a monitoring program to determine capping effectiveness. Elutriate data are sometimes used in estimating the potential effects on water quality due to placement of the contaminated material. Biological characterization may include water column bioassays, benthic bioassays, and bioaccumulation tests. The results of these biological tests are useful in determining potential water-column effects during placement, and acceptable exposure times before placement of the cap begins.

Selection of a Potential Capping Site (3)

The selection of a potential site for capping is subject to the same constraints and tradeoffs as any other open-water placement site. The major considerations in site selection include: bathymetry, currents, water depths, water column density stratification, bottom sediment characteristics, and operational requirements such as distance and sea state (Truitt 1987a). However, in addition to normal considerations, the capping site should be in a relatively low-energy environment with little potential for erosion of the cap.

Bathymetry forming a natural depression will tend to confine the material, resulting in a CAD project. Placement of material on steep bottom slopes should generally be avoided for a capping project. Water-column currents affect the degree of dispersion during placement and the location of the mound with respect to the point of discharge. Of more importance are the bottom currents which could potentially cause resuspension and erosion of the mound and cap. The effects of storm-induced waves on bottom current velocities should also be considered. Recent case studies have indicated that water depth is of particular interest in evaluating the potential suitability of a site for capping operations (Palermo 1989). The deeper the water at the site, the greater the potential for water entrainment and dispersion during placement. However, deeper water depths also generally provide more stable conditions on the bottom with less potential for erosion. Numerical models for evaluation of dispersion and spread (8, 10) and for sediment transport and erosion (12, 13) can aid in evaluation of alternative sites.

Selection and Characterization of Capping Sediment (4)

The capping sediment used in a capping project to cover contaminated sediment may be a matter of choice. For economic reasons, a capping sediment is usually taken from an area which also requires dredging. If this is the case, there may be a choice between projects, and scheduling of the dredging is an important consideration. In other cases, removal of bottom sediments from areas adjacent to the capping site may be considered. If CAD is under consideration, removal of material to create CAD cells for stockpiling and later use in the capping operation can be considered (Averett and others 1989 and Sumeri 1989).

The capping sediment should be characterized as described above for the contaminated sediment. However, the capping sediment must be one which is acceptable for unrestricted open-water placement (that is, a clean sediment). The evaluation of a potential capping sediment for open-water placement acceptability would be accomplished using appropriate techniques under either Section 404 or Section 103. Physical characteristics of the capping sediment are also of particular interest in capping design. Density (or water content), grain-size distribution, and cohesiveness of the capping sediment must be evaluated. The characteristics of the capping sediment should be compatible with the contaminated sediment, considering the placement technique for both. Previous studies have shown that both fine-grained materials and sandy materials can be effective capping materials.

Equipment and Placement Technique for Contaminated Sediment (5)

A variety of equipment types and placement techniques have been used for capping projects. The important factors in placement of the contaminated material are reducing water-column dispersion and bottom spread to the greatest possible extent. This minimizes the release of contaminants during placement and provides for easier capping. For LBC the dredging equipment and placement technique for contaminated sediment must provide a tight, compact mound which is easily capped. This is most easily accomplished with mechanical dredging and barge release. If CAD is under consideration, hydraulic placement of the contaminated material may be acceptable.

Specialized equipment and placement techniques can also be considered to increase control during placement and reduce potential dispersion and spread of contaminated material. These might include use of submerged diffusers or submerged discharge points for hydraulic pipeline placement, hopper dredge pumpdown with diffuser, or gravity-fed tremie for mechanical or hydraulic placement (Truitt 1987b).

Equipment and Placement Technique for Capping Sediment (6)

The major design requirement in selection of equipment and placement of the cap is the need for controlled, accurate placement to specify the resulting density and rate of application of capping material. In general, the cap material should be placed so that it accumulates in a layer covering the contaminated material. The use of equipment or placement rates which might result in the capping material displacing or mixing with the previously placed contaminated material should be avoided. Placement of capping material at equal or lesser density than the contaminated material would generally meet this requirement.

Specialized equipment and placement techniques can be considered to increase control of capping material placement. The movement of submerged diffusers, submerged discharge points, or tremies can be controlled to spread capping material over an area to a required thickness. Incremental opening of split-hull barges along with controlled movement of the barges during surface release has been used for mechanically dredged capping material (Sumeri 1989).

Selection of Navigation and Positioning Equipment and Controls (7)

Controlled and accurate placement of both the contaminated and capping material is an integral part of a successful capping project. Once the dredging equipment and placement techniques and potential capping site have been selected, the needs for navigation and positioning equipment and controls can be addressed. The objective here is to place the material (whether by the bargeload, hopperload, or by pipeline) at the desired location in a consistently accurate manner so that mounding can occur and so that adequate coverage by the cap can be attained. For pipeline placement in shallow water, the desired positioning of the pipeline discharge can be maintained with little difficulty. Accurate navigation to the placement site and precise positioning during material placement by bottom-dump barge or hopper dredge is more difficult, especially for sites well offshore. State-of-the-art equipment and techniques should be employed to assure accurate point placement to the extent deemed necessary. Taut-moored buoys; mooring barges; various acoustical positioning devices; and computer-assisted, real-time helmsman's aids should be considered. In all cases, barges or scows must be required to release the material within a prescribed radius of the designated point of placment. A positioning system for the disposal barges must be specified which has sufficient accuracy to ensure placement within the minimum specified radius of placement. Diligent inspection of operations to ensure compliance with specifications is essential.

Evaluate Compatibility of Site, Materials, and Equipment

At this point in the design, the contaminated material has been characterized, a capping sediment has been selected and characterized, equipment and placement techniques have been selected for both materials, and navigation and positioning needs have been addressed. These essential components of the design (3, 4, 5, 6, and 7) should now be examined as a whole with compatibility in mind.

A major consideration in compatibility is an acceptable match of equipment and placement techniques for contaminated and capping material. For example, if the contaminated material were mechanically dredged and released from barges, the capping material could be similarly placed or could be placed hydraulically. However, if the contaminated material were hydraulically placed, then only hydraulic placement of the capping material may be appropriate due to the potentially low shear strength of the contaminated material. Guidelines for selection of compatible equipment are found in Truitt (1987b).

Compatible scheduling of the contaminated material placement and capping operation is essential. The exposure of the contaminated material to the environment and need to allow consolidation of the contaminated material to occur prior to cap placement (9) must be balanced in scheduling both placement operations. Availability of equipment and funding and the possibility of equipment breakdowns or other delays should be considered in determining if the capping schedule is compatible with the contaminated material placement schedule.

If the components are compatible, additional and more detailed design requirements can be addressed. If there is a lack of compatibility at this point, a different capping site (3), a different capping sediment (4), or different placement equipment and techniques (5, 6) must be considered. A close examination of the project design components at this decision point is essential before performing the more detailed and costly evaluations which come later in the design process.

Predict Mixing and Dispersion of Contaminated Sediment (8)

If water-column effects during placement of the contaminated material are of concern, an evaluation in accordance with Section 404 or Section 103 should be performed. Such an evaluation may involve comparison of predicted water-column contaminant concentrations with water quality criteria or predicted water-column dredged material concentrations with bioassay test results. Use of available mathematical models to predict the water-column dispersion and mixing would be an integral part of such evaluations (EPA and USACE 1990 and Johnson 1990). In addition, the prediction would indicate what portion of the contaminated material would be released during placement and would not eventually be capped. If barge release or hopper dredge release is used, the model would also indicate the initial spread of a single bargeload. This information would be used in determining the mounding characteristics for the entire contaminated material volume to be placed. If water-column release is unacceptable, control measures could be considered to reduce the potential for water-column effects, or other dredging equipment and placement techniques (5) or use of another capping site (3) could be considered. Control measures could include use of a submerged discharge point, submerged diffuser, tremie pipe, hopper dredge pumpdown, or similar equipment and procedures (Truitt 1987b).

Determine the Required Cap Thickness and Exposure Time (9)

The cap must be designed to chemically and biologically isolate the contaminated material from the aquatic environment. The determination of the minimum required cap thickness is dependent on the physical and chemical properties of the contaminated and capping sediments, the potential for bioturbation of the cap by aquatic organisms, and the potential for consolidation and erosion of the cap material. Laboratory tests have been developed to determine the thickness of a capping sediment required to chemically isolate a contaminated sediment from the overlying water column (Sturgis and Gunnison 1988). These tests can also be performed in the presence of bioturbating organisms (Brannon 1985). An evaluation of the potential for colonization of the capped site by bioturbating organisms and the behavior of those organisms with respect to intensity and depth of burrowing must be made. The minimum required cap thickness is considered the thickness required for chemical isolation plus that thickness of bioturbation associated with organisms likely to colonize the site in significant numbers.

The integrity of the cap from the standpoint of physical changes in cap thickness and long-term migration of contaminants through the cap should also be considered. The potential for a physical reduction in cap thickness due to the effects of consolidation and erosion (12, 13) can be evaluated once the overall size and configuration of the capped mound is determined. The design cap thickness can then be adjusted such that the minimum required cap thickness is maintained.

Most consolidation of the contaminated material will occur within a few weeks of placement, and the cap placement could be delayed an appropriate time period to allow the majority of consolidation to occur. Such a delay also holds advantage from the standpoint of resistance of the contaminated deposit to displacement during cap placement. However, a delay exposes the contaminated material to the environment. An appropriate delay between contaminated material placement and capping must balance environmental exposure with the engineering requirements of stability and the scheduling constraints of the dredging required for capping.

Long-term migration of contaminants through the cap can potentially occur due to consolidation of the contaminated material and the diffusion process. The techniques for evaluation of consolidation (Poindexter-Rollings 1990) can be used to estimate the cap thickness potentially affected by the movement of contaminated pore water (Brannon and Poindexter-Rollings 1990). The effect of long-term diffusion on the design cap thickness would normally be negligible, because long-term diffusion of contaminants through a cap is an extremely slow process and contaminants would be adsorbed to the clean cap material particles. If deemed necessary, an evaluation of contaminant transport by diffusion can be made (Lerman 1979).

The test for chemical isolation has determined the minimum required cap thickness to be on the order of 1 ft for most sediments tested to date. Bioturbation depths are highly variable, but would be on the order of 1 to 2 ft for most organisms which would populate a site in great numbers. Considering the fact that small thicknesses of materials cannot be easily placed by conventional dredging operations, the minimum cap thickness for most projects will therefore be on the order of 3 to 4 ft plus an appropriate allowance for potential erosion and consolidation.

Evaluate Spread and Mounding (10, 11)

The mound geometry, including contaminated material mound and cap, will influence the design of the cap and volume of capping material required. The smaller the footprint of the contaminated material as placed, the less volume of capping material will be required to achieve a given cap thickness. For LBC sites, the spread and development of the contaminated material mound is dependent on the physical characteristics of the material (grain size and cohesion) and the placement technique used (hydraulic placement will result in greater spread than mechanical placement). Assuming that the material from multiple bargeloads or pipeline can be accurately placed at a single point, the angle of repose taken by the material and the total volume placed will dictate the mound spread. However, little data is available on the volume changes resulting from entrainment of water during open-water placement or the shear strengths of dredged material initially deposited in open-water sites. For these reasons, estimates of mound spread have been made based on the observed characteristics of previous mounds created with similar placement techniques and similar sediments (Palermo and others 1989).

Evaluate Stability, Erosion, and Consolidation (12, 13)

The deposit of contaminated dredged material must be stable against excessive erosion and resuspension of material before placement of the cap. The cap material must be stable against long-term erosion for the required cap thickness to be maintained. The potential for resuspension and erosion is dependent on bottom current velocity, potential for wave-induced currents, sediment particle size, and sediment cohesion. Site selection criteria as described above would normally result in a site with low bottom current velocity and little potential for erosion. However, if the material is hydraulically placed, a thorough analysis of the potential for resuspension and erosion should be performed. Conventional methods for analysis of sediment transport should be used to evaluate erosion potential (Teeter 1988, and Dortch and others 1990). These methods can range from simple analytical techniques to numerical modeling. In the analysis of erosion, the effects of self-armoring due to the winnowing away of finer particles should be considered.

Consolidation of the mound of contaminated material should be examined for its effect on mound slopes and volume occupied within the placement site. In general, consolidation of the contaminated mound will result in more stable conditions. The same is true for consolidation of the cap material. However, consolidation of the cap results in a reduced cap thickness. Therefore the potential for cap consolidation should be considered in the overall design of the cap thickness. Techniques have recently been developed for evaluation of consolidation of mounds (Poindexter 1989 and Poindexter-Rollings 1990).

If the potential for erosion and consolidation of either the contaminated material or cap is unacceptable, an alternate site (3), alternate capping sediment (4), or alternate placement techniques (5, 6) can be considered. Control measures such as incorporating an erosion-resistant layer in the cap design can also be evaluated (Environmental Laboratory 1987).

Develop a Monitoring Program (14)

A monitoring program should be considered as a part of any capping project design. The main objectives of monitoring would normally be to ensure that the contaminated sediment is placed as intended and with acceptable levels of contaminant release, the cap is placed as intended and the required capping thickness is maintained, and the cap is effective in isolating the contaminated material from the environment (Palermo and others 1989). Monitoring plans for capping projects should include a more intensive effort during and shortly after placement operations, with a declining level of effort in future years. Physical, chemical, and biological elements may be included in a monitoring plan. In all cases, the objectives of the monitoring effort and any remedial actions to be considered as a result of the monitoring should be clearly defined as a part of the overall project design.

Summary and Conclusions

A capping operation should be treated as an engineered project with fully considered design, construction, and monitoring to ensure that the operation is adequate. The design requirements for an LBC or CAD project include characterization of both contaminated and capping sediments, selection of an appropriate site, selection of compatible equipment and placement techniques, prediction of mixing and dispersion during placement, determination of the required capping sediment thickness, prediction of material spread and mounding during placement, evaluation of cap stability against erosion and bioturbation, and development of a monitoring program.

There is a strong interdependence among all components involved in designing a capping project. When an efficient sequence of activities for design of an LBC or CAD project is followed, unnecessary data collection and evaluations can be avoided and a fully integrated design will result.

References

Averett, D. E., Palermo, M. R., Otis, M. J., and Rubinoff, P. B. 1989. "New Bedford Harbor Superfund Project, Acushnet River Estuary Engineering Feasibility Study of Dredging and Dredged Material Disposal Alternatives; Report 11, Evaluation of Conceptual Dredging and Disposal Alternatives," Technical Report EL-88-15, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brannon, J. 1985. "Effectiveness of Capping in Isolating Contaminated Dredged Material from Biota and the Overlying Water," Technical Report D-85-10, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brannon, J., and Poindexter-Rollings, M. E. 1990. "Consolidation and Contaminant Migration in a Capped Dredged Material Deposit," *The Science of the Total Environment*, Vol 91, pp 115-126.

Dortch, M. S. and others. 1990. "Methods of Determining the Long-Term Fate of Dredged Material for Aquatic Disposal Sites," Technical Report D-90-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Environmental Laboratory. 1987. "Disposal Alternatives for PCB-Contaminated Sediments from Indiana Harbor, Indiana" Volume 1, Miscellaneous Paper EL-87-9, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Francingues, N. R., Palermo, M. R., Lee, C. R., and Peddicord, R. K. 1985. "Management Strategy for Disposal of Dredged Material: Contaminant Testing and Controls," Miscellaneous Paper D-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Johnson, B. H. 1990. "User's Guide for Models of Dredged Material Disposal in Open Water," Technical Report D-90-5, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Lerman, A. 1979. "Geochemical Processes in Water and Sediment Environments," John Wiley and Sons, New York.

Palermo, M. R. 1989. "Capping Contaminated Dredged Material in Deep Water," *Proceedings of the Specialty Conference Ports 89*, American Society of Civil Engineers, Boston, MA.

Palermo, M. R., and others. 1989. "Evaluation of Dredged Material Disposal Alternatives for US Navy Homeport at Everett, Washington," Technical Report EL-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Poindexter, M. E. 1989. "Monitoring Dredged Material Consolidation and Settlement at Aquatic Disposal Sites," Environmental Effects of Dredging Technical Note EEDP-01-5, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Poindexter-Rollings, M. E. 1990. "Methodology for Analysis of Subaqueous Sediment Mounds," Technical Report D-90-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Shields, F. D., and Montgomery, R. L. 1984. "Fundamentals of Capping Contaminated Dredged Material," *Proceedings of the Specialty Conference Dredging 84*, American Society of Civil Engineers, Clearwater, FL.

Sturgis, T., and Gunnison, D. 1988. "A Procedure for Determining Cap Thickness for Capping Subaqueous Dredged Material Deposits," Technical Note EEDP-01-09, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Sumeri, A. 1989 (May). "Confined Aquatic Disposal and Capping of Contaminated Bottom Sediments in Puget Sound," *Proceedings of the WODCON XII, Dredging: Technology, Environmental, Mining*, World Dredging Congress, Orlando, FL.

Teeter, A. M. 1988. "New Bedford Harbor Superfund Project, Acushnet River Estuary Engineering Feasibility Study of Dredging and Dredged Material Disposal Alternatives; Report 2, Sediment and Contaminant Hydraulic Transport Investigations," Technical Report EL-88-15, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Truitt, C. 1987a. "Engineering Considerations for Subaqueous Dredged Material Capping" Background and Preliminary Planning, Environmental Effects of

Dredging Technical Note EEDP-01-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Truitt, C. 1987b. "Engineering Considerations for Capping Subaqueous Dredged Material Deposits Design Concepts and Placement Techniques," Environmental Effects of Dredging Technical Note EEDP-01-4, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

US Environmental Protection Agency and US Army Corps of Engineers. 1990. "Draft Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters," EPA-503-8-90/002, Environmental Protection Agency Office of Marine and Estuarine Protection, Washington, DC.