DESIGN SEQUENCE FOR ENVIRONMENTAL DREDGING

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ABSTRACT

The U.S. Army Corps of Engineers is assisting the U.S. Environmental Protection Agency in developing technical guidance for contaminated sediment remediation. One effort currently underway is the development of technical guidance for environmental dredging. Environmental dredging and its associated processes are complex. So, a technically sound evaluation of environmental dredging as a remedy component requires an efficient and comprehensive evaluation of these processes. Environmental dredging is normally considered as an operational component of a remedy, but in essence, the evaluation process can also be considered a design sequence. Various aspects of an environmental dredging design 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 generation of residuals; consideration of control measures; and development of operations and monitoring plans. This paper illustrates a logical and efficient design sequence for environmental dredging and the relationship between the various processes and decision points in determining acceptability of an environmental dredging design. Once finalized, the design sequence will be incorporated into the EPA technical guidance for environmental dredging now under development.

Keywords: Production, sediment resuspension, contaminant release, residual sediment

INTRODUCTION

"Environmental dredging" may be defined as dredging performed specifically for the removal of contaminated sediments for purposes of remediation. There is a range of considerations in selecting environmental dredging as a remediation approach, and the decision to dredge should be based on a clear evaluation of all the possible remedy options and their associated risk reduction benefits. The evaluation, design and application of environmental dredging involves many different aspects, and much of the cost and complexity for an environmental dredging remedy is inherent to the disposal/treatment components as opposed to the dredging component. However, the effectiveness of the environmental dredging process itself continues to be a major subject of debate for these projects (Palermo, Francingues, and Averett 2003).

A earlier paper presented at the 2003 WEDA annual meeting in Chicago and a revised version of that paper published in the WEDA *Journal of Dredging Engineering* (Palermo, Francingues and Averett 2003 and 2004) discussed dredging equipment selection factors for environmental dredging projects. The information in those papers was subsequently included in the recently published EPA Superfund Sediment Guidance (EPA 2005). This paper is a follow-up to the 2003 and 2004 papers in that it presents a complimentary aspect of the evaluation process for environmental dredging.

NEED AND APPLICABILITY OF A DESIGN SEQUENCE

Environmental dredging and its associated processes are complex. A technically sound evaluation of environmental dredging as a remedy component therefore requires an efficient and comprehensive evaluation of these processes. The design sequence described here assumes that a decision has been made to evaluate environmental dredging as a potential remedy component for the project under consideration, and this decision has been made within the context of an overall evaluation of remedial options. The design sequence also assumes that other components of a dredging remedy normally considered critical to success (e.g. source control, rehandling and transport, disposal and/or treatment, etc.) will be appropriately considered and will be appropriately integrated with the environmental dredging component. The design sequence therefore focuses on the environmental dredging process itself, the transport of the dredged sediment normally considered as an integral part of the dredging process (e.g., by barge or pipeline), and those processes and activities directly related to the dredging (e.g., associated monitoring).

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Evaluation of environmental dredging involves an engineering and environmental assessment of site and sediment conditions, the selection of equipment and operational approach, evaluation of complex processes such as sediment resuspension, contaminant release, and residual sediments, and development of monitoring and management plans for implementation. There is a strong interdependence between all these components of design for an environmental dredging project.

Figure 1 is a flowchart illustrating the major steps in the evaluation/design process for environmental dredging. Environmental dredging is normally considered as an operational component of a remedy, but in essence, the evaluation process can also be considered a design sequence. The flowchart illustrates the recommended sequence and relationship between the various processes and the major decision points in determining acceptability of an environmental dredging design.

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. A range of approaches and tools from the simple to the more complex are available for many of the steps in the evaluation process. For example, conceptual level evaluations requiring minimal data and computational effort can be used in the Feasibility Study (FS) phase evaluations, while more detailed evaluations can be used for the Remedial Design (RD) phase evaluations under CERCLA (or equivalent phases under other regulatory programs).

Each of these design steps must be appropriately evaluated, and some of these processes must be considered for environmental dredging in a manner different than for navigation dredging. The design sequence illustrated in Figure 1 follows a logical progression. But these processes are interrelated, so the evaluation or design process cannot be followed in a purely linear fashion. The design sequence therefore includes several decision points and allows for iteration of evaluations as needed to arrive at an efficient design that meets the project objectives.

It should also be noted that the design process can be evaluated for multiple dredge types, dredge sizes, and operational approaches to allow for comparisons and to determine the best combination of equipment for the given project. The process can also be evaluated for a range of dredging options, e.g. removal of the total area/volume requiring remediation or a partial removal of specific areas and/or depths to allow for optimizing the effectiveness or implementability of dredging as a remedy component.

STEPS IN THE DESIGN SEQUENCE

General descriptions of the various steps in the environmental dredging design sequence are given in the following sub-sections. Each block in the flowchart in Figure 1 is numbered, with each block referenced to the number in parentheses in the sub-section headings. The specific tools, models, tests, and methods of evaluation for the various design steps cannot be covered in detail in this paper, but the general approach in addressing each step is described. Additional details on the technical approach for each step are available in the EPA ARCS Remediation Guidance Document (EPA 1994) and the EPA Superfund Sediment Guidance (EPA 2005), and more comprehensive treatment of the technical approaches will be included in the EPA *Guidance for Environmental Dredging of Contaminated Sediments* (Palermo *et al*, in preparation).

Define Objectives (1)

The initial step in the design is to 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:

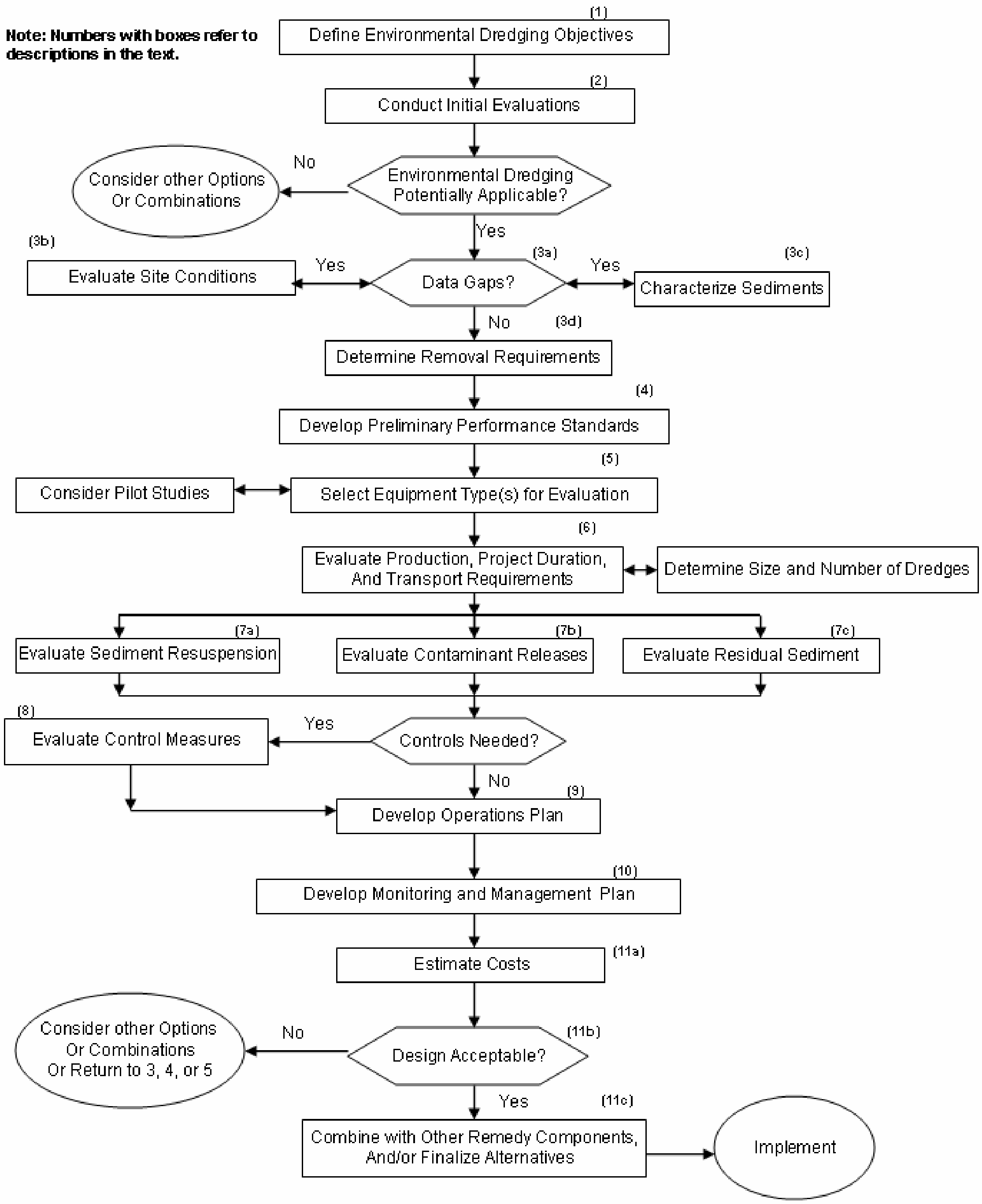

Figure 1. Flowchart illustrating environmental dredging design sequence.

- Dredge with sufficient accuracy such that contaminated sediment is removed and 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,
- Minimize and/or control resuspension of contaminated sediments, downstream transport of resuspended sediments, and releases of contaminants of concern to water and air; and,
- Dredge the sediments such that residual sediment is minimized or controlled.

The objectives may vary, depending on the nature of the remedy under consideration. For example, residual sediments would be a process of importance for a dredging-only remedy component, but may not be an issue for a remedy component involving partial dredging followed by placement of an engineered cap.

Conduct Initial Evaluations (2)

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. This step corresponds to the screening evaluations conducted for the FS stage of evaluation. However, the initial evaluations could be conducted as early as the recon phase or the remedial investigation (RI) phase. Earlier initial evaluation of potential applicability of dredging would allow for tailoring the site and sediment investigations in the RI phase to collect necessary data for further evaluation of dredging in the subsequent FS phase.

The initial evaluations include: 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. If environmental dredging is potentially applicable for the site, the evaluations should proceed. It is particularly important to identify major constraints at this stage, such as the non-availability of on-site disposal, etc. 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.

Identify Data Gaps (3a)

The initial evaluations should provide a basis for determining any data gaps pertaining to environmental dredging which should be filled. This step will be considered differently for the RI, FS, or RD phases. At the RI phase, this step will entail design of the field and laboratory investigations that will be essential to evaluation of dredging in the FS phase. At the FS phase, this step will entail identification of data gaps in the RI for those aspects needed for dredging feasibility evaluations and conceptual level cost estimates. At the RD phase, this step may entail identification of dredging-specific laboratory tests or modeling efforts needed for detailed design of a selected environmental dredging remedy. Data gaps can be identified by comparing the needed site and sediment characterization data with the existing information.

Evaluate Site Conditions (3b)

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 (especially slopes), currents, wave energies, 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.

Characterize Sediments (3c)

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 areal extent and depths to be dredged. As with evaluation of site conditions, the process may be iterative.

Determine Dredgeability and Removal Requirements (3d)

Once data gaps are appropriately filled, the dredgeability and removal requirements for environmental dredging can be determined. 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 removal requirements include defining the areas slated for dredging; thicknesses of sediment layers requiring dredging; consideration of factors such as overburden, slopes, need for box cuts, layback slopes, and overdredge allowances; limits on precision of removal; and an estimate of the total volume of material to be dredged. In the FS stage, the anticipated dredging prism and estimates of volume to be dredged can be based on the available data and initial consideration of operational factors. For the RD, the dredge prism must be defined in detail and a final estimate of dredging volumes determined.

Develop Performance Standards (4)

Technical evaluations must be based on the ability of a given dredging design to meet performance or design standards. 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. Such standards should be initially defined in the FS phase at least in general terms, and the standards should be refined and finalized in more specific terms in the RD phase.

Select Equipment Types for Evaluation (5)

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 (Palermo and Francingues 2004 and EPA 2005). A preliminary operational strategy (to include a dredging sequence, depths of cuts, cut slopes, consideration of allowable overdredging, etc.) can be developed at the FS stage. 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. Multiple dredge types and operational approaches may be selected for evaluation in the FS phase, but the selection is narrowed for more detailed evaluations in the RD phase. In some cases, field pilot studies can be considered to confirm the evaluations for the site specific conditions.

Evaluate Production, Project Duration and Transport Requirements (6)

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 in *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. 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, and possible transport or disposal-related 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. A range of production rates for a range of dredge sizes may be calculated, and the numbers and sizes of dredges finally 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.

Evaluate Sediment Resuspension (7a)

Once the required size and number of dredges is selected for the design, an evaluation of sediment resuspension, contaminant release, and residual sediments is possible. These evaluations are critical in determining the potential short-term effectiveness and long-term effectiveness of environmental dredging for the site. 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.

Evaluate Contaminant Release (7b)

Releases of contaminants of concern in dissolved phase to water and releases of volatile contaminants to air are directly related to sediment resuspension. At the FS stage, the evaluations of contaminant release may be based on simple partitioning models. In the RD phase, this evaluation could be based on laboratory tests such as the Dredging Elutriate Test (DRET) or 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.

Evaluate Residual Sediment (7c)

Residual sediment refers to the contaminated sediments left in or adjacent to the dredging footprint at the completion of a dredging operation. The residuals can be generated by the dredging operation as "fallback", sloughing from the dredge cutface, or resettlement of resuspended sediments. "Undredged inventory" can also be left below the cutline due to dredging inaccuracies or incomplete sediment characterization. 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. Although at present there are no standardized methods for prediction of the thickness or contaminant concentration in residual layers, predictions can be based on field experience (there are a limited number of studies summarizing data from completed projects) or 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.

Determine Need for and Effectiveness of Control Measures (8)

The results of the evaluations of sediment resuspension, contaminant releases, 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. 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.

Develop an Operations Plan (9)

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 FS stage, 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 at the RD stage, 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.

Develop a Monitoring and Management Plan (10)

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 FS 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 RD stage, the Monitoring Plan should be developed in detail as a written document, 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.

Estimate Costs (11a)

Cost estimates for the project should be developed to include costs for dredging operations, control measures, and monitoring costs. Appropriate contingencies should also be included. At the FS stage, the costs are developed primarily for comparison of costs for a range of alternatives. At the RD stage, the cost estimates are refined as the design for a selected dredging alternative is developed, typically through 30%, 60%, and final design stages. Along with implementability and effectiveness considerations, the costs are critical in determining the overall acceptability of the design.

Determine Acceptability of the Design (11b)

The overall acceptability of the environmental dredging design can now be evaluated in terms of implementability, effectiveness, and cost. If the dredging design is acceptable, it can be carried forward for integration with other components of the removal remedy. If the evaluations indicate that the dredging design is not acceptable, the design should be re-evaluated. This re-evaluation may begin with collection of additional site and sediment data, consideration of differing removal volumes or areas (perhaps including consideration of partial dredging with capping or other non-dredging components for the remedy), revision of the performance standards, or selection of a different dredging equipment type for evaluation.

Combine with other Remedy Components and Implement (11c)

Once the environmental dredging design is found to be acceptable, it can be combined with other remedy components (such as long distance transport, rehandling and treatment, and disposal) to form a complete removal remedy option. The completed design is either carried forward for comparison with other remedial options in the FS phase of evaluation or is carried forward from the RD phase for preparation of plans and specifications and implementation of the remedy.

CONCLUSIONS

The following conclusions are made regarding the development of an Environmental Dredging design sequence:

- Environmental dredging and its associated processes are complex, therefore, a technically sound evaluation of environmental dredging as a remedy component requires an efficient and comprehensive evaluation of these processes.
- Environmental dredging design must consider: 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 generation of residuals; consideration of control measures; and development of operations and monitoring plans.
- Figure 1 illustrates a logical and efficient design sequence for environmental dredging and the relationship between the various processes and decision points in determining acceptability of an environmental dredging design. The design sequence follows a logical progression, but iterative evaluations will be required in many cases before arriving at an acceptable design.
- The final version of this design sequence will be incorporated as appropriate in the EPA *Guidance for Environmental Dredging of Contaminated Sediments* now in preparation.

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