USACE TECHNICAL GUIDELINES FOR ENVIRONMENTAL DREDGING OF CONTAMINATED SEDIMENTS

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ABSTRACT

Environmental dredging is defined as dredging performed specifically for the removal of contaminated sediments for purposes of remediation. The U.S. Army Corps of Engineers has recently published *Technical Guidelines for Environmental Dredging of Contaminated Sediments* for the U.S. Environmental Protection Agency. These guidelines provide detailed information on environmental dredging to support USEPA's 2005 *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites*. Various aspects of the environmental dredging guidelines include: defining objectives of the dredging component of the remedy; initial determination of the feasibility of dredging; identification of data gaps; site and sediment characterization to support the evaluation of dredging; determining the removal requirements; developing performance standards; selecting dredging equipment types suitable for the project; estimating production rates and duration of the project; evaluation of sediment resuspension, contaminant release, and residuals; consideration of control measures; and development of operations and monitoring plans. This paper provides an overview of the contents of the environmental dredging guidelines and applicability of the guidelines to sediment remediation projects.

Keywords: Sediment Remediation, Dredging Equipment, Resuspension, Residuals, Contaminant Release

INTRODUCTION

Background

Options commonly considered for remediation of contaminated sediments include monitored natural recovery, in situ capping, and environmental dredging followed by treatment or disposal. Environmental Dredging is defined as follows:

> ***Environmental dredging*** - the removal of contaminated sediments from a waterbody for purposes of sediment remediation.

Environmental dredging using several equipment types and approaches, followed by treatment and disposal of the contaminated material and residuals management, has been the most frequent cleanup method for sediment used by the Superfund program and has been selected as the cleanup method for contaminated sediment or a component of the remedy at more than 100 Superfund sites, and nearly all of the larger sites.

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The concept of environmental dredging is a relatively new one, and much of the publicly available information on environmental dredging based on cleanup experience has been developed within the past 15 to 20 years. General technical guidance on environmental dredging is included in the recently published the USEPA Superfund Sediment Guidance (EPA 2005). However, the USEPA Office of Solid Waste and Emergency Response recognized the need for more detailed information to help project managers in evaluating environmental dredging. Detailed information for planning, selecting equipment, designing operational strategies, and predicting effectiveness had been largely site-specific, and no comprehensive technical guidelines on environmental dredging existed. The U.S. EPA therefore tasked the U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) to develop and publish *Technical Guidelines for Environmental Dredging of Contaminated Sediments* (Palermo et al. 2008), http://el.erdc.usace.army.mil/elpubs/pdf/trel08-29.pdf, referred to in this paper as the "guidelines".

Earlier papers presented at the 2006 WEDA annual meeting in San Diego and the 2007 Battelle 4th International Conference on Remediation of Contaminated Sediments in Savannah presented overviews of the guidelines as they were being prepared. This paper is an update of these earlier descriptions and presents a summary of the technical guidelines report as finally published.

Purpose, Scope, and Applicability

The purpose of the guidelines is to provide detailed technical procedures for planning, designing, implementing, and monitoring environmental dredging operations for purposes of contaminated sediment remediation. The procedures are compatible with and support the USEPA Superfund Sediment Guidance (EPA 2005) by providing detailed information regarding evaluation of environmental dredging as a remedy component. The intended audience includes all stakeholders potentially involved in evaluating environmental dredging for purposes of feasibility studies, remedial design, and implementation. The scope is limited to the technical aspects of the environmental dredging process itself, the transport of the dredged sediment (i.e., by barge or pipeline), and those processes and activities directly related to the dredging (e.g., associated monitoring). The guidelines are intended to be applicable to contaminated sediment sites evaluated under various environmental laws and regulatory programs, and the information provided can be applied at any of several phases of a sediment remediation project including the Remedial Investigation (RI), Feasibility Study (FS), and Remedial Design (RD) phases under the CERCLA framework, or similar phases under other remedial frameworks.

Environmental Dredging Objectives and Processes

It is important to initially identify the processes of importance for the site and define the objectives of the environmental dredging operation. The objectives of environmental dredging would normally include:

- Dredge with sufficient accuracy such that contaminated sediment is removed and sediment cleanup levels are met without excessive removal of clean sediment;
- Dredge the sediments in a reasonable period of time and in a condition compatible with subsequent transport for treatment or disposal;
- Reduce and/or control resuspension of contaminated sediments, downstream transport of resuspended sediments, and releases of contaminants of concern (COCs) to water and air; and,
- Dredge the sediments such that generation of residuals is reduced and/or controlled.

A number of factors and processes must be appropriately considered and evaluated to ensure that an environmental dredging operation achieves the above objectives, as well as the objectives of the remedy. Figure 1 is a conceptual illustration of environmental dredging and related processes of importance. These processes are defined as follows (Bridges et al. 2008).

> ***Removal*** is the process by which sediments are dislodged from the sediment bed and lifted or transported out of the dredge cut. Dredges dislodge sediment by mechanically and/or pneumatically penetrating, grabbing, raking, cutting, or hydraulically suctioning and/or scouring the sediment bed. Once dislodged, the sediment is lifted out of the dredge cut either hydraulically through a pipe or mechanically, as with buckets. Dredges can therefore be categorized as either mechanical or hydraulic depending on the basic means of transporting the dredged material from the sediment bed.

Resuspension is the process whereby bedded sediments are dislodged and dispersed in the water column by the dredging operation. The resuspended sediment particles may settle in the dredging area or be transported downstream.

Release is the process by which the dredging operation results in the loss of contaminants from the pore water of the sediment bed or from contaminants sorbed to resuspended sediment into the water column or air. The dissolved and colloidal contaminants that are released to the water column are typically transported farther downstream than contaminants sorbed to resuspended sediment.

Residuals are contaminated sediments remaining in or adjacent to the dredging footprint after completion of the removal/dredging operation. There are numerous potential causes for residual sediment contamination, but residuals can be broadly grouped into two categories: 1) undisturbed residuals (also commonly termed undredged inventory) and 2) generated residuals. Undisturbed residuals are contaminated sediments found at the post-dredge sediment surface that have been uncovered by dredging but not fully removed. These residuals may have been unidentified during characterization and therefore located below the cut line or may result from dredging inaccuracies or other factors such as the presence of structures, debris or irregular hard bottom features. Generated residuals are defined as sediment dislodged, but not removed, by dredging which falls back, spills, sloughs, or settles in or near the dredging footprint and forms a new sediment layer. The level of concern associated with the residuals depends on both the concentration and bioavailability of the contamination in the sediment and the density and thickness of the contaminated surface layer.

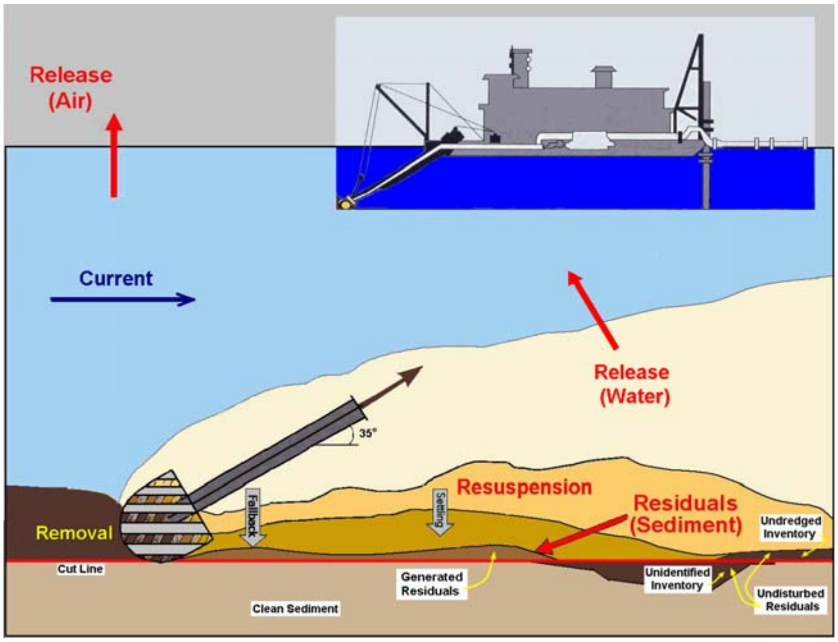

Figure 1. Conceptual illustration of environmental dredging and related processes.

Evaluation Sequence for Environmental Dredging

Environmental dredging is a complex process. A technically sound evaluation of environmental dredging as a remedy component requires a comprehensive evaluation of many steps. The guidelines therefore include an evaluation/design sequence. Figure 2 is a flowchart illustrating the major steps in the evaluation/design process.

The flowchart illustrates the recommended sequence and relationship between the various processes and the major decision points in evaluating environmental dredging. The evaluation sequence assumes that a decision has been made to evaluate environmental dredging as a potential remedy component for the project under consideration and other components of a dredging remedy will be considered and appropriately integrated with the environmental dredging component.

The steps shown in the flowchart span both the conceptual level of design and evaluation normally developed for a feasibility evaluation and the more detailed evaluations needed for a remedial design. Evaluation approaches and tools ranging from the simple to the more complex are available for many of the steps in the evaluation process. The design process may be performed for multiple dredge types, dredge sizes, dredge ancillary equipment (e.g., positioning equipment, boosters, cutterhead or suction head) and operational approaches to allow for comparisons to determine the best combination of equipment for the project specific sediment, site and performance criteria. The structure of the guidelines report (and this paper) generally follows the design sequence.

INITIAL EVALUATIONS

Initial evaluations should be conducted, based on existing information and data, to determine the potential applicability of environmental dredging as a remedy component for the site. The initial evaluations include: setting objectives; a comparison of known site, sediment, and project conditions to those conducive to a dredging remedy; consideration of the advantages and disadvantages of environmental dredging as compared to other remedy approaches or combinations of approaches; consideration of environmental dredging as a component of a complete dredging and treatment/disposal remedy approach; and identification of significant project requirements and constraints. The recently published EPA Superfund Sediment Guidance (EPA 2005) contains a listing of considerations for these initial evaluations.

As part of the initial evaluations, it is particularly important to identify major constraints at this stage, such as the non-availability of on-site disposal, etc. It is also important to consider needs for integrating the environmental dredging component of the remedy with other components such as the subsequent transport of sediment by other means (such as truck or rail), sediment dewatering, sediment and water treatment, and rehandling and disposal options for dredged sediment.

If environmental dredging is potentially applicable for the site, the evaluations should proceed. If site conditions or institutional constraints indicate that a full dredging remedy is not a potentially feasible or desirable option, other remediation options or combined remedies such as partial dredging followed by capping and/or monitored natural recovery should also be considered.

SITE CONDITIONS AND SEDIMENT CHARACTERIZATION

Data Gaps

The initial evaluations should provide a basis for determining any data gaps pertaining to environmental dredging which should be filled. Site and sediment characterization occurs throughout the Remedial Investigation (RI) and Feasibility Study (FS) and information is gathered for developing the site conceptual model and identifying remedial alternatives. Much of this information is useful for designing the environmental dredging alternative during Remedial Design (RD). However, the data are not usually sufficient, and additional data quality objectives may be formulated and fulfilled for purposes of design. Data gaps can be identified by comparing the needed site and sediment characterization data with the existing information.

Site Conditions

Depending on the data gaps identified at a particular phase of evaluation, the conditions for the contaminated sediment site under consideration for remediation must be defined or refined. This includes gathering the needed data on physical characteristics of the waterbody (water depths, bathymetry and slopes, currents, wave energies,

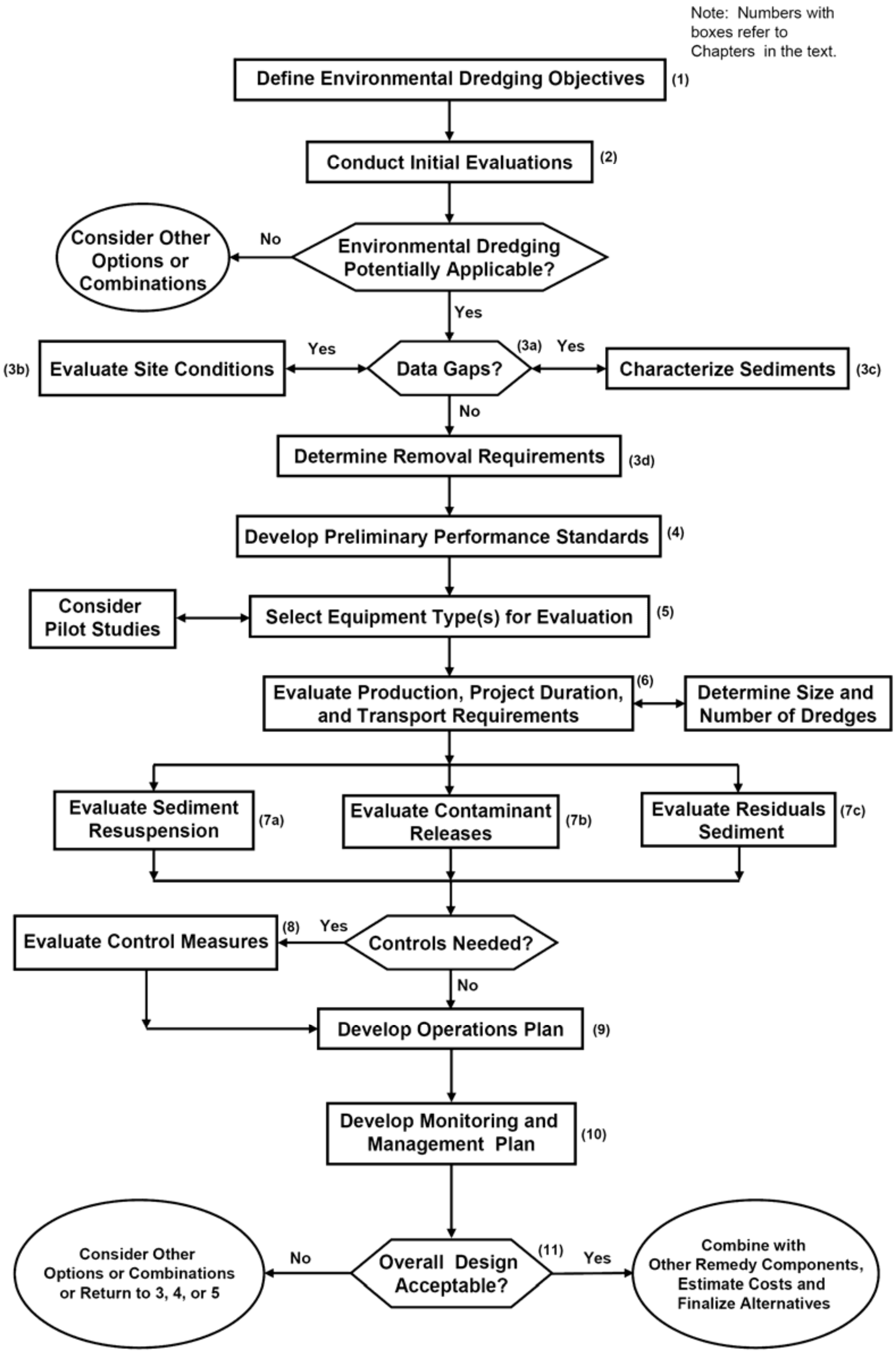

Figure 2. Flowchart illustrating the environmental evaluation/design sequence.

etc), waterbody uses (navigation, recreation, water supply, wastewater discharge, etc), the presence and nature of major infrastructure (bulkheads, piers, abandoned pilings, bridges, utility crossings, pipelines, etc.); the presence and nature of debris in the sediments; information on geotechnical conditions (stratification of underlying sediment layers, depth to bedrock, physical properties of foundation layers, etc). It is particularly important to identify site conditions critical to dredging implementability such as potential to undermine the shoreline or shoreline structures. The process of filling data gaps on site characterization may be iterative in that several tiers or phases of investigation may be warranted.

Sediment Characterization

In a similar manner, the contaminated sediments under consideration for dredging must be characterized, filling any data gaps critical to evaluation of environmental dredging. This includes the physical and chemical characteristics of the sediments. These characteristics should be determined both horizontally and vertically. The results of the characterization, in concert with the cleanup level defined for the remedy, will determine the potential aerial extent and depths to be dredged. As with evaluation of site conditions, the process may be iterative.

Removal Requirements

Once data gaps are appropriately filled, the removal requirements for environmental dredging can be determined to include evaluations related to dredgeability, debris removal, and the areas, depths and associated in-situ volume to be dredged. Dredgeability evaluations focus on the ability of various equipment types to effectively remove the sediments, to include consideration of factors such as the presence and extent of debris, the shear strength of the sediments, the presence of underlying hardpan or rock bottoms, etc. At this stage, the presence of debris can be considered in planning for separate debris removal operations if needed. The estimate of volume to be dredged should be based on defining the areas and thicknesses of sediment layers requiring dredging as well as consideration of factors such as overburden, slopes, need for box cuts, layback slopes, overdredge allowances, and limits on precision of removal.

PERFORMANCE STANDARDS

Performance standards are numeric limits or criteria related to environmental dredging processes or operations as defined in the record of decision (ROD). Such performance standards are sometimes needed to satisfy project objectives related to short-term and long-term effectiveness, environmental protection, project duration, and overall costs, forming the basis for determining feasibility, costs, and needs for controls. Performance standards may include applicable water quality and air quality standards, limitations on or minimum requirements for production, and standards for dredging effectiveness (usually defined in terms of meeting a cleanup level). The potential performance standards include those related to meeting Applicable or Relevant and Appropriate Requirements (ARARs) under CERCLA (or the equivalent requirements under other regulatory programs) and specific standards related to dredging performance.

EQUIPMENT CAPABILITIES AND SELECTION

With site conditions and sediment characterization data available and performance standards defined, a dredge equipment type(s) and size(s) can be selected for evaluation. Selection should be made considering pertinent equipment capabilities and selection factors related to the capabilities of equipment and the compatibility of equipment with site and sediment conditions, transport and rehandling requirements, and disposal options. The guidelines provide descriptions of both the capabilities and selection factors for equipment categories of wire-supported conventional clamshell, wire-supported enclosed bucket, fixed-arm articulated bucket, conventional cutterhead, swinging ladder cutterhead, horizontal auger, plain suction, pneumatic, specialty, diver-operated, and mechanical excavation. Quantitative information is provided for the equipment capabilities related to operating production rate, percent solids, vertical and horizontal operating accuracy, and minimum and maximum dredging depths. Qualitative ratings are provided for selection factors related to sediment resuspension control, contaminant release control, residual sediment/ cleanup level, transport by pipeline, transport by barge, positioning control, maneuverability, portability/ access, availability, debris/ rock/ vegetation, hardpan/ rock bottom, sloping bottom, flexibility for varying conditions, and thin lift/ residuals removal.

Multiple dredge types and operational approaches may be initially selected for evaluation, but the selection is narrowed for more detailed evaluations. Once an acceptable equipment type and dredging approach is selected, a preliminary operational strategy (to include a dredging sequence, depths of cuts, cut slopes, consideration of allowable overdredging, etc.) can be developed. A major decision at this stage is usually focused on mechanical versus hydraulic dredging, and in many cases, both dredging approaches are evaluated and compared. In some cases, field pilot studies can be considered to confirm the evaluations for the site specific conditions.

PRODUCTION AND TRANSPORT REQUIREMENTS

An evaluation of production will determine the required size and numbers of dredges needed to meet the project requirements, the duration of the project, and transport requirements (such as the need for booster pumps or the required number of transport barges). Dredging production refers to the rate of sediment volume removed, usually measured as in situ volume of sediment removed per unit time. Production can be considered and defined in several ways, and it is important to distinguish between operating production rate (the average production rate during periods of continuous operation while removing full production cuts) and overall or sustained production rate (the average production rate across a full operating season). Estimates of the operating production rate will depend on the equipment characteristics, site conditions, sediment properties, location of disposal or rehandling facilities, etc. Operating production rates are related to effective versus non-effective time, required cut thicknesses, dredgeability, limitations related to water quality or volatiles, need for enclosures, monitoring requirements, and possible transport or disposal-related constraints. Sustained production rates are driven by the need for both production and partial or "cleanup" passes, constraints on allowable times for dredging due to operational and quality of life issues, environmental windows or other seasonal constraints. Unfortunately, considerations for timely completion of the project; the need to meet performance standards for resuspension, release, and residual; and, compatibility with transport, treatment, and disposal requirements are not always completely compatible. Lower production rates as compared to navigation dredging are the norm.

The guidelines provide methods for estimating both operating and sustained production rates for both mechanical and hydraulic dredges. Based on the estimated production rates, the numbers and sizes of dredges can be selected to meet the performance standards or desired project duration. If there are no specific production related performance standards, the project duration can be evaluated in terms of a reasonable timeframe for completion, and for small projects, possible completion of the work in a single dredging season.

A major consideration in selecting equipment and an operational approach for environmental dredging is the method for transporting the sediment and the compatibility of that method with subsequent treatment and/or disposal requirements. Typically, there is a "process train" for dredging, transport, rehandling, pre-treatment, treatment, and ultimate disposal, though not all projects require all steps. The environmental dredging process must be compatible with the initial transport, rehandling, and pretreatment steps. For some equipment types, transportation could be viewed essentially as a separate process (e.g., transportation by barges filled by mechanical dredges), provided there is sufficient transport capacity to not hinder dredge production and operating time. In other cases, the transportation process is inherent to the removal process, as it is in the case of hydraulic dredging with pipeline transport directly to the next process step. Many other combinations are also possible. In general, transportation and rehandling requirements should be integrated with dredge production so as not to constrain production by the rehandling and transport components of the remedy.

RESUSPENSION, RESIDUALS AND RELEASE

Once the required size and number of dredges are selected for the design, evaluations of sediment resuspension, contaminant release, and residual sediments are possible. These evaluations are critical in determining the potential short-term effectiveness and long-term effectiveness of environmental dredging for the site. The most recent approaches for evaluating these processes were documented in the proceedings of a workshop held at the USACE Engineering Research and Development Center (ERDC) in April 2006 on Relating the "4 Rs" of Environmental

Dredging: Resuspension, Release, Residual, and Risk (Bridges et al. 2008). The information in the guidelines on evaluating resuspension, release, residual, and risk reflects the results of this workshop.

Sediment Resuspension

Resuspension evaluations usually rely on an estimate of the resuspension "source strength", i.e. the mass of sediment resuspended per unit time, coupled with a model for prediction of suspended solids concentrations as a function of distance and time. These estimates can be based on field experience (a number of published papers have summarized resuspension data for completed dredging projects), or empirical or analytical models (e.g., the USACE DREDGE model). Results can then be compared to performance standards for resuspension or water quality standards for suspended sediments or turbidity. The need for control measures (such as restrictions on the rate and timing of operations or deployment of silt curtain containments) can then be determined.

Contaminant Release

Releases of contaminants of concern in dissolved phase to water and releases of volatile contaminants to air are directly related to sediment resuspension. At early stages of evaluation, the estimates of contaminant release may be based on simple partitioning models. For detailed evaluations, estimates could be based on laboratory tests such as the Dredging Elutriate Test (DRET) and the flux chamber tests for volatilization. Results of both release evaluations and sediment resuspension evaluations can be used in combination to estimate concentrations of contaminants in the water column or volatilized to air, and these can be compared to water quality standards or air quality limits established for the project. As with sediment resuspension, these comparisons will determine the need for control measures.

Residual Sediment

Residual sediment refers to contaminated sediment (at contaminant concentrations above the action level) found at the post-dredge surface of the sediment profile, either within or adjacent to the dredging footprint. Residuals can be composed of both "generated residual" left by the dredging operation and "undisturbed residual" remaining below the cutline due to dredging inaccuracies or other factors. It can be important to distinguish the differences between undisturbed residuals and generated residuals, as they may pose different risks, may require different methods for prediction, and may require different monitoring and management responses.

The thicknesses of residual sediment left behind and the concentration of contaminants in the residuals determine the effectiveness of environmental dredging in meeting cleanup levels. The guidelines include methods for predicting generated residuals based on field experience (there are a limited number of studies summarizing data from completed projects) and the characteristics of the sediment profile to be dredged. An estimate of residuals will determine the potential need for control measures such as cleanup passes or placement of post-dredging residual caps.

CONTROL MEASURES

The results of the evaluations of sediment resuspension, contaminant release, and residual sediments should be compared with the performance standards to determine if control measures are needed. If needed, operational controls or engineered controls can be evaluated for potential effectiveness for the site and sediment conditions. Operational controls include those associated with the dredging operation itself, such as selection of a different dredge type or size, addition of controls such as wash tanks for buckets, changes in the rate of operation or advancement of the dredge, etc. Engineered controls include structural containments such as sheet pile enclosures or silt curtain containments for control of sediment resuspension. Controls for residual sediments would include placement of post-dredging residual caps.

The degree of controls needed is a site-specific or area-specific decision. Therefore, controls should be applied only when conditions clearly indicate their need and should not be set as a requirement solely because they can be applied. If controls are deemed necessary and potentially effective, such controls would be included in the design and the potential impacts to the operational plan and schedule appropriately considered.

OPERATING METHODS AND STRATEGIES

Once the removal requirements are determined, dredge type and size selected, production rates evaluated, and need for additional controls for resuspension, release and residuals established, all information should be available to develop an operations plan. At the feasibility stage of evaluation, the Operations Plan may be developed only to a conceptual stage, and may include only a basic description of how the dredge will operate (e.g., a general description of the dredging prism, the number of production cuts, consideration of overdredging allowance, and a general concept of removal sequence). But for remedial design and implementation, an Operations Plan should be developed in detail as a written document, agreed to by all parties. The plan should include a detailed dredging prism; delineation of dredging management units; description of dredge cuts, layback slopes, and box cuts; a sequence of operations; detailed mob-demob and construction timeline; complete descriptions of all equipment to be used; design and use of control measures; methods for monitoring progress and payment; etc.

MONITORING AND MANAGEMENT

A Monitoring Plan should be developed to ensure the various performance standards are met. Elements of the plan should address processes related to both short-term effectiveness (e.g., meeting limits on production and project duration, resuspension, and releases) and long-term effectiveness (e.g., meeting limits on residuals and cleanup levels). At the feasibility stage, the Monitoring Plan may be developed only to a conceptual stage with general monitoring approaches established for purposes of developing conceptual level cost estimates. For the design and implementation stage, the Monitoring Plan should be developed in detail as a written document, and agreed to by all parties (in some cases the Operations and Monitoring Plans could be combined into a single document). The detailed Monitoring Plan should include the monitoring equipment and techniques to be used (e.g. specific instruments, sampling devices, coring equipment); the protocols for sampling, handling and testing of samples (e.g. numbers and locations for sampling, compositing schemes, and testing procedures); and a description of how the monitoring data will be interpreted.

There should also be a Management Plan, established in advance, describing specific actions to be taken based on the results of the monitoring. Management actions would typically be developed in a tiered fashion, depending on the monitoring results, and may include provisions for additional or more intensive monitoring, a slow-down or cessation of operations, or implementation of control measures.

SUMMARY, INTEGRATION AND CONCLUSIONS

Summary and Integration

This paper summarized contents of the USACE *Technical Guidelines for Environmental Dredging of Contaminated Sediments*, prepared for the USEPA Office of Solid Waste and Emergency Response. This new document is intended as supporting information for the recent USEPA Contaminated Sediment Remediation Guidance for Hazardous Waste Sites, by providing guidelines for evaluating various technical aspects of environmental dredging as a potential remedy component.

The results of evaluations as described in the guidelines will determine the overall acceptability of the environmental dredging component of the remedy. Overall acceptability of the environmental dredging design should be evaluated in terms of providing environmental protection, meeting performance standards, and balancing criteria related to implementability, effectiveness, and cost. If the evaluations indicate that the dredging design is not feasible, aspects of the design should be reevaluated. This reevaluation may begin with collecting additional site and sediment data, considering differing removal volumes or areas (perhaps including consideration of partial dredging with capping or other non-dredging components for the remedy), revising the performance standards, or selecting a different type of dredging equipment for evaluation. If the overall dredging design is feasible, it can be carried forward for integration with other components of the removal remedy. The dredging design should be combined with other dredging remedy components (such as long distance transport, rehandling and treatment, and disposal) to form a complete removal remedy alternative(s). The completed alternative is either compared with other remedial alternatives in the FS phase of evaluation or is fully developed in the RD phase for preparation of plans and specifications and eventual implementation of the remedy.

Conclusions

The main conclusions in the guidelines report are:

- Environmental dredging is the removal of contaminated sediments from a water body for purposes of remediation.
- Environmental dredging removes contaminated sediments from the aquatic environment. Recent advances in equipment operation and design have reduced residuals and allowed projects to meet cleanup objectives. However, the potential for sediment resuspension and associated contaminant release and the magnitude and quality of residual sediments may limit the effectiveness of environmental dredging as a remedial approach at some sites.
- Residuals management should be an integral part of any remedy using environmental dredging to ensure that cleanup levels are achieved.
- Environmental dredging is normally considered as an operational component of a remedy. However, sediment removal is just one of the components of an environmental dredging remedial operation that is designed to fit within a system. The design of the system evaluates the interrelationships of the components in a sequence with major decision points in determining acceptability of an environmental dredging design (see Figure 2).
- Knowledge of site conditions and sediment characteristics is critical to the evaluation of environmental dredging as a potential remedy component. Inadequate site and sediment characterization is one of the major causes for problems associated with implementation of environmental dredging, and can potentially cause delays, higher costs, unacceptable environmental impacts, and failure to meet cleanup levels and remediation goals.
- Selection of equipment for environmental dredging must be considered in the context of the entire project. The dredging operation must be compatible with and fully integrated with the materials handling, transport, treatment, and ultimate disposal of the dredged material. A number of factors must be considered in evaluating and selecting equipment for environmental dredging. The *quantitative* capabilities and limitations of equipment commonly available in the United States for environmental dredging related to removal precision, production rates, dredging depths, etc., vary among equipment types and designs. Data related to the equipment selection factors that are a function of site and sediment conditions is *qualitative*.
- Many equipment types are suitable for environmental dredging. No single equipment type or design is best suited for all projects. Selection of equipment should be site-specific and sediment-specific. Each dredge type has both advantages and disadvantages with respect to operational characteristics and selection factors. For many projects, multiple dredge types may be used to optimize operations, e.g., one dredge for production cuts and another dredge for thin cuts and/or residuals passes.
- Although conventional dredges normally used for navigation dredging (e.g., conventional clamshells or cutterheads) can be effective for environmental dredging, evolving technologies for dredge and dredgehead designs (e.g., enclosed buckets, articulated fixed-arm mechanical, swinging ladder cutterheads, and articulated ladder cutterheads) may offer better performance for environmental dredging.
- Accurate removal of contaminated sediment without excessively removing clean material is critical for cost-effective environmental dredging. Positioning technology now allows a dredging cut line to be set within an accuracy of several inches, generally better than sediments can be characterized. Detailed site and sediment data are essential for realizing benefits of dredging accuracy. Data locations for both physical and chemical sediment parameters should be precisely located both horizontally and vertically.
- Overdredging, combined with other appropriate environmental dredging BMPs, particularly in a cleanup pass, can greatly improve dredging effectiveness for achieving cleanup levels.
- Estimates of production rate for environmental dredging can be developed using the approaches used for navigation dredging. The size and numbers of dredges required for the project and the time required for

project completion are dependent on both the operating production rate and the sustained production rate over a dredging season.

- All dredges resuspend some sediment, but removal can generally be achieved at an efficient rate with acceptable resuspension rates. Operational and engineering control measures can be applied to reduce the impacts of sediment resuspension.
- Sediment resuspension results in release of dissolved contaminants to the water column and release to the air through volatilization. Operational and engineering control measures can be applied to reduce the impacts of dissolved contaminants and volatilization.
- All dredges will leave behind some residuals, but the magnitude of residuals is difficult to predict. Residual sediment can be a major issue, directly affecting cost and effectiveness.
- Management options for residuals include monitored natural recovery, placement of a thin residuals cap, placement of an engineered isolation cap, cleanup dredging passes, and additional production dredging passes. Selection of residuals management options should be based on thickness and contaminant concentrations in layers of residuals and engineering/operational constraints.
- An operations plan or work plan should be developed for environmental dredging projects. It should include how the project is delineated and sequenced horizontally and vertically; how the dredge will operate with respect to vertical depth increments, production and cleanup passes, overdredging allowances, etc.
- A monitoring and management plan should be developed for environmental dredging projects to ensure compliance with performance standards. It should include descriptions of the monitoring approaches and tools to determine production and completion times, sediment resuspension and contaminant releases, volatile releases and dredging effectiveness as it relates to removing the targeted sediments and limiting residuals. Management actions, to include use of control measures, should be pre-determined prior to project implementation and should be documented in the monitoring and management plan.
- Environmental dredging design should be project-specific, site-specific and sediment-specific.
- Environmental dredging operations are highly complex and their performance effectiveness is highly project-, site-, and sediment-specific. The available data from these operations are limited, which constrains the general conclusions and understanding that can be drawn from past projects. Therefore, additional data collection is crucial to further enhancing understanding of dredging as a remedial alternative for contaminated sediments.

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