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EEDP-06-1 through EEDP-06-17

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Section 06-Management
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Environmental Effects of Dredging Technical Notes

CE SEDIMENT COLLECTION AND ANALYSIS METHODS

PURPOSE: This note summarizes responses to a recent survey of US Army Corps of Engineers (CE) sediment collection and analysis methods used in conjunction with planning dredging and disposal operations. The survey was designed to provide an overview of sediment collection and analysis programs and how these programs are conducted. Information gathered from the survey will be used to generate topics of discussion for a meeting to be held in June 1987 on sediment-analysis cost reduction. The survey and the meeting are part of a multi-year CE effort to reduce the overall costs associated with collecting and analyzing sediment samples.

BACKGROUND: Sediment collection and analysis prior to dredging can be extensive and costly. Results of the analysis can often affect the fate of a dredging project since disposal decisions are based on many factors that include the types and concentrations of contaminants in the sediment, sediment toxicity, and bioavailability of contaminants. Selection of sampling locations, sampling techniques, number of samples collected, and necessary tests should represent a careful balance between the needs of the dredging project and reasonable cost.

Cost control must encompass all aspects of sampling and analysis. The first step is to review any data previously obtained from the vicinity of the dredging project and to ensure consideration has been given to all information that may impact the development of the sample-collection plan. Past contaminant histories from other dredging projects in the area can indicate that there are specific contaminants in the sediment. This information could be used to determine the optimal number of samples to collect for sediment characterization.

Analytical costs are directly related to the number of samples analyzed and the parameters for which each sample is analyzed. Obtaining samples is a minor portion of the overall sampling and analytical cost on most projects. Therefore, it is common practice for more samples to be collected than are initially analyzed. The additional samples may be archived for possible future chemical analysis but must be stored and cared for properly. Biological tests and chemical tests other than bulk or total chemistry analyses cannot be performed on sediment samples that have been archived because chemical changes occur in archived sediment that may affect the accuracy of results. Should the need for biological testing be identified after the initial sample collection, additional samples would have to be collected, increasing sampling costs.

ACKNOWLEDGMENTS: The following is a list of the Districts/Division contacted and the individuals who responded to the survey described in this technical note: Buffalo (Dick Leonard), Chicago (Mike Neely and Jan Miller), Detroit (Frank Snitz), Galveston (Rick Medina), Jacksonville (Jim McAdams), Los Angeles (Sandy Lemlich), Mobile (Paul Bradley), New England (Jim Bajek), New Orleans (Rodney Mack), Norfolk (Terry Getchel), Portland (Rudd Turner), St. Paul (Robert Whiting), Seattle (Keith Phillips), and Walla Walla (Tim Bartish).

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Description of Survey Techniques

Thirteen CE Districts and one CE Division (FOAs) were surveyed by telephone. The FOAs surveyed are shown in Figure 1. Each FOA contacted has

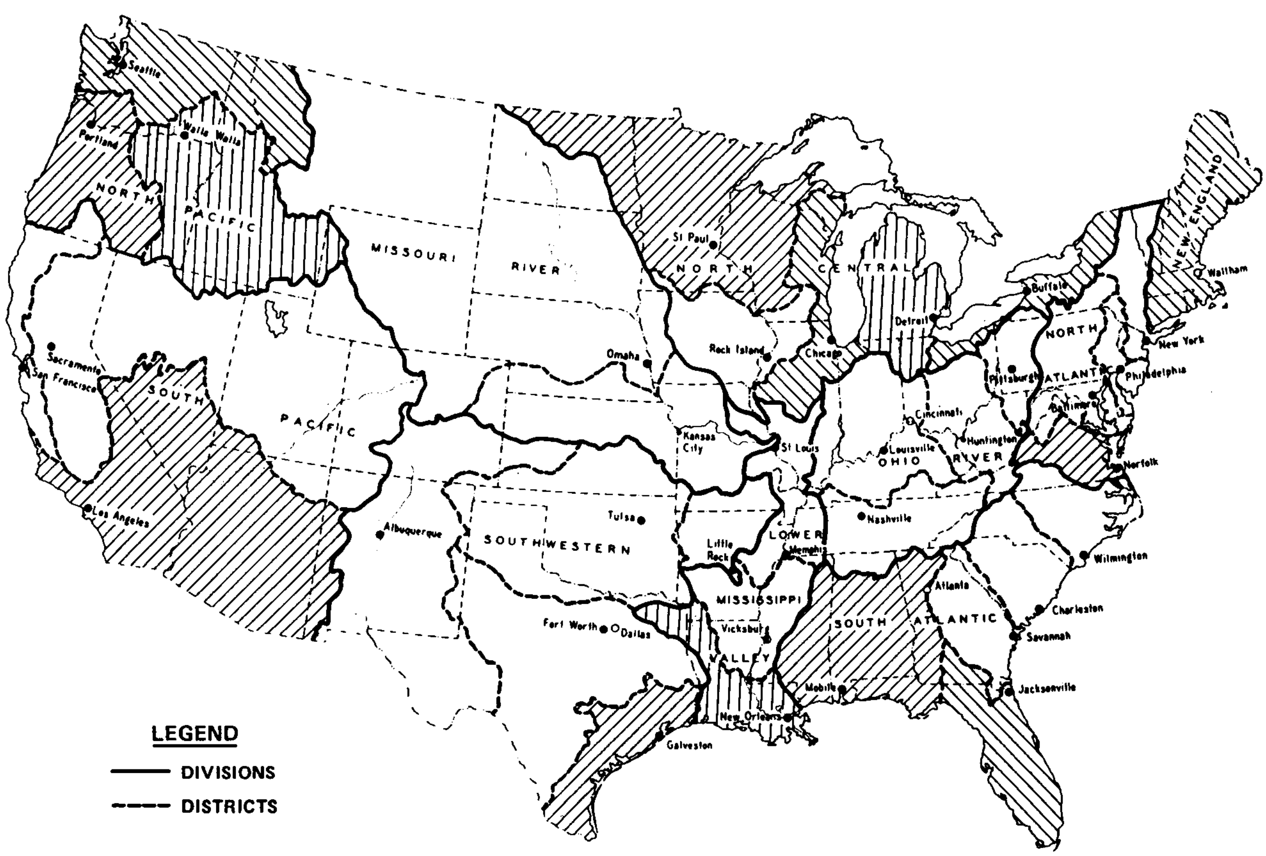

Figure 1. FOAs contacted in survey (cross-hatched areas) of CE sediment sampling and analysis methods

significant dredging and disposal operations. Responses were solicited from individuals in the FOAs whose responsibilities included planning, conducting, or managing sediment sample collection and analysis. Responses to the survey have been consolidated in Table 1.

Interpretation of Survey Responses

Question: What types of navigable waters comprise the majority of dredging projects within FOA's jurisdiction?

Response: Respondents represented FOAs engaged in maintaining the spectrum of waterways managed by the CE. Many of the FOAs surveyed have responsibility for maintaining more than one type of waterway. This suggests that FOAs must be flexible in their approach to sediment sampling due to variations in the land use surrounding the project area and in the hydrology of the waterways.

Remarks: Any cost-reduction guidelines and methods must recognize the site-specific differences involved in managing dredging operations.

Question: What approach do you take to design a sediment-sampling plan?

Response: All FOAs responded that the design of a sediment-sampling plan was strongly influenced by site-specific characteristics (e.g., size, sediment, topography) and project requirements (e.g., depth of dredging, state and Federal regulations). Some respondents amplified their remarks, stating that historical data about the general project area and local concern about particular contaminants are important considerations influencing the design of a sediment-sampling plan.

One FOA samples along a transect at fixed distances from the project boundary. Further investigation revealed that the FOA is involved in predominantly maintenance dredging operations, where relatively shallow sediment deposition is common. The project center line is used as a linear reference, and shoals are sampled along a line that is perpendicular to the center line.

Occasionally, FOAs collect samples within a grid overlaid on the project area. Grid sampling results in collecting and analyzing a greater number of sediment samples than is the case with other sampling plans; therefore, it is not routinely used for sediment-sample collection.

Remarks: Although grid sampling is more expensive, its use increases the statistical accuracy of sediment characterization. It is generally used when the sediment to be dredged is suspected to contain high levels of hazardous or toxic substances and precise knowledge of the location(s) and levels of these substances within the project area is desired.

Question: Do written procedures exist for designing and executing a sediment-sampling plan?

Response: Five of the fourteen FOAs polled have written procedures for designing and executing a sediment-sampling plan. Three of these five FOAs use procedures developed by state and other Federal agencies. The other two FOAs developed their own procedural handbooks, incorporating Federal, state, and local guidelines into one comprehensive document.

Remarks: Scientifically based recommendations on the volume of sediment to be represented by one sample and on specific analytical test parameters could lead to a reduction in analytical costs. Such recommendations would add uniformity to the process by which sediment sampling and analysis are planned, organized, and executed.

Question: What method do you use to collect sediment samples?

Response: The most common methods of sediment-sample collection are grab, gravity core, and Vibracore. Twelve of the FOAs collect core samples, and ten collect samples by the grab method. Several FOAs use a remote camera to aid in viewing the sediment surface prior to sampling.

Remarks: Method selection depends on many factors, such as equipment available for collecting samples, depth of sediment to be dredged, type of dredging to be performed (construction versus maintenance), and analytical tests to be performed.

Question: How do you determine sampling depth?

Response: Sampling-depth determination depends on specific situations (6 responses), types of dredging to be performed (5 responses), and sediment-sampling methods used (2 responses). One FOA considers the size of the project to be the primary factor in selecting the depth of sampling. "Situation dependent," "type of dredging to be performed," and "sediment-sampling method used" responses are virtually identical in their meanings: the type of dredging to be performed depends on the project (i.e., the situation), and the sediment-sampling method used depends on the equipment available for sampling and the characteristics of the sediment to be dredged (i.e., the situation).

Question: To what depth do you collect sediment samples?

Response: Most of the FOAs collect samples from the sediment surface or to the proposed dredging depth. Grab sampling is associated with the collection of sediment from the bottom's surface and can also be used to sample to the depth of dredging when the depth of material to be dredged is shallow (<3 ft). Core sampling generally involves sampling of the sediment to the depth of dredging or beyond. Incremental sampling is a variation on the depth-of-dredging method; core samples collected from incremental depths are segregated and analyzed separately.

One FOA uses a standard sampling depth of 4 ft for all of its sediment-sample collections. The reason is due to a mechanical limitation imposed by the sampling instrument: a KB core sampling device that will only penetrate to a depth of 4 ft. Since the FOA is involved primarily in maintenance dredging to relatively shallow depths, a 4-ft core is adequate for characterizing most sediment.

Remarks: Generally, respondents considered the top 4 ft of sediment to be the likeliest strata for locating contaminated material in sediment subject to routine maintenance dredging. The sediment-sampling depth for construction (new work) dredging depends on the depth of dredging to be performed, contaminant history of the area, and the hydrological and sediment-loading factors influencing the project site.

Question: What determines the number of samples collected?

Response: Respondents interpreted this question in two ways: the number of samples taken per sampling station and the number of samples taken from the entire project area. Most said that the number of samples taken depends on the size of the project in cubic yards or its area in square feet and thus a sample represents a specific volume or area of sediment to be dredged. This approach allows FOAs to characterize thin and thick sediment deposits in a like manner. FOAs differ in the volume or area of sediment to be represented by one sample because local and regional requirements influence the volume or area of sediment permitted to be represented by one sample.

Remarks: It is noteworthy that only one FOA responded that the number of sediment samples collected depends on the money available for collection and analysis. Funding limitations apply uniformly to all FOAs and influence the sediment-sample collection and analysis efforts from the project planning phase.

CE cost-reduction efforts should include guidance on the volume of sediment to be represented by an individual sample and the conditions under which that volume should be decreased or increased.

Question: How do you select the method of sample collection?

Response: The method by which samples are collected is strongly influenced by site-specific characteristics of the project, sediment type, and available equipment. Regulatory requirements, sedimentology, site history, and the proposed method of disposal are also determining factors.

Remarks: Specific sediment-testing procedures and testing objectives are important considerations in choosing between grab and core sampling alternatives. Availability of equipment is perhaps the key determinant. FOAs and contractors do not generally have the equipment necessary to conduct sampling by several different methods. In FOAs where no core sampling equipment is available, core samples are simply not taken. The ability to choose the best sampling method results in more accurate characterization and stratification of the sediment profile.

Question: How do you determine the locations of sampling stations?

Response: Several FOAs collect sediment samples at fixed distances from the project boundary or else along a transect of the dredging project center line. Other FOAs divide the project site into segments of similar materials of a specific volume (e.g., 20,000 cu yd of sediment), and samples are collected from stations located within each segment.

Remarks: Stations should be located to provide a good representation of sediment contained within a specific portion of the project area. Generally, stations are selected after careful evaluation has been made of the industrial history of the areas influencing the sediment within the project boundaries. Sediment type influences sampling station location when certain contaminants are of concern. For example, when organic compounds are suspected to exist within the project area, sediment having a significant clay fraction should be sampled more intensively than a sediment that is mostly sand because organics are associated with the fine grained fraction.

Samples are collected at sites located adjacent to a sampling station. In practice, vessels used to collect the samples are positioned on the station, and samples are collected from around the vessel within the range of the working distance of the crane used to maneuver the sampling device.

Sampling at fixed distances from the project boundary or along the project center line usually ignores historical influences, areas of expected sedimentation, and subsurface topography. However, in areas of low contamination or where sediment heterogeneity precludes statistical assessment at a reasonable cost, these methods may be the most effective and cost efficient.

Sampling segments of similar material of a specific volume provides means to identify and isolate material from any segment containing contaminated sediment. The advantage of this method is that the contaminated dredged material can be disposed of separately from clean dredged material, thus reducing the volume of dredged material requiring special disposal management methods and the associated costs of long-term monitoring.

Question: How many samples are collected at each station?

Response: Collection of more than one sediment sample at each sampling station is common. Multiple samples are used to obtain an indication of sediment variability at a station and to avoid the expense and the delay of returning to the project site to collect another sample if the initial sample analysis appears to be erroneous.

Remarks: FOAs not collecting replicate samples at each sampling station should be encouraged to do so because sampling error, sediment variability, or analytical variability may affect the accuracy of analytical results. Replication acts to mitigate the influences of these random errors. One wrong data point could affect dredged material disposal management decisions for sediment represented by a particular sampling station and thus could affect the overall cost of the dredging project.

Replicate samples from each sampling station would not necessarily require complete analysis. In waterways subject to frequent traffic, contaminants can be expected to be homogeneously distributed throughout the sediment surrounding a particular sampling station due to the mixing effects caused by vessels' propellers. Under these circumstances, grain-size analysis might be sufficient to conclude that the samples have like characteristics and that the chemical analysis conducted on one sample would precisely reflect the sediment from which it was extracted.

An alternative to replication is to reduce the volume of sediment represented by each sample. This alternative is likely to result in higher analytical costs, but it produces a better characterization of the sediment to be dredged. Another drawback to this technique is that no indication of the variability of samples at each station is provided.

Question: How many of the sediment samples collected are analyzed?

Response: Nine FOAs analyze all sediment samples collected. Five FOAs archive a portion of the samples collected. Samples archived are replicates, additional samples collected in areas suspected of having contamination, or portions of the original sample not routinely analyzed. When composite samples are used for analysis, portions of the individual samples that made up the composite sample are usually archived. These individual samples can be analyzed later if the results of the composite sample show high levels or questionable types of contaminants. The period of time samples are archived varies and depends on the availability of storage facilities and local practice.

Question: How do you select contaminants of concern?

Response: Selection criteria for analytical tests on sediment samples are generally based on a standard list of contaminants (priority pollutant list) and historical data that may suggest the necessity for other less-routine tests. State regulations impact the analyses required by some FOAs as do recommendations by other governmental agencies.

Remarks: Historical data play a key role in the selection of contaminants to be assayed. Careful review and analysis of the industrial history of the watershed or tributaries of a waterway may raise the expectation of higher levels of certain contaminants in specific areas. If the historical sediment and contamination data of the waterway influencing a project site were reviewed prior to designing the sample collection plan, sampling stations could be adjusted to sample shoals where accumulation of a specific contaminant is most likely.

Question: What types of analytical tests are performed on the sediment samples?

Response: Sediment samples are subjected to a wide variety of tests. Chemical and physical tests are required by all of the FOAs surveyed. The most common analyses performed on the sediments are heavy metals, pesticides, oil and grease, and grain size. Biological testing has been used sporadically by about half of the FOAs. Both animal and plant bioassays are used by those FOAs, with animal bioassays performed more often. Some analytical tests are routinely performed on sediment by some of the FOAs in response to state and local regulations or historical contamination data (Responses 12 and 13, Table 1).

Question: How confident are you that your sampling program accurately characterizes sediment to be dredged?

Response: Most FOAs are confident that collected samples accurately characterize the sediment to be dredged. One respondent stated that he was highly confident in his professional judgement, but not confident in statistical representations.

Question: Do you have any local cost-reduction methods in use?

Response: Half of the FOAs are taking measures to reduce costs associated with sediment sampling and analysis. The other half responded that minimizing costs was standard procedure.

The following lists the cost-reduction methods in use by one or more of the FOAs surveyed:

> Doing nonquantified gas chromotography scans and selecting individual compounds to track rather than selecting specific compounds for analysis saves approximately $100 per sediment sample.
>
> Contracting sediment sampling and analysis results in lower costs because of competitive procurement.
>
> Researching historical data impacting project sites allows for sampling to be conducted at areas that are most likely to be contaminated and thereby reduces the initial number of samples required to characterize the sediment.
>
> Characterizing waterways and harbors based on past sampling and historical data eliminates the need to sample some project sites because adjacent sites having similar characteristics were adequately sampled during a previous dredging project.
>
> Using a tiered approach to testing* to eliminate unnecessary suites of tests of clean material and for early identification of contaminated sediment that will limit disposal alternatives.
>
> Compositing and archiving subcomposites (for later analysis if needed, based on analytical results of composite sample) to avoid possible expense and delay of returning to the project site to collect additional samples.

Conclusions and Recommendations

The survey results suggested several areas wherein sampling and analytical costs may be reduced. The following topics are suggested for discussion at the sediment-analysis cost reduction meeting to be held in FY 87. Recommendations of the meeting will be published in a subsequent technical note.

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* N. R. Francingues, Jr., et al. 1985. "Management Strategy for Disposal of Dredged Material: Contaminant Testing and Controls," Miscellaneous Paper D-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

- Development of criteria for determining the volume of sediment to be represented by one sampling station under a variety of site-specific conditions.
- Development of a computerized system for storage and retrieval of historical contamination data. The system should have a standard entry format and be readily adaptable to all FOA data-processing equipment.
- Review current procedures for and costs of sediment-sample analysis. Determine if contracting for analysis at the national or regional level would be cost effective, responsible, and reliable.
- Review the battery of analytical tests performed on sediment to determine if there are any alternative methods available to obtain the required information at a reduced cost.
- Review use of biological testing. Determine the role of bioassays in sediment analysis and determine whether sampling costs could be lowered through the increased or decreased use of bioassays.
- Develop procedures for determining the accuracy of sample-compositing plans and assess the risks involved with sample compositing.

Table 1. Responses to Sediment Sampling Survey

What types of navigable waters comprise the majority of dredging within FOA's jurisdiction?

Rivers - 14 Harbors - 12 Lakes - 3 Estuarine - 11

What approach do you take to design a sediment-sampling plan?

Site specific - 14 Historical information - 3 Local concerns - 3

Fixed distance between stations - 1 Grid sampling - 1

Do written procedures exist for designing and executing a sediment-sampling plan?

Yes - 5 No - 9

What method do you use to collect sediment samples?

Core samples - 12 Grab samples - 10 Stratified layer sampling - 4

How do you determine sampling depth?

Situation dependent - 6 Type of dredging to be performed - 5
Sampling method used - 2 Size of project - 1

To what depth do you collect sediment samples?

Sediment surface - 11 Depth of dredging - 8
Incremental - 1 Standard depth - 1

What determines the number of samples collected?

Depends on size of the project in cubic yards or its area in square feet - 7
Two to four per site - 2 One per site - 1 Varies depending on project - 1
One per 300 to 400 linear feet - 1 Depends on money available - 1

How do you select the method of sample collection?

Site specific - 4 Regulatory requirements - 2
Sedimentology and site history - 3 Method of disposal - 1

How do you determine the locations of sampling stations?

Representative locations - 8 Industrial history - 6
Sediment type - 2 Fixed distance from boundary - 2
Transect along project center line - 1 Depends on disposal method - 1

How many samples are collected at each station?

Varies with project - 8 One, no replication - 4
Two replicates - 1 Three or four replicates - 2

How many of the sediment samples collected are analyzed?

All samples analyzed - 9 Varies with project - 4 One per station - 1

(Continued)

Table 1. (Concluded)

How do you select contaminants of concern?

Standard list - 8   Site history - 7
Recommendation from other agencies - 3
Fixed group rate - 1   Required by state - 2

What types of analytical tests are performed on the sediment samples?

Entries represent type of test (number of FOAs).

Chemical (14)	Physical (14)	Biological (8)
Heavy metals (10)	Grain size (10)	Animal bioassay (8)
Pesticides (6)	Specific gravity (3)	Plant bioassay (1)
PAHs (3)	Settling rate (4)	
PCBs (5)	Void ratio (1)	
Organics (3)	Total solids (1)	
Oil and grease (7)		
COD (3)		
Phosphorus (2)		
Ammonia (2)		
DDT (2)		
TOC (6)		

How confident are you that your sampling program accurately characterizes sediment to be dredged?

Highly confident - 3   Confident - 8
Fairly confident - 3   Not confident - 1

Do you have any local cost-reduction methods in use?

Yes - 7   No - 7

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Environmental Effects of Dredging Technical Notes

TECHNIQUES FOR REDUCING THE COSTS OF SEDIMENT EVALUATION

PURPOSE: This note summarizes recommendations for reducing the costs of sediment evaluation developed by attendees of the Sediment Evaluation Cost Reduction Working Group meeting held 15-19 June 1987 at the Holiday Inn, Vicksburg, Miss. Attendees were representatives of the Federal, State, and international agencies and private concerns and each was considered to be an expert in his field. The Working Group meeting was held under the auspices of the Dredging Operations Technical Support (DOTS) Program. Recommendations contained herein are readily applicable to the sediment evaluation phase of dredging operations.

BACKGROUND: The environmental fate of contaminants contained in dredged material concerns the Corps of Engineers and many other agencies, groups, and individuals who desire to prevent adverse environmental impacts due to the disposal of contaminated dredged material. Characterizing sediments as to the presence and concentration of contaminants in dredged material becomes increasingly more expensive as new contaminants of concern are added to the list of those whose presence must be assayed. The objective of the Working Group was to recommend techniques to reduce the costs of evaluating and characterizing sediments without compromising the quality of Corps environmental impact assessments for dredged material disposal.

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Introduction

The Corps approach to sediment evaluation in making dredged material management decisions is based on a "Management Strategy for Disposal of Dredged Material," as detailed in Francingues et al. (1985). The dredged material disposal strategy employs a "reason-to-believe" approach to sediment evaluation. By using this approach, the number of evaluative tests performed on a particular sediment sample depends on the expectation of the presence of contamination and the amount of data required to characterize the sediment. This approach led to the development of a tiered testing scheme--a series of progressive tests and decision alternatives. The testing tier that results in the most intense and comprehensive characterization of the sediment is the terminal tier.

The Corps commitment to the management strategy as a management tool for dredged material disposal, including adequate assessment of the environmental consequences, was outlined in a 23 December 1986 letter to Corps Field Operating Agencies (FOAs) by MG H. J. Hatch, Director of Civil Works. At a long-term dredged material management strategy conference held in Jackson, Miss., in August 1985, the FOAs responsible for dredging operations expressed concern over the potentially high costs involved in implementing the management strategy. The techniques for reducing sediment evaluation costs discussed in this technical note were recommended by members of the Sediment Evaluation Cost Reduction Working Group and are considered to be immediately applicable to sediment evaluation programs. Other recommended techniques generated by the Working Group for reducing costs are being evaluated and, once fully developed and verified, will be made available to the FOAs.

Application of cost-reduction techniques

Most of the nearly 300 million cubic meters of sediment annually removed from our Nation's waterways is uncontaminated or is considered relatively clean and is acceptable for a wide range of disposal alternatives. The evaluation of this material does not require extensive testing and expense. However, the cost of sediment evaluation can escalate rapidly as the number of potential contaminants and the degree of contamination increases. It is for contaminated sediments that cost-reduction recommendations have the greatest potential for application with tangible cost savings. While implementation of some of the recommendations made by the Working Group may initially be more expensive to conduct, cost savings will be realized through improvements in the quality of data collected and, subsequently, fewer requirements for retesting. The other benefit of these recommendations is that FOAs, regulating agencies, and the public will have more confidence in the decisions regarding disposal of dredged material.

Organization of the
Working Group meeting

The meeting participants were divided into five groups, each of which was tasked to develop recommendations to improve the cost efficiency of a specific component of the sediment evaluation process: (1) design of the sampling plan, (2) sediment collection and handling, (3) sediment analysis, (4) bioassessment of sediments, and (5) the economics of sediment evaluation. The procedures recommended in this technical note represent the consensus of the members of the individual groups. Published references are cited where applicable.

The Working Group identified elements of the sediment evaluation process that may help reduce costs while still providing adequate environmental protection prior to dredged material disposal. These are:

a. Proper design of the sediment sample collection plan, to include:
   (1) Reviewing historical data.
   (2) Selecting a scientifically based sediment sample collection scheme.
   (3) Dividing the project area into management units.

b. Proper collection and handling of sediment samples, including:
   (1) Collecting core samples whenever possible.
   (2) Using proper sediment storage techniques.
   (3) Compositing samples when appropriate.

c. Inclusion of quality control and quality assurance in all aspects of the sediment evaluation process.

d. Use of chemical and biological screening techniques when appropriate.

e. Use of decision risk analysis to identify and correct weaknesses in the sediment evaluation process.

Ways in which each of these can reduce the cost of testing dredged material are discussed below.

Design of the Sampling Plan

Historical information is very important in the design of a cost-effective sediment sampling plan. Reviewing historical data gives the sampling plan designer the first opportunity to apply the reason-to-believe rationale. A key to the value of historical data is the adequacy and accuracy of the documentation attached to it. To be of value, historical data should provide the reviewer with the date and exact location of the sample, how it was collected, and how it was handled or stored. Historical data lacking detailed information may not provide an accurate representation of the waterway to be dredged. Use of incomplete historical data may adversely impact the design of the sampling plan. A poorly designed plan may lead to the selection of a more costly disposal option.

Depending on the sources of contamination and the quality of the data, historical data up to several years old can be used with a high degree of confidence in its validity. Historical information is considered to remain valid for up to 2 years in areas of active contamination, and up to 5 years in areas where there are no active sources of contamination. Older data can be used with caution. For example, when older data are used, the sampling plan designer should consider the effect of time and waterway dynamics on the data's validity and, if necessary, omit the data or include the data with a lower degree of confidence.

Selection of sample collection sites

Pertinent historical data can be applied to provide a presampling characterization of the dredging project and can assist the sampling plan designer in selecting the method to be employed. The sampling methods most often used to characterize sediments are: (1) haphazard, (2) worst-case, (3) random, (4) stratified random, and (5) exhaustive.

The haphazard method is not based on sound scientific principles. It is based on the sampling plan designer's personal biases or is used to satisfy the concerns of various special interest groups. There is a considerable risk of not adequately or accurately characterizing the project area when this method is used. Unfortunately, the haphazard method has been historically employed on some dredging projects. Although it may be a low-cost method, it is not cost effective in the long term and produces data of low confidence value. This method should not be employed on Corps dredging projects, and its use should be discouraged on non-Federally funded dredging projects.

Another sampling method assumed to be low cost is the worst-case method. In this technique, sediment sampling is concentrated in isolated areas identified as likely to be contaminated (referred to as "hot spots") through historical data analysis. Incomplete characterization of sedimentation in the project area is an inherent problem when this method is selected. More complete characterization of the project area may later be required by other regulatory agencies, thus requiring the collection of more samples. Also, disposal costs may be much higher under worst-case sampling, if the disposal decision was based on data obtained from a small portion of the project that is not representative of the majority of the sediment to be dredged.

The random sampling method is most useful when no reliable historical data are available or when available information indicates that the sediment within the project area is homogenous. Under these circumstances, the project area can be divided into units of equal size and the entire area sampled randomly. The optimum number of samples to be collected can be determined by applying statistical principles, and the units to be sampled can be determined by use of a random number table. Properly employed, random sampling will result in high confidence in the characterization of the sediment.

Similar to random sampling, the stratified random sampling method allows the factors most likely to influence the accumulation of contaminants to be incorporated into the design of the sampling plan. The entire project area is divided into units and sampled, but consideration of historical data permits the sampling intensity to be skewed in the direction of units where contamination is most likely to be found. This method is similar to the worst-case method in that the worst-case area or zone is divided into sampling units. The zone is sampled by randomly selecting sampling units, from within the zone, and collecting the required number of samples for the zone. Stratified random sampling differs from the worst-case method because the entire project area is divided into zones and each zone is sampled. This method permits sediment zones to be characterized with a high degree of confidence, is scientifically sound, and in many cases offers a lower total cost than worst-case sampling.

In the exhaustive sampling method the project area is divided into equal-sized units, and each unit is sampled. This method is not recommended for routine sampling programs because of the high cost involved. It does permit characterization of the sediment with a very high degree of confidence; however, its use may be necessary on projects having widely distributed contamination from a number of sources. The exhaustive method of sampling is usually cost prohibitive and not necessary.

Management units

The concept of dividing the project area into units was introduced in the discussion of sampling techniques. Units are areal or volumetric subdivisions of the dredging project designed to enhance management of the sediment sampling and dredging programs. Management units can be sized to equate to the volume of dredged material that can be dealt with separately in a dredging operation. For instance, on a project historically characterized as having clean sediment, the management unit may be larger than on a project shown to have localized shoaling containing highly contaminated sediment.

The major cost-savings benefit from dividing project areas into management units is that each management unit or each zone of management units can be characterized independently. Management units or zones permit a dredged material disposal decision to be made for each unit or group of units. Consequently, management units can be managed either individually or collectively, thereby reducing the volume of sediment disposed of in higher cost confined disposal sites.

Collection of Sediment Samples

The sampling plan designer should keep a perspective of the cost of the sample collection operation when selecting sampling sites and determining the number of samples to be collected. Normally, the costs of collecting, handling, transporting, and storing additional samples are minimal when compared to the total cost of the sample collection effort. Therefore, the sampling plan designer should take additional samples in areas in which he suspects potential contamination and store them for further analysis should it be required. By collecting and storing additional samples on the initial effort, the need for a follow-up sample collection effort may be avoided.

Much money can be saved by selecting the appropriate sample collection equipment. Daily costs for several sediment sample collection methods are listed in Table 1. The largest determinant of sampling costs is the size of the vessel required to support the sampling equipment used. Other important factors are the number of personnel required to operate the equipment and the collection time per sample. The data presented Table 1 allow a comparison to be made between two collection methods. For example, in comparing the clamshell dredge and the small vibracore, costs per day are similar. However, when the capabilities of the two are compared, the core sample obtained from the vibracore can be much more useful for detailed characterization of sediment layers than a grab sample from the clamshell dredge. In contrast, if

Table 1

Daily Costs for Several Sediment Sample Collection Methods*

Collection Method	Approximate Cost/Day	Number of Samples/Day
Drilling	>$10,000	1-2
Large vibracore (>10-ft core length)	$8,000-$10,000	2-4
Small vibracore (≤10-ft core length)	$3,000-$4,000	3-8
Clamshell dredge	$3,000-$4,000	6-10
Gravity core	$1,000	10-20
Surficial grab	<$1,000	15-40

Note: Table is used courtesy of Mr. Rudd Turner, USAE District, Portland.
* Based on current equipment and labor costs in Oregon.

large volumes of sediment are required from near-surface strata, such as for a full-scale bioassay, a clamshell dredge may be the most efficient sediment collection method.

Storage techniques

Once collected, a sediment sample must be stored in such a manner as to prevent the occurrence of undesirable chemical reactions or volatilization. (For a more in-depth discussion of sediment storage, refer to US Environmental Protection Agency/US Army Corps of Engineers (1981).) Storage techniques and conditions vary with the analytical procedure(s) to be performed on the stored sediment sample. Several short-term sediment sample storage studies have suggested that storage time has no effect on the chemical stability or toxicity of stored sediment (Nebekur et al. 1984; Schwartz et al. 1985; Maleug, Schuytema, and Krawezyk 1986).

The studies on the stability of sediment samples in storage are significant and, when fully developed, sediment sample storage may have the potential to reduce sediment evaluation costs substantially. Proper storage of sediment samples will encourage the collection of a greater number of sediment samples. Samples not required for immediate analysis and the individual components of composite samples could be stored and be readily available if a need for further analysis arises. Proper sample storage will potentially reduce the need to resample a project site, thereby reducing or eliminating the costs of resampling.

Sample compositing

Often, the cost of characterizing a sediment lies not in the number of parameters for which a sample is assayed, but in the number of samples to be assayed. Sample compositing--homogenating several samples into one for analysis--may result in significant cost savings by decreasing the number of laboratory samples analyzed. A carefully conceived compositing scheme can reduce costs and improve confidence in the data obtained by reducing variability. The compositing scheme should be linked to the sampling plan, i.e., a priori to sample collection and analysis. Included in the compositing scheme should be such considerations as where (on boat or in lab) and how samples are to be composited and how individual samples will be split and stored.

One use of composited samples is for sediment screening. Screening is useful for scanning a sediment sample to detect the presence of contaminants. This use may be of great value when insufficient historical data are available to properly apply the reason-to-believe criteria and references are needed to select a sampling method to be employed. Compositing reduces the number of samples required for analysis.

Quality Control/Quality Assurance

All participants in the Working Group meeting expressed the need to ensure adequate quality control in all stages of the sediment evaluation process. Quality control and quality assurance are vital to the success of the Corps' dredged material management program. Quality control involves all the steps that enter into a dredged material disposal decision. Quality assurance is a management function. Quality assurance measures include programming quality control checks into the decision-making process and ensuring that these checks are performed routinely. Quality control begins with the review of historical data and ends with a review of the decision-making factors leading to sediment characterization and the dredged material disposal alternative recommended.

The benefits of a good quality control program are many, but the two most important benefits are increased confidence in management decisions and decreased program costs. Why? Increased confidence comes from having a scientifically sound basis for collecting samples, using the best available collection method, handling and storing samples properly, and having confidence that the analytical lab performed the analyses correctly. Cost savings are achieved by eliminating resampling, reducing reanalysis, and characterizing the sediment in a manner that permits individual management units to be disposed of in an appropriate manner. Simply stated, quality control and quality assurance increase confidence in results; good results produce good decisions.

Sediment Analysis

The cost of analyzing sediment samples varies widely among contractors. Bids for sediment analysis tend to be linked to the contractor's knowledge of Corps needs; experienced contractors usually submit lower bids than inexperienced contractors. Conversely, caution should be exercised when an extremely low bid is received, as this may indicate that the bidder has limited experience or may not practice the desired quality assurance/quality control. As a precautionary measure, it is recommended that pre-work order performance audits be required.

The use of screening assays may be appropriate when organic contaminant concentrations are of concern. The screens may eliminate the need to analyze for certain organics and, more importantly, may aid in reducing the cost of dredged material disposal if the screens do not indicate the presence of restricted contaminants.

Biological Assessments

No technically defensible cost-reduction techniques are currently available for regulatory biological assessment tests. Biological screens that are now available may be useful in comparing and ranking sediments within a project area; however, only a few have been fully developed. *Daphnia*, mysid, and amphipod sediment toxicity tests have been developed and are considered to be screening tests. Other screening tests that require less sediment and produce results more rapidly are being developed. Biological screens are useful in determining where to concentrate more intensive and expensive studies.

Dredged Material Disposal Decision Risk Analysis

Throughout this technical note the term "confidence" has been used. Though discussed and at times quantified, the use of confidence as a factor in the decision-making process has not been dealt with.

Confidence can be defined as the decision-maker's acceptance of a fact as being true and accurate. Confidence can be modified to the degree to which the decision-maker accepts the fact as true and accurate. In other words, confidence is the absence of doubt, and doubt tempers the degree to which something is accepted as factual.

Applying this definition to the reason-to believe test, each component in the decision-making framework has the potential to be in error. Therefore, each component can be assigned a level of confidence. By evaluating and assigning each component a level of confidence, a degree of confidence in the decision can be determined. The degree of confidence in a decision is equal to the lowest level of confidence for any of the decision components. By assigning a degree of confidence to each decision component, the amount of uncertainty in the decision can be estimated. This is known as a risk analysis.

How will performing risk analysis improve sediment evaluation and reduce costs? First, it will identify weak points in the decision-making process and may allow the weaknesses to be corrected prior to the decision's becoming final. Second, it will serve as an educational tool, allowing weaknesses to be identified, analyzed, and hopefully prevented in the future (thereby improving quality control). Lastly, it can be used to analyze and evaluate several sample plan designs from a viewpoint other than the immediate costs of collecting and evaluating sediment samples.

Summary

Cost savings are achievable, but they will require cooperation from all parties involved in dredged material management. Implementation of the techniques described in this technical note may result in immediate cost reductions. Other techniques are being considered and, if verified, have the potential to substantially reduce sediment evaluation costs.

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Environmental Effects of Dredging
Technical Notes

ENGINEER MANUAL SERIES ON DREDGING AND
DREDGED MATERIAL DISPOSAL

PURPOSE: This technical note describes a series of Engineer Manuals (EMs) on dredging and dredged material disposal being published by the Office, Chief of Engineers, US Army. The note describes the purpose of the manual series, intended audience, major topics covered, availability of published manuals, and the status of future manuals.

BACKGROUND: Manuals already published in the series include EM 1110-2-5025, "Dredging and Dredged Material Disposal"; EM 1110-2-5026, "Dredged Material Beneficial Uses"; and EM 1110-2-5027, "Confined Disposal of Dredged Material." This manual series is the first comprehensive guidance on dredging and disposal developed for routine Corps use.

The guidance contained in the manuals was developed based on experience of the Corps Districts and Divisions and research conducted under the Dredged Material Research Program (DMRP) and subsequent research programs managed under the Environmental Effects of Dredging Programs (EEDP). As additional information becomes available, the EM series will be updated with published changes or new manuals.

ADDITIONAL INFORMATION OR QUESTIONS: Contact the EEDP program manager, Dr. Robert M. Engler, commercial or FTS: (601) 634-3624. Questions on the content of respective manuals and suggestions for changes or additions can be directed to the author, Dr. Michael R. Palermo, (601) 634-3753, for EM 1110-2-5025 and EM 1110-2-5027, or Dr. Mary C. Landin, (601) 634-2942, for EM 1110-2-5026.

Description of Engineer Manual Series

Technical guidance for planning, design, operation, and management of Corps of Engineers projects is normally published in Engineer Manuals (EMs). The information and procedures contained in EMs are not considered policy or regulation, but rather official guidance. Use of alternate procedures should be justified on a technical basis.

The Office, Chief of Engineers, US Army is publishing a series of EMs on dredging and dredged material disposal. Manuals published thus far include the following:

EM 1110-2-5025, "Dredging and Dredged Material Disposal"

EM 1110-2-5026, "Dredged Material Beneficial Uses"

EM 1110-2-5027, "Confined Disposal of Dredged Material"

These manuals have been developed for routine use by engineers and scientists in Corps Districts and Divisions involved in all aspects of dredging projects. The information contained in the manuals is applicable to all functional areas (i.e. planning, design, construction, operations, and maintenance). Descriptions of the purpose and scope of each manual are given in the following paragraphs.

EM 1110-2-5025, "Dredging and Dredged Material Disposal"

EM 1110-2-5025 is the "umbrella" manual of the series. The manual includes a description of dredging equipment and disposal techniques used in the United States and provides guidance for activities associated with both new work and maintenance projects. The manual also provides basic guidance on evaluating and selecting dredging equipment. A descriptive overview of disposal alternatives is provided, since more detailed guidance on disposal alternatives is available in other manuals in the series.

The major topic areas contained in EM 1110-2-5025 are as follows:

Design considerations for dredging projects
Dredging equipment and techniques
Factors in equipment selection
Dredge operating characteristics
Advances in dredging technology
Environmental considerations for dredging
Sediment resuspension due to dredging
Evaluation of dredged material pollution potential
Influence of disposal conditions on impacts
Overview of open water disposal
Overview of confined disposal
Habitat development as a disposal alternative

EM 1110-2-5026, "Dredged Material Beneficial Uses"

EM 1110-2-5026 provides guidance for planning, designing, developing, and managing dredged material for beneficial uses. The manual incorporates ecological concepts and engineering designs with biological, economical, and social feasibility.

The major topic areas contained in EM 1110-2-5026 are as follows:

Dredged material as a resource
Logistical considerations for beneficial use
Habitat development case studies
Habitat development selection process
Wetland habitat development with dredged material
Upland habitat development with dredged material
Island habitat development
Aquatic habitat development
Beaches and beach nourishment
Aquaculture
Parks and recreation uses
Agricultural and related uses
Strip mine reclamation and landfill cover use
Multipurpose and other land use
Construction and industrial/commercial uses
Baseline data collection and monitoring techniques
Site valuation

EM 1110-2-5027, "Confined Disposal of Dredged Material"

EM 1110-2-5027 provides guidance for planning, designing, constructing, operating, and managing confined dredged material disposal areas. Site design to retain suspended solids during disposal operations and to provide adequate short- and long-term storage capacity is included.

Major topic areas contained in EM 1110-2-5027 are as follows:

Field investigations and sampling
Site selection to avoid groundwater impacts
Settling tests for evaluation of solids retention

- Consolidation tests for evaluation of long-term storage
- Design for solids retention
- Design for storage during filling
- Weir design
- Design of chemical clarification systems
- Prediction of dredged material consolidation
- Dredged material dewatering operations
- Design and construction of dikes
- Operation and management activities
- Long-term management plans

Status of Additional Manuals

An additional manual entitled "Open Water Disposal of Dredged Material" is now in review. Major topic areas contained in this manual include: open water disposal environments and associated dredging practices, short-term and long-term physical fate of material disposed in open water, ecological evaluation of open water disposal, site designation and selection, environmental impacts, control measures, and site management and monitoring.

Availability of Manuals

Engineer manuals are published and distributed by the Office, Chief of Engineers, US Army. The manuals can be obtained by written request addressed to:

US Army Corps of Engineers
Publications Depot
2803 52nd Avenue
Hyattsville, MD 20781-1102

The title and number of the EM should be included in the request.

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Environmental Effects of Dredging Technical Notes

CURRENT DISTRICT DREDGED MATERIAL DEWATERING PRACTICES

PURPOSE: This technical note summarizes the current US Army Corps of Engineers state of practice in dewatering dredged material. State-of-practice dewatering methods are methods currently in full-scale use by one or more Corps of Engineers District Offices (Districts) as contrasted with state-of-the-art methods, which may not have been demonstrated in full-scale applications. The Corps of Engineers conducted research to investigate state-of-the-art dredged material dewatering techniques under the Dredged Material Research Program (DMRP). Based on DMRP research, a number of dewatering methods have been recommended for implementation.

The purpose of this note is to describe which of the dewatering practices recommended by DMRP research have been implemented and to determine whether these practices work as well in full-scale applications as was envisioned based on research studies. Also, innovative dewatering techniques developed or applied by the Districts is documented to encourage further investigation and possible use.

BACKGROUND: Dewatering dredged material is a concern only in confined upland disposal areas because of the potential gain in storage volume accomplished by removing water and the improvement of the soil properties upon dewatering. Because of increasing concern regarding use of land adjacent to or near the water body being dredged, dewatering is becoming more and more important. Land use concerns are typically based on aesthetic, environmental, development, and political concerns.

ADDITIONAL INFORMATION: Contact Ms. Marian E. Poindexter, commercial and FTS: (601) 634-2278, or the manager of the Environmental Effects of Dredging Programs, Dr. Robert M. Engler, (601) 634-3624, for additional information.

Dewatering Methods

Dewatering (also referred to as densification) of dredged material may be divided into two major categories: physical and mechanical methods. Physical methods include application of a surcharge load once a surface crust capable of supporting the load has developed, underdrains to promote drainage of water from the bottom of the dredged material layer, and desiccation of the surface due to the natural phenomena of evaporation and transpiration. Mechanical methods include surface mixing (tillage) to break up the surface crust and surface trenching to promote efficient drainage of rainfall which would otherwise pond on the surface and need to be removed by evaporation.

Although other state-of-the-art dewatering methods were investigated (Tiederman and Reischman 1973, Garbe et al. 1974, Environmental Engineering Consultants 1976, Haliburton et al. 1977, Johnson et al. 1977, Chamberlain and Blouin 1977, Brown and Thompson 1977, Bartos 1977, O'Bannon 1977, Palermo 1977, Haliburton 1978, and Hammer 1981), desiccation due to surface evaporation was found to be the most cost-effective means of causing volume reduction in dredged material. It was found that surface trenching could be incorporated with natural evaporation to obtain efficient containment area dewatering (Haliburton 1978). The other methods of dewatering dredged material were found to work with varying degrees of success, and in general to depend on material characteristics.

District Dewatering Survey

This study consisted of a survey of Districts using upland dredged material disposal areas. The survey form asked for information regarding:

Number and size of upland disposal areas.

Rate at which these existing disposal areas are being filled.

Dewatering methods used--past and present.

How effective these methods have been in full-scale use.

Primary purpose(s) for dewatering at these disposal areas.

Types of monitoring used to identify dredged material volume reduction due to dewatering.

Economic effectiveness of dewatering (does it produce significant volume reduction considering the cost associated with the dewatering method).

The survey of District dewatering methods is summarized in the following paragraphs. The responses illustrate the similarities and differences among Districts with regard to dredged material dewatering practices. Table 1 is a summary of active dewatering methods.

Table 1

Dewatering Practices Used by Survey Respondents

District	Number of Upland Disposal Areas	Dewatering Methods Used (number of sites in use)
Charleston	70	trenching (8) underdrains (3)
Detroit	15	underdrains (1)
Galveston	200	trenching (8)
Norfolk	1	trenching (1)
Philadelphia	76	trenching (10)
Savannah	12	trenching (7)
Wilmington	76	trenching (3) underdrains (1)

Charleston District

The Charleston District operates 70 disposal areas, ten of which are managed intensively for dewatering. The larger disposal areas which are managed for dewatering, along with the size, disposal frequency, and disposal volume (in million cubic yards, or MCY), are tabulated below:

Name	Size acres	Disposal Frequency	Volume Disposed per Dredging, MCY
Clouter Creek	1,600	continuous	3.0*
Daniel Island	700	annual	1.5
Morris Island	550	alternate years	1.5
Yellow House Creek	600	annual	0.5
Drum Island	150	alternate years	1.0
Waccamaw Neck	280	alternate years	1.0
Waccamaw Point	140	alternate years	1.0
Sampit River	230	alternate years	1.0

* Averages about 3.0 MCY per year.

Trenching is used at all of the disposal areas listed above. Underdrains are used at Drum Island, Daniel Island, and Sampit River disposal areas. Figure 1 shows the construction of an underdrain system at one of the Charleston dredged material disposal areas. Perforated pipe wrapped in a geotextile filter fabric is placed in trenches and backfilled with dewatered

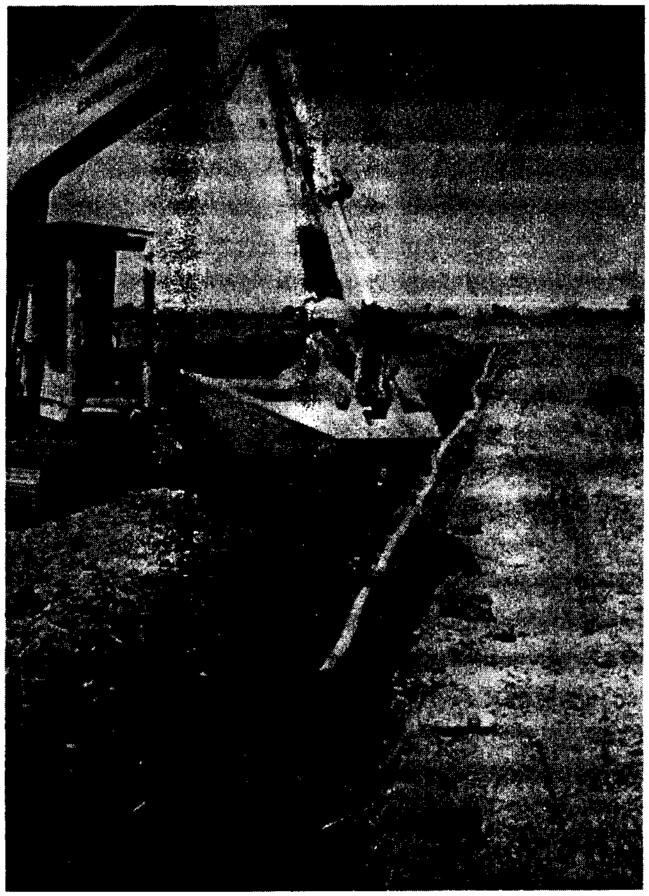

Figure 1. Construction of underdrains at Daniel Island, Charleston District

dredged material. The Charleston District reports that both of these methods effectively accelerate the rate of dewatering by removing free water from the subsurface lifts of dredged material. The primary purposes for dewatering dredged material in the Charleston District are to allow equipment access to the disposal area's interior to obtain dry borrow material required for dike raising and to regain storage volume at the site.

Crust formation resulting from material evaporative drying allows other dewatering activities in the disposal areas. The dried crust provides a base for equipment to operate on while trenching. This promotes further dewatering which provides dewatered dredged material for subsequent stripping and use as construction material for dike raising.

Experience indicates that perimeter trenching can be initiated before the "ideal" crust forms. When a ditch section is not stable and caves in during construction, continued digging at a shallower depth is recommended, followed later by deepening of the ditch. The initial shallow ditch will help drain the area in preparation for the eventual deeper ditch.

Detroit District

The Detroit District manages 15 disposal areas which are either upland, nearshore (peninsular), or island types. The size of these disposal areas ranges from 8 to 700 acres; most are used on an annual disposal frequency with between 0.01 and 0.5 MCY disposed per year. Adjustable weirs or sand filters are provided at all confined disposal areas, except one which does not have an outlet. Underdrains are used at one disposal area.

These dewatering practices are considered to be effective in providing an acceptable amount of dewatering. Dewatering practices are implemented to provide additional volume for more dredged material disposal and to prevent ponding of water. It is felt that evaporative drying does provide for significant dredged material volume reduction. The Detroit District recommends the use of alternate disposal cells followed by natural dewatering (consolidation and evaporation) in alternate seasons.

Galveston District

The Galveston District manages 200 dredged material disposal areas. The annual amount of dredging work performed is estimated to be between 35 and 40 MCY per year. The Galveston District performs trenching at the following disposal areas:

Gulf Intracoastal Waterway, Area No. 85.
Gulf Intracoastal Waterway, Area No. 86.
Gulf Intracoastal Waterway, Area No. 90.
Gulf Intracoastal Waterway, Area No. 2.
Gulf Intracoastal Waterway, Area No. 3.
Houston Ship Channel, West Jones Area.
Galveston Harbor and Channel, Pelican Island Area.
Galveston Harbor and Channel, San Jacinto Area.

The primary purposes of the District's dewatering program are to consolidate the foundations for new dikes and to provide borrow material for dike raising. The trenching is effective since it allows rain to quickly drain off the drying material, thus preventing resaturation of the previously dried material. Perimeter ditches also aid in drying borrow areas within containment areas; this in turn allows material from borrow areas to be used in dike construction.

Evaporative drying is beneficial in providing a material which is easier to handle and is dry enough for use in dike construction. Also, crust formation makes it possible for draglines to operate inside the disposal areas during dike construction by the "side-cast" method. The primary benefit of trenching for the District is increased storage volume.

The Galveston District would like to see the development of more efficient equipment which would trench faster and with less applied ground pressure. They would like to start trenching sooner and to minimize the cost of trenching.

Norfolk District

The Norfolk District manages the 2,500-acre Craney Island Disposal Area for dewatering. This site is subdivided into three containment areas of approximately 800 acres each. Dredged material is disposed into Craney Island on a semicontinuous basis for a total of approximately 5 MCY per year. Disposal is rotated among the three individual containment areas so that each one receives dredged material for one year and is allowed to dry for two years. The three Craney Island compartments are actively dewatered during the two-year drying period by trenching.

Aerial surveys show that additional storage volume has been realized due to dewatering efforts over the last two years. The District is currently monitoring volume reduction during dewatering using aerial surveys along with settlement plate evaluations. A secondary benefit of dewatering efforts is accessibility of the interior of the disposal area.

The Norfolk District is currently evaluating the potential use of underdrains placed in surface trenches in the crust from the previous disposal. Based on experiences with dewatering, the Norfolk District recommends that dewatering practices should be developed and used to the greatest extent possible.

Philadelphia District

The Philadelphia District manages approximately 32 disposal areas which are government owned and approximately 44 disposal areas which were obtained by local sponsors. All of these are upland-type disposal areas. The disposal areas which are managed for dewatering along with size, disposal frequency, and disposal volume are tabulated on the next page:

Name	Size acres	Disposal Frequency	Volume Disposed per Dredging, MCY
Oldmans	201	annual	2.4
Pedricktown North	560	3 out of 6 yr	2.4
Pedricktown South	525	3 out of 6 yr	2.4
Killcohook A,B,C	1,160	2 areas: 3 out of 8 yr	
		1 area: 2 out of 8 yr	0.5
Willmington Harbor	150	2.5 out of 5 yr	0.9*
Edgmoor	210	2.5 out of 5 yr	0.9*
Courthouse Point	170	alternate years	0.5
Pearce Creek	250	annual	0.3

* Averages about 0.9 MCY per year.

Dewatering is performed by trenching as well as by placement of thin lifts of material over a larger area versus placing of thick layers over a smaller area. Dewatering is effective because it provides volume reduction, provides better material for dike raising, improves trafficability within the disposal area, and prevents ponding of rainwater which resaturates the previously dried material.

Some of the Philadelphia District's disposal areas have been used for storage of large quantities of dredged material and therefore have rather high dikes. When dikes are raised, the new dike must be constructed on top of and inside of the existing dike. The foundation material for the raised dike section is the material located just inside the old dike section. Because perimeter trenches are filled with relatively soft dredged material to a deeper depth than the remainder of the disposal area, perimeter trenching is believed to undermine the foundation for high dikes.

The main benefit of evaporative drying is the increase in trafficability for perimeter dike construction. The Philadelphia District recommends that unless a District has large areas available for dredged material disposal, dewatering practices should be used whenever possible. Also recommended is the use of District-owned ditching equipment which allows dewatering management to be an internal operation instead of being conducted at the discretion and for the benefit of a local sponsor.

The Philadelphia District believes that identifying beneficial uses for large volumes of fine-grained dredged material would provide a breakthrough in improving dredged material disposal operations. For example, if dewatered dredged material could be removed from the disposal area for a beneficial use, then the useful life of existing disposal areas would be increased, avoiding the need for as many new disposal areas. Also development of disposal areas in ways which allow use by the local population might reduce local opposition.

Savannah District

The Savannah District manages 11 Corps and 3 Navy disposal areas. Two are open water disposal areas and twelve are upland disposal areas. Seven of the upland disposal areas are managed for dewatering. The disposal areas managed for dewatering, along with size, disposal frequency, and disposal volume, are tabulated below:

Name	Size acres	Disposal Frequency	Volume Disposed per Dredging, MCY
Area 12	1,195	annual	3.50
Area 13A	1,481	alternate years	1.60
Area 13B	589	alternate years	1.60
Argyle-Hutchinson	340	annual	0.45
Mainside	160	annual	<1.00
Jones-Oyster Bed	2,637	alternate years	0.50
Area 14	792	18 months	0.35

Trenching is used on a regular basis at Area 12, Area 13A, Area 13B, Jones Oyster Bed, and Area 14 disposal areas. The Argyle-Hutchinson and Mainside disposal areas are trenched at irregular intervals. Figure 2 shows the construction of trenches at a Savannah dredged material disposal area using a low ground pressure, rubber-tired vehicle with a trench digging attachment. The Savannah District reports that trenching is very effective since it shrinks dredged material which increases disposal area capacity and also reduces mosquito-breeding habitat. In the long term the volume reduction due to dewatering reduces the required frequency for dike improvements which reduces costs. The Savannah District reports that two primary purposes for their dewatering program are to provide additional volume for dredged material disposal and mosquito control.

The main benefit of evaporative drying is the formation of the surface crust which is essential for ditching activities. Some reduction in volume is achieved through evaporative drying, but significant volume reduction is achieved through ditching.

Figure 2. Construction of trenches at Savannah

The Savannah District does not recommend purchasing prototype equipment for dewatering activities. Some prototype equipment the Savannah District used broke down, needed frequent repairs, and did not work as well as advertised. The Savannah District would like to use equipment with lower ground pressure than is currently in use. Their problem is the same as other Districts in that trenching is needed for dewatering, but some dewatering must occur before trenching can be accomplished.

Wilmington District

The Wilmington District operates 76 upland disposal areas of which three are actively undergoing dewatering. These include the 800-acre Eagle Island, 250-acre MOTSU DA4, and 125-acre MOTSU DA1 disposal areas. The Eagle Island disposal area receives approximately 1 MCY of dredged material per year with trenching performed to aid in dewatering. The MOTSU DA4 disposal area receives approximately 1.5 MCY per year of dredged material with trenching performed to assist dewatering. The MOTSU DA1 disposal area receives approximately 0.6 MCY of dredged material from dredging performed every three years with both trenching and underdrains used for improved dewatering.

The Wilmington District reports that trenching enhances drying, increasing the available dry material for dikes and the volume capacity of the site. The Wilmington District has experimented with an underdrainage technique using perforated 5-in.-diameter drainage pipe wrapped in filter fabric. The wrapped pipes are laid on the dried crust from the previous disposal, taking advantage of the natural slope of the dredged material to facilitate drainage. The next layer of dredged material is then placed over the drainage pipes. The underdrainage system has been flowing continuously for nearly three years and is effective in removing water from the material near the bottom of each layer of dredged material.

Additional Studies

Additional studies investigating dredged material dewatering are in progress at WES. A technical report providing more detailed information on this subject is currently in draft form. Dr. Jack Fowler, Geotechnical Laboratory, WES, is preparing a video report illustrating successful dredged material dewatering practices. A recent field study investigated trafficability requirements of equipment working in dredged material disposal areas to gather information about field conditions which are necessary before equipment can successfully work in disposal areas. A report on this field study is also forthcoming.

Summary

Previously conducted DMRP research investigated a number of dewatering techniques for potential use in confined dredged material disposal areas. Evaporative drying combined with surface trenching was determined to be a cost-effective method for use with large volumes of dredged material. Use of underdrainage systems was found to be technically feasible, but more expensive than surface trenching.

A survey of Corps of Engineers District Offices provided information on dewatering practices being used by the various Districts. This survey found that approximately 60 percent of the Districts responding to the survey use surface trenching to enhance evaporative drying of their confined disposal areas. Also, 25 percent use underdrainage systems to promote dewatering in their disposal areas. Underdrainage systems were found to be feasible in some Districts since the surface crust of a previously dried dredged material layer provided an in-place pervious horizontal drainage layer which merely had to be intercepted by trenching and provided with a drainage path to the weir.

Those Districts which have active dewatering programs report that their dewatering efforts are successful in meeting their objectives for dewatering. These objectives include accelerating the removal of water from the dredged material and allowing for the removal of more water from the dredged material than would otherwise be possible. Both of these objectives allow for an increase in storage at a given disposal area. The increased storage capacity prolongs the life of the disposal area and allows for the construction of dikes using dewatered dredged material. The consensus of those Districts with active dewatering programs is that the use of surface trenches and underdrains works well in full-scale practice, just as was envisioned based on DMRP research.

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Environmental Effects of Dredging Technical Notes

ECONOMIC OPTIMIZATION OF CONFINED DISPOSAL AREA DIMENSIONS

PURPOSE: The purpose of this technical note is to present preliminary information on selecting dimensions for confined dredged material disposal facilities to obtain minimum cost for land and dikes.

BACKGROUND: Confined disposal facilities must be sized to provide adequate volume to store the disposed sediments and to meet effluent water quality standards. Given a sediment volume, designers may select CDF dimensions (length, width, ponding depth, and lift thickness) from wide ranges that meet both storage and water quality constraints. This note provides guidance on selecting these CDF dimensions to achieve minimum cost.

ADDITIONAL INFORMATION: This technical note was prepared by Dr. F. Douglas Shields, Jr. with input from Drs. Paul R. Schroeder and Michael R. Palermo. For additional information, contact Dr. Shields, (601) 634-3707, or the manager of the Environmental Effects of Dredging Programs, Dr. Robert M. Engler, (601) 634-3624, for additional information.

Introduction

The most recent Corps of Engineers guidance for confined disposal facility (CDF) design, Engineer Manual 1110-2-5027 (Headquarters, US Army Corps of Engineers 1987), provides a method for determining the minimum required site area and volume given a mean ponding depth ($\bar{d}$) and pond length-to-width ratio (L/W). Total cost is not considered. In cases where the shape and area of available land are not severely constrained, the designer may select a combination of diked area and height (CDF dimensions) to provide the required volume at minimum total cost. The approach described in this technical note will allow a designer to select CDF dimensions that will result in CDF costs substantially less than those that result from straightforward application of the EM guidance.

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Limitations

The method described here is applicable to rectangular CDFs only. If the available land at the CDF site is not the right shape or is not big enough for the least-cost rectangular design determined using this procedure, the procedure can still be used to select the least-cost alternative rectangular design that does fit the site. Furthermore, application of this guidance will often result in smaller land area requirements, particularly where land costs are high. This method is not limited to designing new CDFs; it can also be used to select the most economical way of configuring an existing CDF to receive a given flow and still meet effluent standards.

A CDF designer must select pond length, width, and depth and decide whether to use spur dikes and, if so, how many to use. The first step in sizing the CDF is to determine the volume the dredged material will occupy in the CDF at the end of the last disposal event. If the CDF design is for one cycle of filling, drainage, and drying, the results of a long-term column settling test (Figure C-2, p C-6, EM 1110-2-5027) may be used to determine dredged material volume. In certain cases, the nomograph in Figure 1 of TN EEDP-02-8 may be used instead of results of a long-term column settling test to determine dredged material volume. If the CDF design is for several cycles of use, consolidation calculations will also be needed (Chapter 5, EM 1110-2-5027).

Once final dredged material volume is determined, the required dike height is determined by dividing dredged material volume by pond area to get lift thickness and adding pond water depth and freeboard. The cost for land for the CDF may be reduced by decreasing the pond area and increasing the dike height to handle the greater lift thickness. However, dike volume, and thus cost, is a geometric function of dike height. In addition, as dike height increases, the land area required for the dikes themselves also increases. For some value of pond area (and the associated required dike height), the total cost, which is approximately the sum of dike cost plus land cost, is minimized. However, CDF dimensions must also meet maximum dike height and water quality constraints if they are to be used. If minimum cost dimensions result in a design that fails to meet the dike height or water quality constraints, additional analysis of costs can be performed to determine the least cost design that does satisfy the constraints. Details follow.

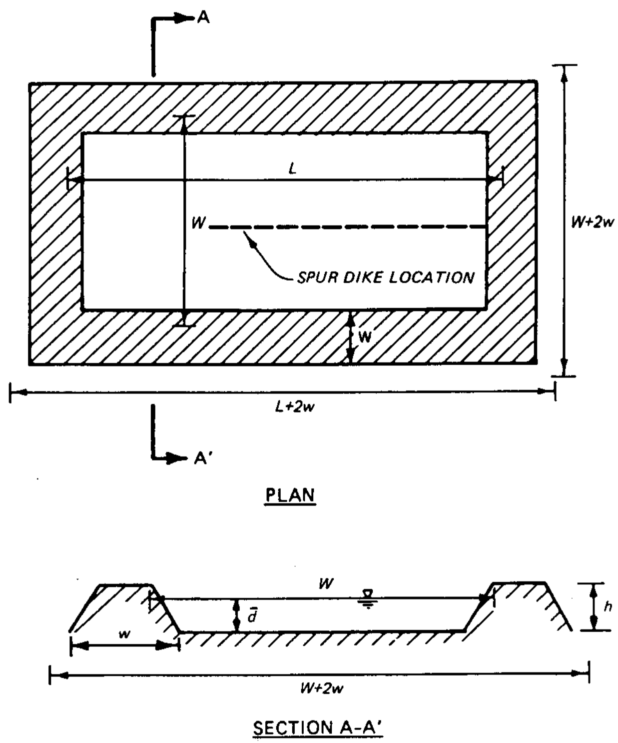

Figure 1. Definition sketch of CDF--
assumptions are given in Table 1

Development and Use of Diagram

Unless water quality constraints control design, least-cost CDF dimensions may be read from a simple diagram. The diagram consists of plots of the controlling dimensionless variables. In order to develop the diagram, controlling dimensional variables are identified. CDF cost is a function of the volume of material to be disposed; its settling characteristics; dike design parameters; the price of land and dikes; the mean flow rate; the number of spur dikes; and the CDF length, width, and dike height. The number of variables can be reduced by assuming a constant crown width and side slope for the perimeter dikes and by forming dimensionless groups of the remaining variables.

In order to illustrate diagram development and use, a simple CDF site configuration was assumed. Basic assumptions used in setting up the problem are given in Table 1, and dimensionless variables are defined in Table 2. A schematic of a CDF is provided in Figure 1 to aid interpretation of Tables 1 and 2.

Table 1

Assumptions

Minimum ponding depth, $\bar{d}$ = 2.0 ft

CDF cost = total land cost + total dike cost
(This implies that weir costs and other costs are negligible, and relocation and right-of-way problems do not affect site shape or size)

Volume of dredged material in CDF at end of disposal, V_m = 100,000 yd^3

The dredged material exhibits settling characteristics shown in Figure 2 (from EM 1110-2-5027)

Dike design:

Maximum dike height = 20 ft

Crown width = 10 ft

Side slope = 1V:3H

Freeboard = 2.0 ft

The site in question is level enough that dikes with uniform cross section have constant crown elevation.

The cost for dikes is simply a constant unit price times the embankment volume.

The price of spur dikes per unit length is 0.5 times the price per unit length of perimeter dikes (U_s = 0.5).

Spur dikes are 0.8 times as long as the length of the pond (L_s = 0.8).

As shown in Table 2, seven basic dimensionless variables were formed. An eighth dimensionless term, the hydraulic efficiency correction factor (HECF), which is a function of two of the seven dimensionless variables, is also important in problem solution. Meanings of four of the seven dimensionless terms are further explained below:

- P* is the dimensionless ratio of the price of land to the price of perimeter dikes.
- Q* is the dimensionless mean flow rate into the CDF.
- V* is a dimensionless measure of the CDF surface area. It is also the ratio of mean ponding depth to dredged material lift thickness.

Table 2

Formulas for Spreadsheet

Dimensionless Variables

$$P^* = \frac{\text{unit price of land, } U_l}{\text{unit price of dike fill, } U_d} \times (V_m^{1/3})$$

$$Q^* = \frac{\text{mean flow rate, } Q \times \text{time required for settling, } t_{req}}{V_m}$$

$$V^* = \frac{(\text{pond length, } L) \times (\text{pond width, } W) \times (\text{mean depth, } \bar{d})}{V_m}$$

L/W = pond length divided by pond width

$L/\bar{d}$ = pond length divided by mean depth

= number of spur dikes

HECF = hydraulic efficiency correction factor

$$\text{HECF} = \frac{1}{[0.9\ (1 - \exp(-0.3(L/W)L_s(\# + 1)^2)]}$$ -- from Shields et al. (1987)

(L_s = 1 when # = 0)

$$C^* = \frac{\text{total CDF cost}}{V_m\ U_d}$$

Dimensional Variables

lift thickness = $\frac{V_m}{L_s W}$

dike height, h = lift thickness + pond depth + freeboard

dike width, w = dike crown width + 2(h/side slope)

side slope = vertical dimension/horizontal dimension

dike cross-sectional area, A_d = (dike crown width v h) + $\frac{h^2}{\text{side slope}}$

pond length, L = $V^* V_m (L/W)/\bar{d}$

(Continued)

Table 2. (Concluded)

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pond width, $W = L/(L/W)$

land area required for CDF = $(L + 2w)(W + 2w)$
(this allows for a strip of land (h - 2/side slope) wide around the outer perimeter of the CDF as shown in Figure 1)

cost for land = $U_1 \times$ land area required for CDF

length of perimeter dikes, $P_{d1} = 2(L + 2w + W)$

length of spur dikes, $S_{d1} = 0.8\ L \times$ number of spur dikes

price of perimeter dikes per unit length = $U_d A_d$

price of spur dikes per unit length = $0.5\ U_d A_d$

cost for dikes = $U_d A_d\ (P_{d1} + 0.5\ S_{d1})$.

total CDF cost = cost for land + cost for dikes

Effluent Water Quality Constraint

$$V^* \geq HECF \times Q^*$$

Dike Height Constraint

$$h \leq 20\ ft$$

A designer calculates P* and Q* from given conditions. He varies L/W , V* , d , and # to minimize C* , yet still meet dike height and water quality constraints.

C* is the dimensionless unit cost of the CDF. It is the ratio of the cost per cubic yard of the CDF to the price per cubic yard of perimeter dikes.

The absolutely least costly CDF design features minimum ponding depth and is square (L/W = 1.0) with no spur dikes. For such a design, C* is a function of V* and P* only. Microcomputer spreadsheets are ideal for computing C* values for a range of V* and P* values. Results may be plotted as shown in Figure 3. To use the diagram, a designer selects V* that minimizes C* for the P* value applicable to the project. LW ($LW = L^2 = W^2$) may then be calculated from V* (Table 1) and d = 2.0 ft . Dike dimensions may then be obtained from the formula in Table 1.

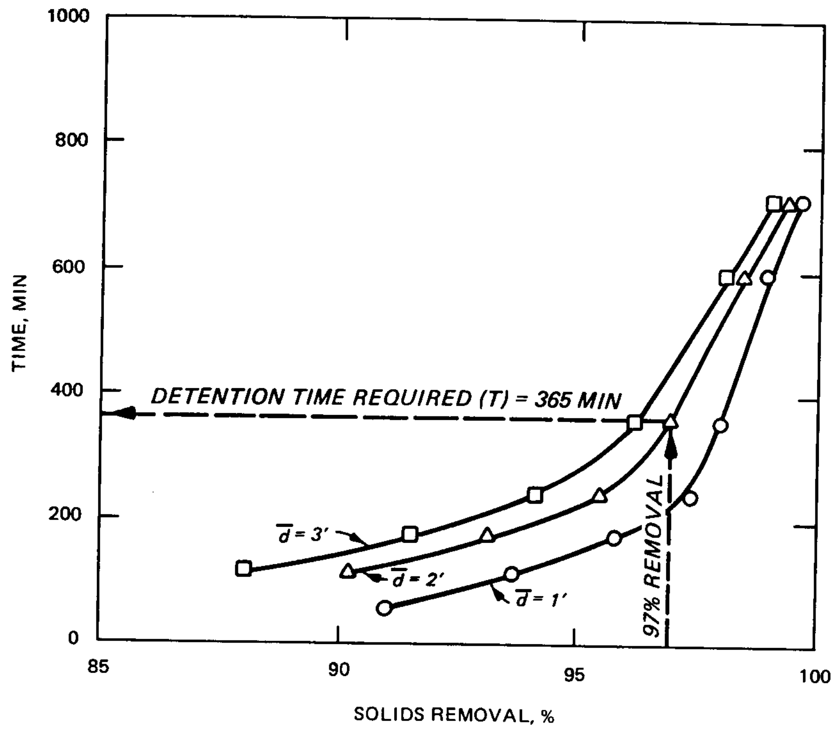

Figure 2. Settling data for dredged material

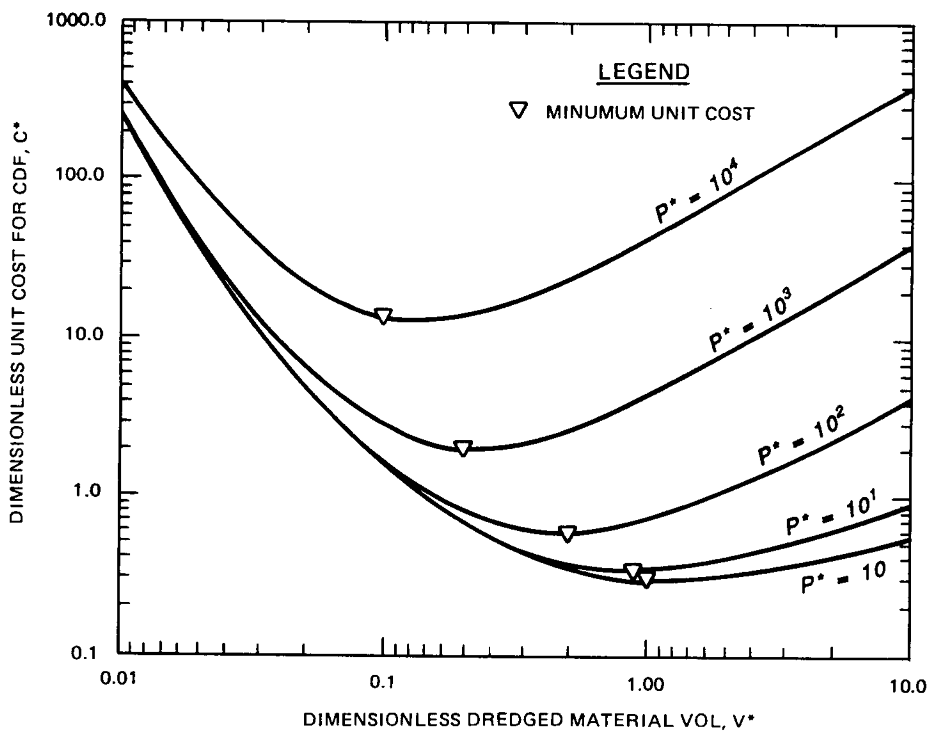

Figure 3. Dimensionless cost for CDF, C* as a function of dimensionless unit price ratio, P* and dimensionless final dredged material volume, V*

Area Constraint

If the area required for the CDF design obtained from a diagram like Figure 3 is too large for the available land parcel, the least-cost design configuration may be obtained by simply using the entire available area and setting dike height equal to lift thickness plus 4 ft (ponding depth and freeboard of 2 ft each).

Dike Height Constraint

Least-cost design configurations from analyses like those that produced Figure 3 must be checked to ensure that they meet dike height and effluent water quality constraints. Dike height may be expressed as a function of V^*. Under the assumptions in Table 1, V^* must be greater than or equal to 0.125 for the dikes to be less than 20 ft high. All least-cost configurations in Figure 3 meet the dike height constraint. Values of P^* higher than those shown in Figure 3 do produce minimum C^* values that violate the stated dike height constraint.

Water Quality Constraint

Least-cost design configurations must also be checked to ensure that they meet the effluent water quality constraint. Basically, the water quality constraint is that the CDF hydraulic mean retention time should exceed the time required for clarification that is determined from laboratory column settling tests. In terms of the previously defined dimensionless variables this constraint may be stated $(V^* / HECF) \geq Q^*$.

If the least-cost design configuration from Figure 3 fails to meet the water quality constraint, the mean retention time must be increased. CDF mean retention time may be increased by (1) reducing the mean flow rate, (2) increasing pond surface area LW, (3) increasing mean ponding depth, (4) increasing L/W, or (5) using spur dikes. Additional spreadsheet analysis may be used to determine which of these five approaches is the most cost effective. Repetitive calculations can be performed to determine the effect of varying Q^*, V^*, ponding depth, L/W, and the number of spur dikes on C^*. Penalty functions can be used to generate large unit costs when total land area, dike height, or water quality constraints are not met. Results of a series of such spreadsheet analyses are presented in Table 3. Spreadsheet formulas should allow for the fact that increasing the ponding depth slightly reduces the required retention time for flocculent suspensions, as shown in Figure 2, and thus also reduces $Q^* = Q\ t_{req}/V_m$ (Table 2).

Table 3 shows that least-cost designs for the assumed conditions call for slight increases in L/W with increasing P* and favor the use of spur dikes when large values of both P* and Q* occur. Less expensive spur dikes like floating baffles (Shields et al. 1987) would favor increasing the number of spur dikes over increasing L/W . Current prices (1988) for floating baffles are about $20 per linear foot. In some cases, baffles may be reused.

As would be expected, Table 3 shows that larger flow rates require larger surface areas and higher land prices favor using less surface area. In other words V* , the dimensionless pond surface area, varies directly with Q* and inversely with P* .

Table 3

Least-Cost* Design Configurations for CDFs

Price Ratio P*	Flow Rate Q*	Surface Area V*	L/W	No. of Spur dikes #	Mean Pond Depth, ft $\bar{d}$	Unit Cost C*
1	0.03	1.125	1.0	0	2	0.303
1	0.30	1.300	1.0	0	2	0.304
5	0.03	1.025	1.0	0	2	0.321
5	0.30	1.300	1.0	0	2	0.325
10	0.03	0.925	1.0	0	2	0.342
10	0.30	0.925	1.5	0	2	0.348
100	0.03	0.475	1.0	0	2	0.587
100	0.30	0.550	1.0	1	2	0.626
1,000	0.03	0.200	1.0	0	2	1.994
1,000	0.30	0.350	1.5	2	2	2.345

* Based on assumptions in Table 1.

Mean ponding depth for examined conditions was always equal to 2.0 ft for minimum cost. Changing the settling characteristics of the dredged material suspension toward slower settling or increasing the unit price ratio above 10,000 would favor greater ponding depth.

Example

A CDF is to be designed for a disposed volume of 100,000 cubic yards with basic assumptions as shown in Table 1. Land costs $3,000 per acre and perimeter dikes may be constructed for $2.60 per cubic yard of dike volume, giving $P^* = 100$. Available dredges range in size from 8 to 27 in. Assuming dredge pumping averages 14 hours per day and using a pipeline velocity of 15 fps yields $0.03 < Q^* < 0.3$. Least-cost design configurations are shown in Table 4. Table 4 shows that unit cost increases with Q^* when Q^* exceeds the V^* value for least-cost design from the diagram in Table 3. Figure 4 shows the effect of mean flow rate on minimum unit cost and on unit cost for a "standard" design with $L/W = 1.0$ and dike height = 8.0 ft.

Table 4

Example--Least-Cost CDF Design

Dredge Size in.	Mean Flow Rate cfs*	Pond L ft	Pond W ft	Pond $\bar{d}$ ft	Total Area for CDF acres	Number of Spur Dikes	Lift Thickness ft	Dike Height ft	Unit Cost $/yd^3
8-18	3-13	801	801	2	19.4	0	4.2	8.2	$1.53
20	16	822	822	2	20.2	0	4.0	8.0	$1.53
27	30	862	862	2	21.8	1	3.6	7.6	$1.63

* This mean flow rate is an average for the entire period it takes to fill the CDF. Mean flow rate was calculated by multiplying dredge pipeline cross-sectional area times pipeline velocity times (100% - percent downtime). Pipeline velocity was assumed to be 14 fps and downtime was assumed to be 10 hours/day, or 42 percent.

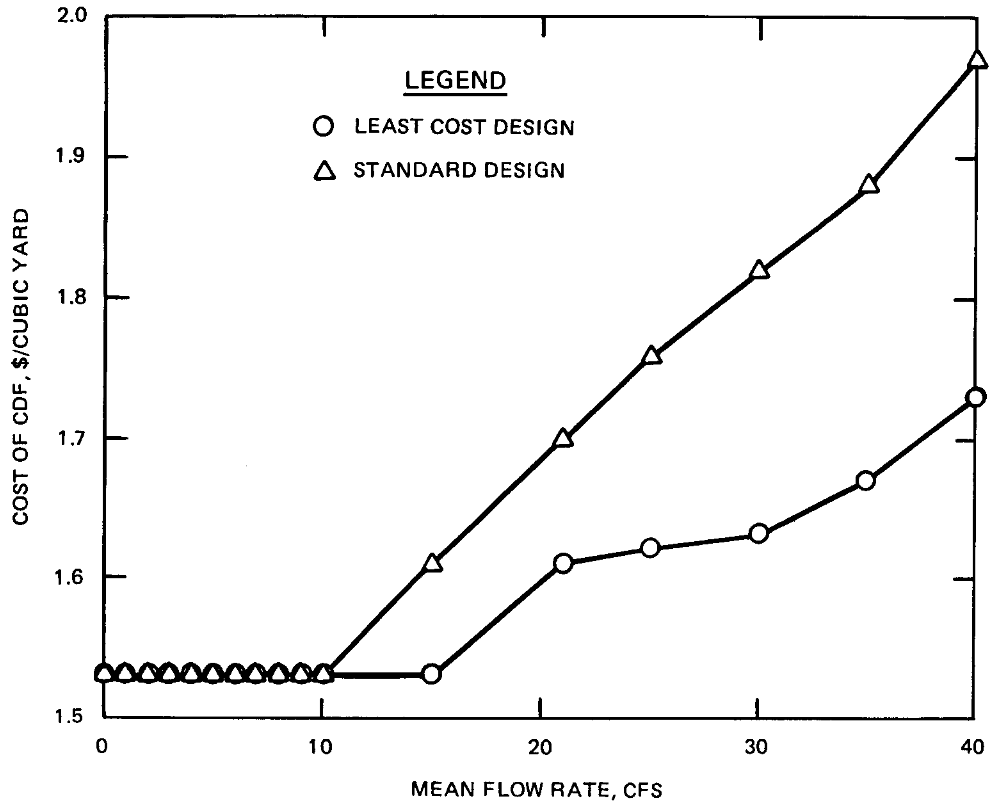

Figure 4. Effect of mean flow rate on CDF unit cost, least cost design and "standard" design with L/W = 2.0 , dike height = 8.0 ft, and no spur dikes

Summary and Conclusions

Over the range of conditions most commonly encountered, economically optimum CDF designs have no spur dikes, have low perimeter dikes, are square, and have a mean ponding depth of 2.0 ft. Surface areas for these designs may be obtained by reading V* from Figure 3 and calculating LW. As the relative price of land to perimeter dikes (P*) increases, the optimum design configuration entails higher dikes and less total land area, length-width ratios between 0 and 1.5, between 0 and 2 spur dikes, and a mean ponding depth of 2.0 ft. To avoid short-circuiting, square CDFs (L/W = 1.0) should either have inflow and outflow points that are located on opposite sides or that are separated by a spur dike.

Water quality constraints become important whenever dimensionless average flow rate, Q*, times the hydraulic efficiency correction factor, HECF , exceeds V* . A number of microcomputer spreadsheet simulations may be run to determine the most cost-effective CDF design that meets water quality constraints.

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Environmental Effects of Dredging Technical Notes

DREDGED MATERIAL CONTAINMENT AREA MANAGEMENT PRACTICES FOR INCREASING STORAGE CAPACITY

PURPOSE: This technical note describes techniques for managing confined dredged material disposal areas to maximize storage capacity. Management of these disposal facilities is recommended to extend their useful life and, thus, minimize the requirement for additional disposal facilities.

BACKGROUND: Large quantities of sediment are dredged from the navigable waterways of the United States annually and must be placed in an environmentally acceptable manner at a designated disposal site. Confined upland sites and subaqueous disposal sites are most commonly used for disposal of dredged material. Presently about 40 percent of dredged material is placed in upland sites. This material has a high water content upon placement and is often located above the existing groundwater table and can conceivably be dewatered to significantly reduce its volume.

The use of confined disposal sites needs to be optimized to increase the quantity of dredged material that can be stored in a site. The quantity of sediment that can be placed in a containment area is determined by the size of the site, the maximum dike height allowed, and the consistency of the dredged material stored in the site. As consolidation (reduction in volume under load) and desiccation (drying) occur, water is removed from the dredged material and the volume of dredged material (soil plus water) to be stored is reduced. As this water is removed, the consistency of the material changes from a very soft material (almost a viscous fluid) toward firm ground; the ultimate consistency of the dredged material will depend upon the amount of water removed, as well as the properties of the dredged material, the frequency of disposal operations, and the management practices used.

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Introduction

A number of techniques can be used to facilitate management of confined upland dredged material disposal areas for maximum storage capacity and useful life. Some techniques must be applied either during or immediately after dredging operations, while others should continue throughout the drying cycle until a subsequent disposal operation begins. These practices can be applied equally well to disposal sites used independently or in conjunction with other disposal areas. Figure 1 is a schematic diagram of a typical dredged material disposal area.

The management techniques described in this Technical Note apply to containment areas in which clean sediments have been placed. Regarding contaminated sediments, the oxidized conditions which can develop when dredged material is dried can favor increased mobilization and release of contaminants. If contaminated materials are involved, the tradeoffs between the benefits of dewatering

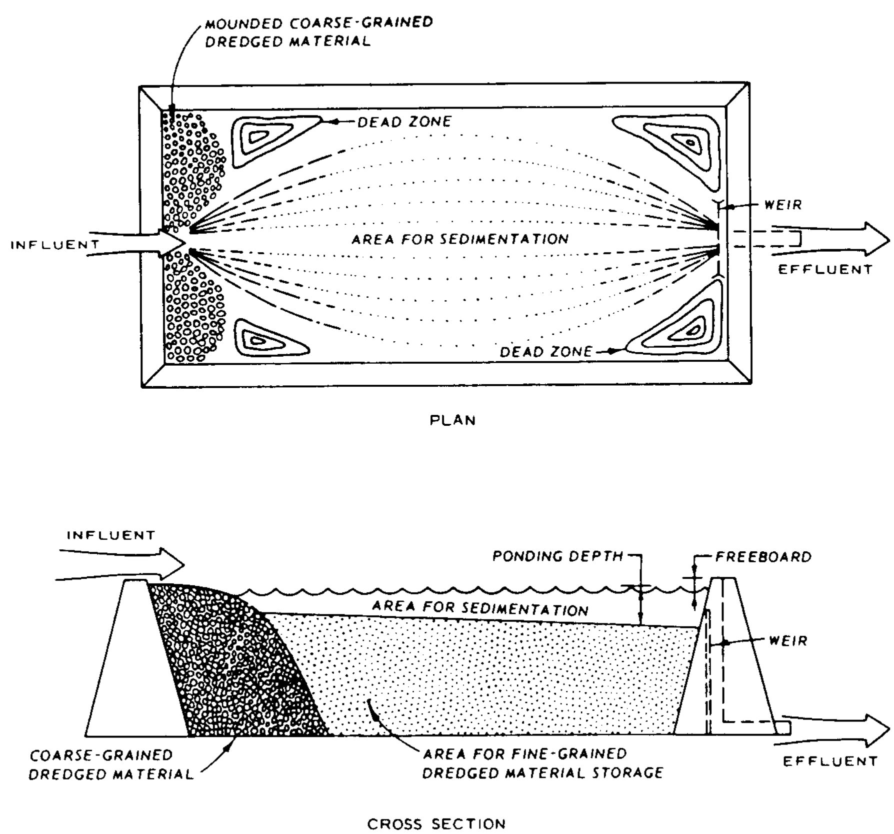

Figure 1. Schematic diagram of an upland dredged material containment area

and drying of the dredged material and the increased potential for contaminant release must be evaluated. If dewatering of contaminated dredged material is to occur, additional constraints on site operation and management may be required.

Management Techniques

The following techniques and procedures should be considered in any comprehensive plan for dredged material containment area management. Use of all techniques is necessary to maximize containment area storage capacity, but the use of any of these procedures will result in some increase in capacity. The benefits gained from site management will depend on which procedures are used and to what degree they are used.

Inflow-outflow locations

Dredged material is usually placed in a confined upland site by hydraulic pipeline dredge, although hopper dredge or barge pumpout may also be used. In either case, the material enters the containment area in the form of a slurry with a concentration of about 150 g/ℓ. As the material is discharged from the pipeline, coarse-grained material will fall out of suspension and form a mound at the discharge point. The remainder of the material (the fine-grained portion) will flow further into the containment area; this material will typically have a surface slope of 0.36V on 100H. Locating the inflow (dredge pipe) and outflow (weir) points at opposite ends of a rectangular disposal area or as far apart as possible in disposal sites of other shapes is, therefore, advisable. A gently and continuously sloping surface will result, which will facilitate later surface water removal. If the inflow point and weirs must be located on the same side of the disposal site, construction of a spur dike (or dikes) to increase settling efficiencies and to avoid later drainage problems should be considered. Figure 2 illustrates the potential drainage problem that often occurs when the inflow and outflow points are not adequately separated.

Surface water ponding

During active dredging and disposal operations, a pond of water should be maintained across the surface of the disposal site. This pond will provide

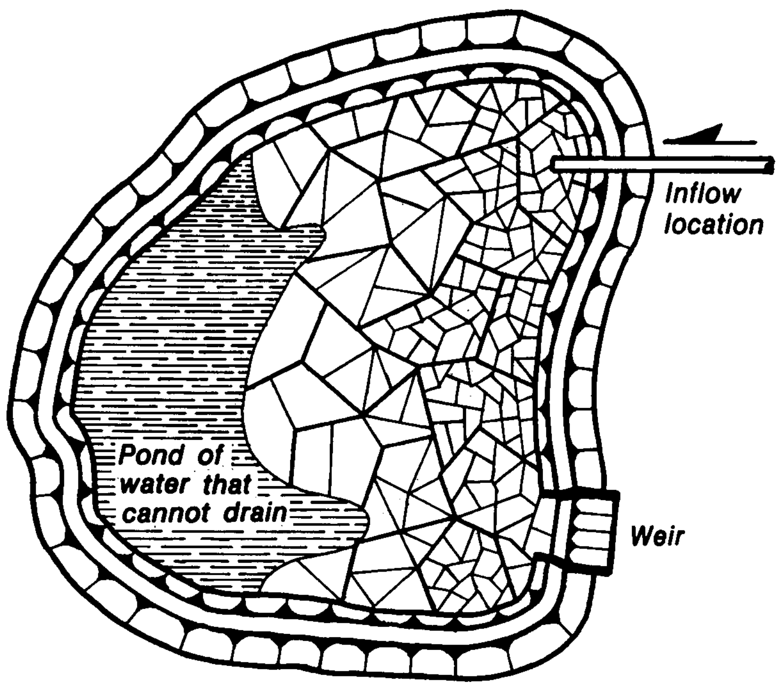

Figure 2. Improper location of inflow point and weir, causing stagnant ponds of water that cannot drain from the site

adequate detention time for sedimentation. A minimum depth of 2 ft of ponded water should be maintained above the solids-water interface.

Immediately after disposal operations are completed, the ponded surface water should be decanted. This can be accomplished by gradual reduction in the weir crest elevation when an adjustable weir is used at the site. The weir crest must be lowered slowly to ensure that acceptable effluent water quality is maintained. When other types of discharge structures are used, the same principle of slow withdrawal should be followed (Headquarters, US Army Corps of Engineers 1987).

Long-term weir operation

After dredging and the decantation of the ponded surface water are completed, site management efforts should be concentrated on maximizing the containment area storage capacity gained from continued consolidation of both the dredged material and the foundation soils and drying of the dredged material. To ensure that precipitation does not result in ponded water, the weir crest elevation must be kept at levels that allow efficient release of surface runoff. This will require periodic lowering of the weir crest elevation as the dredged material surface settles.

Thin-lift placement

Gains in long-term storage capacity through natural drying processes can also be increased by placing the dredged material in thin lifts. Thin lifts are considered to be those dredged material layers initially not over 3 to 5 ft thick. Thin-lift placement greatly enhances potential gains in storage capacity when active dewatering and disposal area reuse management programs are implemented (Headquarters, US Army Corps of Engineers 1987). Thin lifts may be placed either by limiting the amount of material placed during a given disposal operation or by obtaining a site with larger surface area. Implementing this approach requires careful long-range planning to ensure that the larger land area is used effectively for dredged material dewatering, rather than simply being a containment area whose service life is longer than that of a smaller area.

Surface drainage

Surface drainage facilitates dredged material dewatering by providing rapid removal of precipitation and by shortening the drainage path length within the deposit. The method of drainage most often used in containment areas is progressive surface trenching. This entails creating shallow trenches in the soft dredged material within a few months after the ponded water is removed. Then as the dredged material dries and a thicker surface crust forms, the initial trenches are periodically deepened (Headquarters, US Army Corps of Engineers 1987).

Typically, perimeter trenches are first constructed by draglines working from the retaining dikes or from a berm on the interior of the dikes shortly after the surface water is removed (Benson 1988, Poindexter and Walker 1988). These trenches should be constructed as far into the site as the equipment can reach to minimize future stability problems as the dikes are raised. As the perimeter trenches are created, material removed from the trenches is deposited on the interior slope of the dike where it will dry and provide convenient material for dike improvement.

After the dredged material in the containment area has dried sufficiently to support equipment (often 3 to 6 months after disposal), interior trenches should be constructed throughout the containment area. These should be connected to the perimeter trench system to provide rapid movement of water to the weir and out of the site. A consistent grade must be maintained throughout the trench network, and the trench junctions must be clear of blockages (Benson 1988, Poindexter and Walker 1988).

The pattern of interior trenches should be adapted to the geometry of the disposal area. In rectangular areas, parallel trenches running the length of the disposal site are often used; these trenches are then connected to the perimeter trench along the side adjacent to the weir. In irregularly shaped containment areas, a pattern of trenches radiating out from the weir(s) can be used effectively. In any case, the trench pattern should provide efficient drainage of all parts of the disposal site. Trenches are often constructed on 200-ft centers; closer spacing would provide better drainage, but economics and equipment operation within the site often preclude closer trench spacing.

Many types of equipment, including conventional equipment, such as backhoes, draglines, and mini-excavators, have been used successfully to construct interior trenches. However, in the early stages of dewatering, this equipment must often work on mats to reduce the ground contact pressure, even though low ground-pressure equipment is usually used. The most expedient method of interior trench construction uses a rotary ditcher pulled by either a tracked or large rubber-tired vehicle (Poindexter 1989). In addition to the speed of trenching, an advantage of this type of equipment is that it trenches continuously as it moves across the containment area. Thus there are often fewer problems with equipment mobility than there are with equipment (e.g., draglines) which must work from one location for a period of time.

<u>Removal of material</u>

Removal of material from the interior of the disposal site will further increase storage capacity and useful life. Coarse-grained material can usually be removed immediately after the ponded water has been decanted, although this material must have drained sufficiently to prevent a quick condition when equipment begins to operate. Conventional earthmoving equipment, such as bulldozers and front-end loaders, is generally used to remove this material which is often used for dike raising and improvement. In some cases, a market for the material may exist and it may be sold. However, the ownership of the dredged material must first be established, and appropriate legal procedures for sale must be followed.

After a successful dewatering effort, dried fine-grained material can be removed from the containment area. When sufficient crust thickness has developed, the dried material (crust) can be scraped from the surface of the deposit. Bulldozers are often used to windrow the dried material, which is then collected by pans and moved to the dikes or haul roads for their improvement. In some instances, this fine-grained material may have other productive uses, although the grain size may limit its applications.

Individual Site Management

The general management principles discussed above should be implemented for individual containment areas regardless of size. When only one containment area is available for use during an entire dredging project, typically its area is large, consisting of several hundred acres or more, and it is normally used frequently.

Large containment areas, especially those used almost continuously, are difficult to manage to allow time for effective drying of dredged material. However, dividing a large site into several compartments can facilitate management. Each compartment can be managed separately so that while some compartments are being filled, others can be dewatered (Palermo, Shields, and Hayes 1981). For example, the 2,500-acre Craney Island disposal facility in Norfolk District was subdivided into three compartments in 1984 to permit more effective management of the site (Figure 3).

The recommended management scheme for large compartmentalized containment areas involves sequential placement of thin lifts of dredged material into each compartment, as shown in Figure 4. The functional sequence for each compartment consists of dredged material placement, settling and surface drainage, dewatering, and dike raising (often using dewatered dredged material). The operation must be designed to include enough compartments to ensure that each thin lift is dried before the subsequent lift is placed.

Figure 3. Craney Island facility

Multiple Site Management

Multiple disposal site management practices are similar to those for large compartmentalized containment areas. Sequenced disposal activities should be used to allow maximum drying of the dredged material between disposal operations. If several of the containment areas must be used during one dredging operation, the quantity of dredged material to be placed in each site should be proportioned according to surface area of the sites involved. This will ensure that the thinnest lift possible is placed in each containment area. By following these practices, the maximum benefit will be gained from evaporative drying and thus the maximum capacity of each site will be realized.

Assessing Site Capacity

Computational tools are available to assist with various aspects of dredged

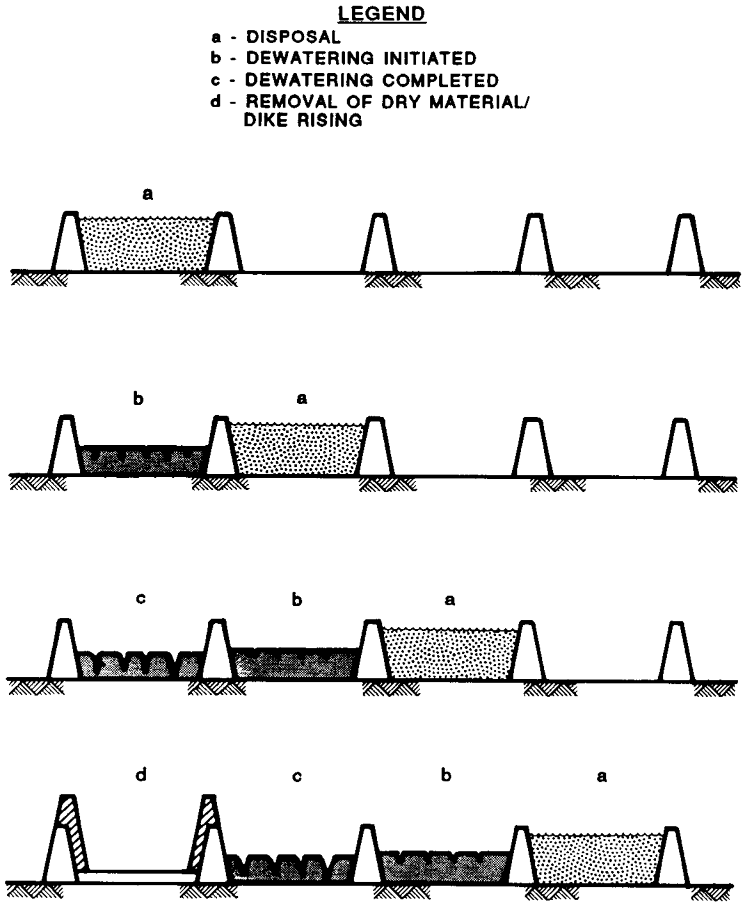

Figure 4. Conceptual dewatering operations for compartmentalized disposal sites

material containment area management. A finite strain consolidation and desiccation computer program entitled "Primary Consolidation and Desiccation of Dredged Fill (PCDDF)" is available (Poindexter-Rollings and Stark in preparation, Benson 1987, and Cargill 1985) to assess the storage capacity and service life of individual containment areas. Another program, D2M2, can be used to optimize use of multiple disposal sites; it is available through the US Army Corps of Engineers' Hydrologic Engineering Center (Ford 1984) and through the US Army Engineer Waterways Experiment System (ADDAMS) (Schroeder 1988).

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November 1989

Environmental Effects of Dredging Technical Notes

ECONOMIC VALUATION OF WETLANDS

PURPOSE: This technical note summarizes the principles and major issues for the economic valuation of wetlands. The valuation information presented here is intended to support the biological assessment of wetland functions and values as set out in the Wetland Evaluation Technique (WET) (Adamus et al. 1987). Subsequent technical notes will present economic valuation methods for specific wetland services, e.g., commercial fisheries.

BACKGROUND: Wetland biological functions and values, as identified by WET or other wetland assessment, support or provide services that are valued by society. For instance, the functions of Groundwater Recharge and Groundwater Discharge support the Water Supply service. The services provided by wetlands have economic value, if there is a demand for the service, and thus represent a relevant factor for consideration in decisions on wetlands. This economic valuation information provides the rationale for inclusion of economic values in the WET evaluation process.

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Introduction

Wetlands provide a variety of services that are valued by society. The ecological functions and values associated with a particular wetland area may give rise to potential for recreation, wastewater treatment, or residential development services. The services provided by a wetland have economic value to the extent that they provide consumer satisfaction or enjoyment, i.e., provide a desirable service, and are scarce (Loomis and Peterson 1984). The relationship of the biological functions of wetlands, identified by a WET analysis, to the services provided by a wetland is often not well understood or may be highly site specific. Table 1 relates wetland functions and values assessed in WET to services valued by society.

Table 1

Services and Supporting Functions and Values

Service: Residential Location Amenity	
Function/Value:	(WET Level 2 Inventory Information)
Service: Agricultural Development	
Function/Value:	(WET Level 2 Inventory Information)
Service: Water Supply	
Function/Value:	Groundwater Recharge Groundwater Discharge
Service: Commercial Harvest of Timber	
Function/Value:	(WET Level 2 Inventory Information)
Service: Wastewater Treatment	
Function/Value:	Sediment Stabilization Sediment/Toxicant Retention Nutrient Removal/Transformation
Service: Recreation	
Function/Value:	Active Recreation Aquatic Diversity/Abundance Wildlife Diversity/Abundance
Service: Erosion Control	
Function/Value:	Sediment Stabilization
Service: Fish and Wildlife Habitat	
Function/Value:	Fish Habitat Aquatic Diversity/Abundance Wildlife Diversity/Abundance
Service: Sociocultural Values	
Function/Value:	Uniqueness/Heritage

Wetland Valuation

Society possesses a number of different notions of the value of natural resources. It is important to clearly define economic value and identify the economic values that valuation in a WET analysis is intended to address. WET was developed to identify and assess the biological and/or ecological functions and values of wetlands. Those functions and values identified in a WET assessment may give rise to services which have economic value. (If there is no service, there is no economic value.)

The total economic value accruing from a resource such as a wetland is determined by society as a whole and so includes a number of different types of economic values. The economic values comprising total economic value include: 1) onsite use values of those persons directly using the resources, e.g. recreator; (2) offsite use values, such as consumers of fish produced from wetland habitat; (3) future use values, the value of use in the future, and (4) nonuse values, i.e., existence and bequest values (Finch and Bergstrom 1988, Loomis and Peterson 1984). The nonuse values arise from the individual's willingness-to-pay for the continued preservation, and the desire to leave the resources to succeeding generations.

Ideally, consideration of economic values would include consideration of the total economic value. Practically and because decisions are made for specified actions to particular wetland parcels, consideration is usually given only to onsite use values. Depending on the specific action or alteration to a wetland, e.g., wastewater treatment or residential development, only a particular service would likely be valued. The other components of total economic value may also be measured. This statement is made to point out that because of the nature of wetland alteration decisions and limited time and resources for the valuation process, the economic values will normally represent only a part of the total economic value.

Valuation of Wetland Services

Valuation principles

The valuation of wetland services requires comparing the value of services "with" the wetland alteration to the value of services "without" altering the wetland. This with and without valuation principle forms the basis for evaluation of wetlands. The difference in value of the services "with" versus "without" the alteration establishes the value of the wetland, which cannot be done simply by looking at the value of development services. The costs that go into producing the wetland services or developing the wetland are subtracted from the "with" alteration benefits.

The services provided by a wetland and valued by society may be provided by nonwetland resources. A key consideration in valuing wetland services is to determine if substitutes exist for wetland services. Habitat for endangered species may be a service for which there is not a nonwetland substitute, whereas residential development may also occur in fastlands.

Valuation process

The value of the wetland will be the lesser of the direct measure of value of the service(s) provided, such as water supply, or the value considering the costs and benefits of a substitute for the services (Shabman and Batie in preparation). A generalized valuation process is summarized here. This is adapted from the evaluation frameworks for unaltered and developed wetlands developed by Shabman and Batie.

Valuation of wetland services first identifies the services that are provided by the wetland in question under both the with and without alteration conditions. The service(s) identified are known as the service vector.

Substitutes for the service(s) are identified, if possible. Identification of substitutes can help identify the value of the wetland services. The value of the services provided by a substitute can be used as a proxy value for the wetland service to be lost. The value of wetland services is reflected in the costs of replacing those services with a substitute. It is critical to identify the least-cost substitute in establishing value because, ideally, society would not pay any more than it has to for the services.

Valuation methods for the services are used as described in the following sections to determine values for the wetland services. For services provided by unaltered wetlands, e.g., water supply or flood control, the value is determined by considering what it costs to replace the services such as through structural or engineering measures. For services resulting from the development of the wetland, e.g., residential development, possible substitutes for the wetland must be considered. If no substitutes exist for the wetland services, such as for some endangered species habitat, the value is equal to the wetland development benefits minus development costs. If substitutes exist, the value attributed to the wetland is the difference in value between the wetland development and development of the least-cost alternative.

Measuring Economic Change

The economic change in the value of the services for the with and without conditions can be measured either by determining the total change in economic surplus due to the wetland alteration, or by measuring the marginal value of a wetland acre. These concepts are explained briefly below and are presented here to give the reader a better understanding of the basis of valuation methods. This discussion is not intended to be exhaustive or definitive. There are differing views on the appropriate measurement for economic change in the value of wetland services.

The total change in economic surplus is the sum of the net economic benefits accruing to the consumers of a service (consumer's surplus) plus the benefits accruing to the producers of a service, the producer's surplus. The total change in economic surplus can be thought of as a measure of how much better off society is due to the wetland alteration. Total change in economic surplus is the appropriate measure when the wetland alteration results in change in the price of a service, due to change in supply and demand resulting from the wetland alteration.

By way of explanation, consumer's surplus is the amount that consumers would be willing to pay above the price of a service. It is surplus or a benefit because the consumer is able to acquire the service at its market value, and the difference between market price and the willingness-to-pay amount is the consumer surplus. The producer's surplus, the net benefits accruing to the producer of the service, is the difference between the per-unit costs of producing the service, i.e., the opportunity costs, and the market price of the service.

Change in economic surplus is the aggregate change, that is, the sum of all the individual changes of producer's and consumer's surpluses. Total change in economic surplus measures the change in economic value resulting from wetland alteration. Because it is a total or aggregate value, economic surplus represents a nonmarginal value, rather than a per-wetland-acre, marginal measure. Total recreation value or average recreation value per user would be determined, rather than recreation value per acre.

The marginal value of a wetland is the economic value of the services gained or lost from the alteration of an incrementally small wetland area (Shabman and Batie in preparation). As Shabman and Batie point out, if a wetland permit decision involves an incrementally small change in total wetland acreage, it is the change in value with an incremental acre versus without the marginal acre development which should be considered. The development of an incremental acre would likely not affect the overall supply and demand function for a service. For example, the loss of an additional acre of wetland commercial fishery hahitat is unlikely to cause a change in the price paid for fish in a fish market.

Marginal values are reported as a value for the service related to an acre of wetland, such as value of shrimp harvest per acre of wetland. In wetland loss in southern Louisiana, there may be a desire to measure reduction in local commercial shrimpers' total revenue caused by wetland loss. The reduction in total revenue would be measured by multiplying the estimated reduction in shrimp harvest caused by wetland loss by the marginal value (price) of shrimp. The assumption is made that the wetland loss is so small that the aggregate supply curve for shrimp is virtually unaffected, thus leaving the price of shrimp in a store unchanged.

Accounting stance

In considering which measure is appropriate for wetlands, technical and public interest issues should be considered. One consideration is accounting stance. If the interest is in determining contributions to economic well being of the nation, i.e., National Economic Development (NED), then the change in total economic surplus is the appropriate measure (Dwyer, Kelly, and Bowes 1977; Stoll, Loomis, and Bergstrom 1987; US Water Resources Council 1979). Loss of a significant proportion of habitat for a commercial fish species could result in change in overall supply of the fish. In this case, the total change in economic surplus would be important.

If the changes in local or regional economic development are considered important to the wetland evaluation, or if there is concern over income distribution, then marginal values may be the more important measure. Total expenditures and total revenues, for example, are calculated from the marginal value of a wetland service. The loss of shrimpers' revenues stated above is such a use of marginal values. If a permit involves an incrementally small change in wetland area, the marginal value of a wetland acre, measured as the change in total expenditures or revenues, may be significant and of interest from a local or regional economic development perspective.

Further Work

The economic issues summarized here are the basis for valuation of wetlands. A literature review of studies (1970-1985) that valued wetland services has been prepared (Shabman and Batie in preparation) and updated* to identify potential wetland valuation methods that would be used by the Corps. A summary of the review of valuation methods is provided in Technical Note EEDP-06-8. Work has been initiated on guidance documentation for the valuation of wetland services. Guidance will be presented in a series of Technical Notes for the different services provided by wetlands.

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* John P. Titre and Jim E. Henderson. "Updated Literature Review of Valuation of Wetlands, 1985-Present," unpublished report, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

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Environmental Effects of Dredging Technical Notes

SUMMARY OF VALUATION METHODS FOR WETLANDS

PURPOSE: This Technical Note summarizes a review of economic valuation methods for wetlands. The summaries provided herein explain the valuation methods or process and illustrate the data requirements for valuation of wetlands.

BACKGROUND: Wetlands provide many benefits, including fish and wildlife habitat, recreation, flood control, and water quality improvement. These services provided by a wetland have economic value if there is private or public demand for the products, goods, or services. Wetlands have been valued for a variety of wetland services including such things as flood control or water supply benefits, or the value of a wetland for shellfish production or for wetland recreation. A review of wetland valuation studies was undertaken to identify valuation methods that could be used for Corps Planning or Operations activities. This Technical Note summarizes the existing methods for valuation of wetland services, based on a literature review (Shabman and Batie in preparation) and an updated literature search.* The existing valuation methods form the basis for developing guidance for valuation of wetlands to support the Wetland Evaluation Technique (WET) (Adamus et al. 1987), or other wetland assessment effort.

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Introduction

Evaluation of wetlands and wetland alteration projects has focused on the ecological and biological functions of wetland systems. Consideration of economic values in wetland projects has been limited due to lack of understanding of how and when to include economic considerations. A framework for determining

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* J. P. Titre and J. E. Henderson, "Updated Literature Review of Valuation of Wetlands, 1985-Present," US Army Engineer Waterways Experiment Station, Vicksburg, MS.

wetland economic values was developed by Shabman and Batie (in preparation), and summarized in Technical Note EEDP-06-7.

A literature review of wetland valuation studies revealed that few efforts have been made to determine the total economic value of a wetland. Rather, the value of specific goods or services, e.g., recreation, has been the focus. This Technical Note presents the summaries of wetland valuation studies, organized by the services that are valued. Technical Note EEDP-06-7 related these services to the wetland functions and values assessed in WET.

Water Quality

Wetlands improve water quality through sediment/toxicant retention and nutrient removal/transformation. These functions provide cleaner water for downstream areas, and in some areas, wastewater treatment. For the economic benefits of downstream water quality, data are currently being collected to quantify sediment and nutrient transformation activity in bottomland hardwoods in the southeast; little other quantitative data exists. For wastewater treatment, it is possible to calculate costs of treatment by alternative methods.

Valuation of wetland water quality benefits requires identifying the costs of substitutes for the water quality services. The value of the water quality service could be determined by the costs of chemical or other treatment to provide the same level of water quality. For sediment retention, the costs of retention dams or other structures could be used to value the sediment retention services. More quantitative data on wetland sediment and nutrient functions will allow these types of valuations.

The value of a wetland for wastewater treatment is the difference between the costs of using the wetland for treatment and the costs of using the least-cost alternative (Shabman and Batie in preparation). Use of wetlands for wastewater treatment is regulated by states to ensure that the type, nature, and functions of the wetland area are protected (Florida Administrative Code 17-6). The costs for wastewater treatment thus include the long-term monitoring program to ensure compliance with water quality and fish and wildlife standards during operational phases (Schwartz n.d.).

Flood Control

Wetlands store flood waters from upstream runoff. Alterations of a wetland will cause a change in flood-control capacity due to diminished flood storage capacity. Similarly, coastal wetlands provide protection from storm surges. For water resources project evaluation, the annualized value of damages prevented is used to evaluate projects (US Water Resources Council 1983). Thus, the valuation of flood-control services requires determining the flood-control or surge protection capacity of the wetland and determining a value for the flood losses if the capacity is lost. An understanding of the wetland hydrologic budget, i.e., retention capacity, is required to estimate flood damages. For coastal wetlands, valuation requires determining the value of losses that would occur without the storm surges.

A 1971 study of the Charles River Basin in Massachusetts established a value of expected annual damages of $647,000 based on a 30-percent reduction in natural wetland storage, using existing trends in wetland loss (Shabman and Batie in preparation). The value was revised upward in 1976 to $2,022,000. Calculation of total flood-control value involves summing damages caused by floods of different probabilities. The expected annual damages is calculated as the total flood-control value divided by the number of years of project life. These values must be compared to the least-cost alternative.

Several Districts have valued wetland storm surge protection as a part of coastal marsh loss projects. These studies are currently undergoing review.

Water Supply

The groundwater recharge and discharge functions of wetlands provide a potential source of water supply. For valuation, there must be an understanding of the capacity for sustainable yield by the aquifer for water supply. Wetlands have not been extensively used for water supply as evidenced in the literature, likely due to the uncertain relationship between wetlands and aquifer capacity.

The value of a wetland water supply is the lesser of (1) the value of the wetland water supply services to the consumer (if no alternative supply exists), or (2) the difference in costs between the development of the wetland supply and the development costs of an alternative source. To determine the difference in costs between the wetland and an alternative entails determining the costs of providing the water supply from other sources, and then comparing these costs to the wetland source. Gupta and Foster (1975) valued a wetland water supply in Massachusetts (in 1972 dollars). A difference of 7.13 cents per 1,000 gallons was attributed to the wetland water supply.

Recreation

The measure of value for consumptive outdoor recreation used by Federal agencies is the willingness-to-pay (WTP) for recreation. WTP for recreation is the sum of two components: any entrance fee and user costs including all associated travel costs plus any excess amount the recreationist is willing to pay above the user fee and charges. This amount that the recreationist is willing to pay but does not have to pay is the consumer's surplus (Vincent, Moser, and Hansen 1986). There are three accepted methods for determining WTP: (1) Travel Cost Method, (2) Contingent Valuation Method, and (3) Unit Day Values (US Water Resources Council 1983). Use of one method over another is determined by the attributes of the wetland and its recreation use.

Travel Cost Method

The Travel Cost Method uses the costs of travel and the value of travel time as a proxy for WTP. This method assumes that recreationists react to increases in travel expenditures as they do to increases in admission fees. Distance or travel time acts as a barrier for different users. The method is limited because trips with multi-destinations cannot be measured, it does not measure consumer surplus directly, and it cannot evaluate specific components of a wetland recreation experience, such as fishing (Vincent, Moser, and Hansen 1986).

Costanza and Farber (1985) used a Travel Cost analysis to estimate WTP for wetland recreation in Terrebonne Parish, Louisiana. Four distinct rings of travel distances for recreationists to the parish were established, with an estimated annual WTP of $2,153,000 (1985 dollars).

Contingent Valuation Method

The Contingent Valuation Method establishes WTP by developing a hypothetical market for recreation. In this hypothetical market, recreationists respond to changes in price and availability of resources. Contingent valuation assumes the consumer can assign an accurate WTP value to their recreation experience and this valuation can be directly elicited in response to questionnaires. A respondent is asked if they would be willing to pay a stated amount for recreation. Several alternative bidding procedures may be used to estimate maximum WTP. Titre et al. (1988) used a Contingent Valuation analysis for valuing wetland recreation in seven parishes in south Louisiana. This study estimated a WTP value of between $327 and $360 per recreation user per year.

There are several limitations to the use of this method. Because the method is a stated preference approach, there is the potential for the responses to be biased. There is also concern whether individuals actually know their true WTP (Vincent, Moser, and Hansen 1986).

Unit Day Method

The Unit Day Method for estimating WTP relies on expert judgments to approximate average dollar values (US Water Resources Council 1983). Specific criteria for the recreation site and use of the site are associated with ranges of dollar values for WTP. The primary concern with Unit Day values is that the method inherently relies on professional judgment and may not adequately reflect site-specific differences or user preferences.

Habitat

Wetland habitat can be valued as (1) the existence, conservation, or preservation value of the wetland ecosystem; (2) value of commercial fish and wildlife; and (3) nonconsumptive recreation uses, such as sightseeing or bird watching, which are dependent on wetland habitat. The approaches to habitat valuation have been (1) costs to replace wetland habitat and (2) WTP for consumptive and nonconsumptive uses.

The value to society of preserving wetland habitat as an important ecosystem, or for preservation or bequest value (i.e., preserving the wetland for future generations) can be determined through a Contingent Valuation study, as described in "Recreation" above. No studies to date have attempted to determine the existence or conservation value for wetlands. Preservation values have been developed, however, for preservation of wilderness areas, using the Contingent Valuation Method (Walsh, Loomis, and Gillman 1984).

Valuation of wetland habitat for particular species requires establishing the productivity of habitat for those species. In a study of Michigan wetlands, Tilton, Kadlec, and Schwegler (1978) estimated the value of wetlands for pike production. The analysis assumed that an acre of wetland can produce 1,800 pike per year. The value of the natural habitat was evaluated as the cost of purchasing a wetland and upgrading it to produce 1,800 pike a year, or constructing a wetland. This approach was also used to value replacement of a waterfowl area. The study did not document the basis for the productivity figure, and did not include the value of other services, e.g., wildlife habitat, that may also be provided by the wetland.

The ability to link WTP for sport fishing or hunting with potential productivity of wetlands requires linking of WTP information, as described in "Recreation," with habitat assessment models for particular species. The Human Use and Economic Evaluation (HUEE) portion of the Fish and Wildlife Habitat Evaluation Procedures (HEP) provides such a method (US Fish and Wildlife Service 1985). HUEE requires a substantial amount of information to use HEP results to produce economic values. The Habitat Units (HU), the units produced by HEP, must be converted to the number of User Days the HUs could support. There may be little factual or technical basis on which to make this conversion. The value for WTP for a User Day is determined through a Travel Cost or Contingent Valuation Method (see "Recreation"). The User Day values are multiplied by the number of Sustained Use Days to determine total value. There has been limited application of the HUEE analysis, likely due to the extensive data requirements.

The value of habitat for nonconsumptive recreation uses, such as sightseeing and birdwatching, may be determined through Unit Day Values, Travel Cost Method, or through Contingent Valuation Methods (see "Recreation").

Commercial Harvest of Fish and Game

For wetland species that are harvested commercially, there is information on market price, costs of production, and some information on productivity of wetland areas. This information can be used to determine a value per acre for fish and game production. The linkage between wetland habitat and the production of fish and game is difficult to establish because there are so many variable production factors. The relationship of acreage of habitat and other factors of production, to the amount (pounds) of catch or harvest is known as the production function. Because of the complexity of fish and game production, some valuation methods assume a direct relationship between habitat and productivity, i.e., that all acres are of equal productivity. This is likely not the case.

Commercial fishery production

Valuation of wetlands for production of fish, shrimp, oysters, and other species requires developing a relationship between the catch of fish and the habitat, labor, and other production factors required to catch the fish. Of the valuation methods examined, the Marginal Value Product (MVP) method considers more of the production factors associated with the fishery than the other methods, which will only be summarized. However, the method is highly data intensive.

MVP method. The MVP method provides an average value for an acre of wetland habitat by determining the change in total revenue associated with a change in acreage. Marginal products are the change of catch as related to a change in production factors, e.g., habitat (Lynne, Conroy, and Prochaska 1981). The marginal products are normally expressed as change in catch as related to either change in harvest effort, e.g., man-days or numbers of traps, or to a change in habitat acreage. Marginal products expressed as change in habitat acres are of greatest interest. The MVP values, that is, the dollar value per acre, are calculated by multiplying the marginal product by the price per pound of the fish or shellfish.

The MVP method has been used to value oyster production in Virginia (Batie and Wilson 1978) and blue crab production in Florida (Lynne, Conroy, and Prochaska 1981). These studies developed values per acre for production of the species through development of a regression equation for the production function. Data used in the regression analyses covered a large coastal area.

For oyster production, the production function used level of effort, number of acres available for oyster harvest, actual number of acres leased for harvest, and salinity (Batie and Wilson 1978). For each of the coastal counties in Virginia, a marginal product was calculated by using the production function, and using the salinity and other variables for that particular county. The marginal product for each county was multiplied by the dockside price per pound of oysters to give the MVP for each county. For the 17 counties considered, the MVP ranged from $1.13 to $141.46 per acre. The range in MVP for the counties is accounted for by variations in the quantity of wetland, amount of effort required, salinity of the waters, and other variables in the production regression equation.

In the study of blue crab fishery on the Florida Gulf Coast, the catch changed in relation to the number of acres and to the level of effort, i.e., the number of traps (Lynne, Conroy, and Prochaska 1981). For the mean level of effort of 33,000 traps for the entire coast, the yield was 2.3 lb of blue crab per acre. Using the dockside value of $0.25 to $0.30 per pound, the total present value of a wetland acre was estimated at $3.00 for blue crab production.

Other methods for fishery valuation. Several other methods have been used or suggested for valuation of commercial fishery habitat, each with its own limitations. The expenditure method imputes the value of wetland habitat to be the expenditures for the fish harvested (Waters 1986). The value of the wetland for commercial fishery habitat is then the expenditures for harvesting and processing the product; the method ignores the amount the consumer would have been willing to pay above the market price (consumer's surplus) (Waters 1986). The residual return method places the value of the habitat as that value that remains, i.e., the residual value, after all other factors of production are subtracted (Batie and Shabman 1982). The residual return method requires a more quantitative understanding of the fishery production function and supply and demand for the fish than is usually possible.

Commercial game habitat

Less work has been done on valuation of commercial production of furbearers in wetlands. Existing work has used the average productivity of wetlands and existing pelt and carcass prices to value the wetland for furbearer production. The value of muskrats and raccoons for the coastal wetlands of Michigan was calculated by Jaworski and Raphael (1978). This was accomplished by considering the productivity of the wetland for the species (animals per acre), availability of requisite habitat in the wetland, and the market value of the carcass or pelt. Work by the Michigan Department of Natural Resources and other sources provided estimates of the productivity or densities of animals for each of the wetland types. From wetland mapping, the number of habitat acres for each county was determined. Carcass and pelt values reported from the previous year were used to calculate the total value for the furbearers.

Residential Land Development

Development of wetland areas for residential or commercial lots is often highly desirable because of the locational, e.g., on the water, and scenic amenities of such lots. Development and sale of wetland lots for residential use occurs within a functioning land market that affects the value of the residential lot. Valuation of wetland lots has been accomplished through two valuation approaches: (1) Hedonic Price Approach and (2) Land Market Analysis.

Hedonic Price Approach

The Hedonic Price Approach uses regression analysis to determine the value of wetland development based on characteristics of the wetland. A regression model is developed that relates the price of the lot to the wetland characteristics of the site, based on land transfer records of similar sites. Proposed developments are valued by identifying case study areas of a similar developed wetland area, developing a regression model for the case study area and then using the lot characteristics of the proposed development in the model to determine the value of the proposed development (Shabman and Bartelson 1979, Abdalla and Libby 1981).

A study by Batie and Mabbs-Zeno (1985) developed a model for the price of wetland sites in a large development in Virginia. The regression equation expressed land price as a function of waterfront or canal location, size of lot, and other amenities. Examination of the regression results showed a number of things. The market value of lots is dependent on where they are located, e.g., canal or open water, lot size, and the amenities that are available, e.g., sewer. Consumers were willing to pay $0.157 for each square foot of lot, $882 for access to a sewer, and would pay $4,108 for a lot on a canal but $7,410 for a lot on open water. Lots located adjacent to a wetland are valued at $1,120 less than lots not adjacent to wetlands. As with any regression analysis, some interpretation is required. It is uncertain whether the $1,120 lower value means that wetland location is a disamenity or that the lower value reflects reduced development costs over a fastland development, or perhaps there is some other explanation. This regression analysis could have been used as a case study for valuation of potential developments in the area, though this was not the intent of the study.

Land Market Analysis

Land Market Analysis determines the value of the development based on the change in land rents from the development. (Land rents are the revenues generated from the developed property minus labor and other costs of development (Randall 1987)). That is, the wetland development is viewed as a part of the supply of future developed lands in the market. Luken (1976) used Land Market Analysis to determine development values for San Francisco Bay wetlands.

Using a regional analysis, it was estimated that 4 square miles of wetlands would be required for development because there were no fastland, nonwetland alternatives. Luken used changes in aggregate land rents across all land parcels, e.g., commercial or residential, in the region to represent the value of development to 1990 (the end point in Luken's analysis). Land rent values in the region with and without the different levels of wetland development were compared.

Agricultural Development

The incentive to drain wetlands to plant agricultural crops has resulted in much of the loss of wetlands in rural areas (Leitch and Grosz 1988). Until recently, there were no economic incentives for wetland preservation on farms. In 1985, Congress passed the Food Security Act of 1985 including its Swampbuster Provisions. The Act established government target prices for crops and the Swampbuster Provisions made farmers ineligible for government target prices if crops are grown on converted wetlands (Baltezore, Leitch, and Nelson 1987).

The economic value of wetlands for agricultural development is the change in the farmer's economic surplus, i.e., return to the farmer, that results from wetland conversion. Determining a farmer's economic return from wetland conversion can become complicated. Because the farmer will try to maximize net revenues from farming, the decision on whether to drain wetlands must account for the Swampbuster Provisions, the profitability of different crops given the market for the respective crops and government target prices, and the availability of suitable lands to be rented, as substitutes for wetland conversion.

A straightforward way to determine a farmer's economic surplus is suggested by Shabman and Batie (in preparation). Basically they argue that farm budgets can be used to calculate a farmer's net income, i.e., economic surplus, with and without wetland conversion. Prices received for output times production on the developed wetland would be used to calculate gross income. Costs of production on the wetland, including development costs and farm production costs, would be subtracted from gross income to calculate returns to the farmer. The prices and costs used for these calculations must be adjusted for effects from government policies such as the Swampbuster Provisions, agricultural price supports, and other market conditions. The gain in net income from conversion would measure the benefits for farmers of wetland development and, in turn, the cost to farmers of preventing them from converting wetlands.

Baltezore, Leitch, and Nelson (1987) evaluated the profitability of draining for farm lands in North Dakota using linear programming to optimize net return to the farmer. The conclusion for the drain/no drain decisions is that each wetland drainage decision must be made on an individual basis. Regional and county crop productivities and prices, and variations in drainage costs make a site-specific analysis necessary.

The optimization for the North Dakota study used three price options: (1) government target prices provided under the Swampbuster Provisions, (2) historic county average prices based on the preceding five years' local grain elevator prices, and (3) current year forward contract prices, the contract prices between the farmer and grain elevator for delivery of grain in August. Short- and long-term payment of the drainage costs were also considered. The crop production mix of wheat/barley was adjusted to maximize returns. In considering the 55-acre fields, the net revenues generated under the options showed the highest return for long-run government price option ($5,417), next was the long-run historic average ($4,787), followed by the no drainage government target ($4,290) (1986 dollars).

Summary

The economic value of various wetland services can be determined, as indicated by the discussion of the valuation studies. Use of these valuation methods is limited by the data and other resources required for use of the methods and by the limited quantitative understanding of wetland processes. As wetland functions are better modelled and quantified, then economic valuation will become easier.

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Environmental Effects of Dredging Technical Notes

PREDICTING AND MONITORING DREDGE-INDUCED DISSOLVED OXYGEN REDUCTION

PURPOSE: This note summarizes the results of research into the potential for dissolved oxygen (DO) reduction associated with dredging operations. Efforts toward development of a simple computational model for predicting the degree of dredge-induced DO reduction are described along with results of a monitoring program around a bucket dredge operation.

BACKGROUND: The biological impact of dredge-induced DO reduction is sometimes cited as a concern by resource management agencies, as was the case with fishery resource managers presented with a proposal to dredge the Haverstraw Bay portion of the Hudson River Estuary from August through October 1987. Haverstraw Bay is a shallow (2.5 to 3.0 m), wide (5 km) reach of the Hudson River and is an important nursery area for several species of anadromous fishes, including striped bass, *Morone saxatilis*, the juveniles of which congregate in the shoals during late summer-early fall. The New York District and the US Army Engineer Waterways Experiment Station responded to the concern by constructing and applying two simple computational models for predicting the effect of a dredging operation on DO concentrations. A monitoring study was designed and conducted to measure actual dredge-induced DO reduction in Haverstraw Bay and compare these values to those predicted by the models (Lunz, LaSalle, and Houston 1988). A description and comparison of the models and the results of the monitoring program are the subjects of this note.

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Introduction

Previous information on direct measurements of dredge-induced reduction in dissolved oxygen (DO) is limited to three studies: a bucket dredging project in a highly industrialized channel in New York (Brown and Clark 1968), a cutter-head dredge operation in Grays Harbor, WA (Smith et al. 1976), and a hopper dredging project in a tidal slough in Oregon (US Army Engineer District, Portland 1982). Dredge-induced oxygen depletion in the 10-m-deep New York channel ranged from 16 to 83 percent in the mid to upper water column and up to 100 percent in near-bottom layers during placement under conditions involving poor tidal flushing, heavy industrial pollution, and generally low ambient DO levels. Periodic reduction of bottom water DO (up to 2.9 mg/ℓ) was observed in Grays Harbor. Dredge-induced DO reduction (1.5 to 3.5 mg/ℓ) at the 10-m-deep Oregon site (background levels ranging between 3.6 and 6.6 mg/ℓ) was limited to slack-water conditions in the bottom one-third of the water column lasting until tidal flow resumed (within 2 hr). DO levels increased above ambient (by 2.0 mg/ℓ) during dredging under flood tide conditions.

The effect of dredging on DO was studied through modeling designed to estimate DO reduction based on site-specific sediment characteristics (Lunz, LaSalle, and Houston 1988) along with a monitoring program to measure near-field (within 400 m) and far-field (bay-wide) DO conditions around an operating bucket (Houston, LaSalle, and Lunz in preparation). The models described here represent a series of attempts at understanding the cause-and-effect relationships between sediment characteristics and DO depletion.

Basis for the Models

The approach toward modeling dredge-induced DO reduction assumed that reduction was related to the oxygen demand of the sediment being dredged, concentration of sediment suspended by the dredge, and time period that a parcel of water would be exposed to the suspended sediment field around the dredge. Information about the levels of suspended sediments known to occur around operating dredges is readily available (Hayes, Raymond, and McLellan 1984, Hayes 1986, and Havis 1988). The differences between models, therefore, involved different approaches toward estimating oxygen demand of the sediment and the timespan over which these reactions occur.

An initial effort at developing a model of DO reduction (Lunz and LaSalle 1986) used varying estimates of suspended sediment concentrations (100 to 500 mg/ℓ) and estimates of low, moderate, and high benthic oxygen demand (5, 20, and 150 $\mu\ell$ DO/g sediment dry weight) applied to a hypothetical closed cylinder of water for 1 hr. This model predicted minimal depletion, ranging from 0.01 to 0.11 mg/ℓ. The more recent modeling efforts in Haverstraw Bay

(Lunz, LaSalle, and Houston 1988) reflected more refined views of the relationships between sediment compounds and oxygen demand and the timespan over which these reactions occur. Specifically, estimates of oxygen demand were based on site-specific measurements of selected sediment compounds. Estimates of the suspended sediment concentrations in the dredge plume were taken from a study of a bucket dredge operation reported in Bohlen, Cundy, and Tramontano (1979).

Model A used oxygen demand (OD) rates estimated from existing data on the relationship between benthic oxygen demand (4-day BOD) and volatile solids (VS) concentrations reported for the Connecticut River (Issac 1965) to generate a regression equation that predicted OD. Choice of OD as a function of VS was based on a body of literature relating benthic oxygen demand and VS concentrations (see review in Lunz and LaSalle 1986). The use of BOD estimates, however, assumed that OD was a function of both chemical and biological processes acting over a period of days (in this case, 4 days). Volatile solids concentration was estimated from measurements of actual total organic carbon (TOC) in Haverstraw Bay sediments, assuming 100 percent volatilization. DO reduction was assumed to occur over days, reflecting the passage of a parcel of water through a circular dredge plume with varying suspended sediment concentrations with distance from the dredge. The form of the equation was:

$$\underset{(\text{mg DO}/\ell)}{\text{Oxygen Reduction}} = \underset{(\text{mg sed}/\ell)}{\text{Sediment Conc.}} \times \underset{(\text{mg TOC/mg sed})}{\text{Total Organic Carbon Conc.}} \times \underset{(\text{mg DO/mg VS /4 days})}{\text{Oxygen Demand}} \times \underset{(\text{days})}{\text{Residence Time}}$$

With a mean VS concentration of 1.1 percent, oxygen demand was estimated to be 0.008 mg DO/mg VS/4 days (estimated from the equation, 4-day-BOD (mg DO/mg VS) = 7.2 VS, calculated through the origin and based on data in Issac 1965). Residence time of a parcel of water within the dredge plume (2 days) was calculated using data on flow rate (11.3×10^6 m^3/day) and cross-sectional area of the bay (76,992 m). DO reduction was calculated within each of three subportions of a hypothetical circular dredge plume (radii of 100, 1,000, and 1,500 ft), within which suspended sediment concentrations were set at 400, 200, and 100 mg/ℓ, respectively (Bohlen, Cundy, and Tramontano 1979). Application of these parameters led to a predicted DO depletion of less than 0.1 mg/ℓ over a 4-day period (a liberal estimate of residence time). Actual estimates of 4-day BOD for site-specific sediment samples, however, gave a mean value for OD of 0.10 mg DO/mg

TOC/4 days (n = 3), leading to a total 4-day estimate across the plume of 0.8 mg DO/ℓ.

Model B assumed that OD of the sediment being resuspended is largely an immediate, short-term phenomenon (analogous to immediate dissolved oxygen demand or IDOD), attributable to the chemical reactions of the most frequently encountered, readily oxidizable, chemical compounds (i.e., ferrous iron and free sulfides) found in most marine and estuarine sediments. The model assumed that the chemical reactions are rapid (on the order of minutes) and that all of the available compounds become fully oxidized upon suspension in the water column, thereby eliminating the need to consider duration of suspension. Dissolved oxygen reduction was estimated as the amount of DO needed to fully oxidize the material suspended by using stochiometric equivalents for oxidative reaction of these materials at site-specific concentrations. The form of the equation was:

$$\begin{aligned}\underset{(\text{mg DO}/\ell)}{\text{Oxygen Reduction}} = {} & \left[\underset{(\text{mg sed}/\ell)}{\text{Sediment Conc.}} \times \underset{(\text{mg Fe/mg sed})}{\text{Iron Conc.}} \times \underset{(\text{mg DO}/2.327\text{ mg Fe})}{\text{Stochiometric Equivalent of Fe}}\right] + \\ & \left[\underset{(\text{mg sed}/\ell)}{\text{Sediment Conc.}} \times \underset{(\text{mg S/mg sed})}{\text{Sulfide Conc.}} \times \underset{(\text{mg DO}/0.501\text{ mg S})}{\text{Stochiometric Equivalent of S}}\right]\end{aligned}$$

Using mean values of ferrous iron (274.2 ng/mg sediment, n = 11) and free sulfides (1,582.6 ng/mg sediment, n = 11) for Haverstraw Bay sediments, the model predicted DO reductions of 0.3, 0.6, and 1.6 mg/ℓ at suspended sediment concentrations of 100, 200, and 500 mg/ℓ, respectively.

Monitoring Protocol

DO, temperature, and optical turbidity (surface, middepth, and near-bottom) were measured daily in the immediate vicinity (near-field) of the dredge (within 400 m) and weekly across the bay (far-field). Daily monitoring was conducted during periods of lowest expected DO concentrations (sunrise and next slack tide). Measurements were taken at four equidistant stations around the dredge, located 300 ft (91 m) upstream, downstream, and to either side. Two additional stations were located 600 ft (183 m) and 1,200 ft (366 m) downstream from the dredge. A reference station was located outside the dredging area (near the upstream extent of the existing navigation channel). Whether the dredge was operating at the time of each collection was noted, allowing for comparison of dredging and nondredging periods. Weekly monitoring was conducted at 16 stations positioned along three cross-bay transects (Figure 1) and included pre-dredging (3 weeks), dredging (5 weeks), and post-dredging (2 weeks) periods.

Data on the daily deviation of DO concentrations (relative to the reference site) for the most frequently observed worst-case combination of time-of-day and tidal condition (sunrise/ebbing) are summarized in Table 1. For comparative purposes, stations are arranged in order of greatest to lowest theoretical effect on DO reduction based on proximity to the dredge. Observations were recorded for both dredging and nondredging periods.

No statistical differences (Mann-Whitney test, alpha = 0.05) were detected between dredging and nondredging periods for any station or depth of collection. Considerable variation in DO concentration was observed for non-dredging periods

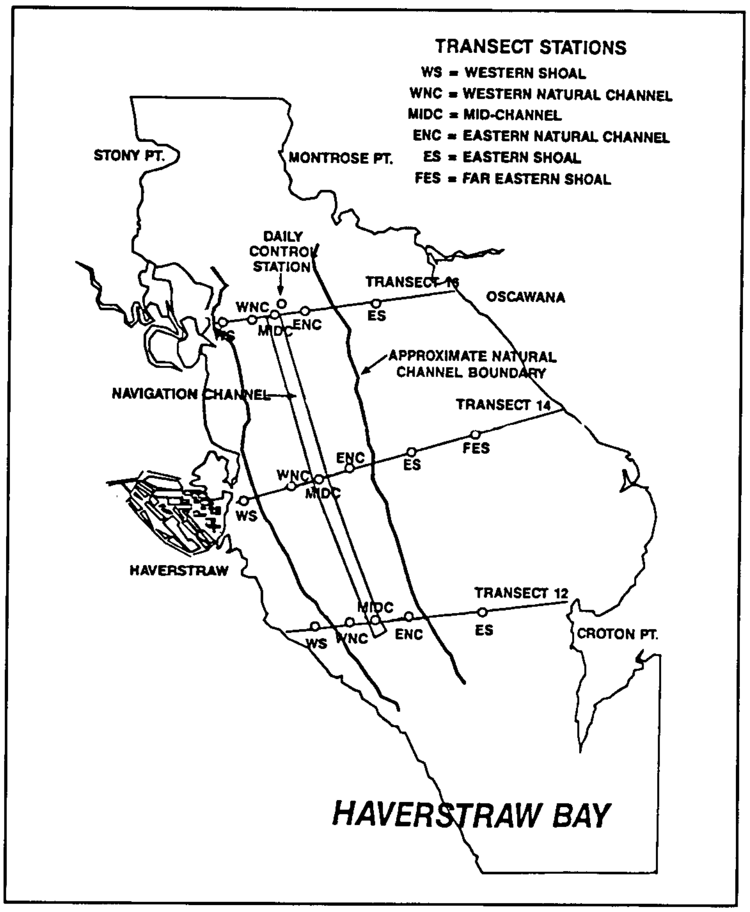

Figure 1. Weekly monitoring transect and station locations in the Haverstraw Bay portion of the Hudson River, New York

Table 1

Mean Deviation in DO Concentration (mg/ℓ), Relative to Reference at Six Locations around a Bucket Dredge during (n = 4) and without Dredging (n = 16) and the Difference Between Dredging and Nondredging

Depth	Operational Status	91 m Down	91 m Lateral	91 m Lateral	91 m Up	183 m Down	366 m Down
Surface	Dredging	-0.08	-0.13	-0.03	-0.20	0.00	-0.13
	Nondredging	-0.18	-0.16	-0.13	-0.10	-0.16	-0.15
	Difference	+0.10	+0.03	+0.10	-0.10	+0.16	+0.02
Middepth	Dredging	-0.10	-0.15	-0.10	-0.23	-0.05	-0.05
	Nondredging	-0.20	-0.14	-0.04	-0.12	-0.11	-0.14
	Difference	+0.10	-0.01	-0.06	-0.11	+0.06	+0.09
Bottom	Dredging	-0.23	-0.13	-0.15	-0.15	-0.10	-0.08
	Nondredging	-0.12*	-0.08	-0.02	-0.03**	-0.04	+0.01
	Difference	-0.11	-0.05	-0.13	-0.12	-0.06	-0.07

Note: Values are for observations made at sunrise, under ebbing tide conditions (from Lunz, LaSalle, and Houston 1988).
* n = 15.

ranging from +0.7 to -0.9 mg/ℓ for surface, +0.3 to -0.8 mg/ℓ for middepth, and +0.3 to -0.6 mg/ℓ for bottom measurements. Reference station variability was often greater than that observed near the dredge. Variation in DO during dredging ranged from +0.4 to -0.6 mg/ℓ for surface, +0.2 to -0.5 mg/ℓ for middepth, and +0.2 to -0.6 mg/ℓ for bottom measurements. Although mean deviations between dredging and nondredging were not significant, the 91 m upstream and downstream stations appeared to be most affected by the dredge. Maximum deviations in DO concentrations, however, were generally less than 0.20 mg/ℓ. Associated data on optical turbidity near the dredge showed levels generally at or below 10 NTU's (equivalent in this system to about 26 mg/ℓ) in the surface and middepth levels to as high as 40 NTU's (equivalent to about 140 mg/ℓ) in bottom waters.

Weekly data on DO and temperature from transect collections were used to calculate percent saturation values which allowed for comparisons of predredging, dredging, and postdredging periods (Table 2). Only near-bottom stations were analyzed (most likely to be affected). Percent saturation was above 70 percent

Table 2

Mean Values (Standard Deviation) of Percent Dissolved Oxygen Saturation at Weekly Transect Stations for Predredging (3 weeks), Dredging (5 weeks), and Postdredging (2 weeks) Periods and the Maximum Difference Between Dredging and Pre- or Postdredging Periods

Transect	Station	Predredging	Dredging	Postdredging	Difference
16	WS*	86.0a** (4.8)	76.1b (4.1)	85.9a (0.4)	9.9
	WNC*	80.2ab (1.3)	74.1a (4.6)	83.7b (3.3)	9.6
	MIDC	77.9 (1.5)	74.2 (7.3)	85.2 (5.3)	11.0
	ENC*	79.9ab (1.3)	73.8a (5.9)	85.2b (2.6)	11.4
	ES	87.8 (9.9)	77.3 (5.7)	83.3 (6.6)	10.5
14	WS	82.8 (2.0)	74.8 (5.8)	82.9 (2.3)	8.1
	WNC	78.6 (7.8)	74.2 (4.8)	81.6 (1.1)	7.4
	MIDC	76.0 (6.9)	73.5 (6.7)	81.1 (0.4)	7.6
	ENC	82.7 (2.8)	73.3 (7.6)	81.2 (1.7)	9.4
	ES	82.3 (1.1)	77.7 (7.2)	86.9 (0.3)	9.2
	FES	104.9 (28.9)	78.4 (8.3)	86.1 (2.2)	26.5
12	WS*	93.4a (13.6)	72.8b (10.1)	83.8ab (0.8)	20.6
	WNC	84.3 (4.2)	72.1 (7.8)	80.6 (2.5)	12.2
	MIDC	75.9 (9.8)	73.3 (8.5)	76.8 (8.1)	3.5
	ENC	84.0 (1.6)	72.6 (7.3)	71.8 (16.6)	11.4
	ES	92.5 (9.7)	81.3 (6.1)	73.2 (14.8)	11.2

Note: WS = western shoal, WNC = western natural channel, MIDC = midchannel, ENC = eastern natural channel, ES = eastern shoal, and FES = far eastern shoal.

* Significant Kruskal-Wallis test, H(0.05,5,3,2) = 5.25.

** a,b--means with no letters in common are significantly different (nonparametric Tukey test, Q(0.05,3) = 2.394).

during dredging and 80 percent during both pre- and post-dredging periods with an overall trend of lower saturation during the dredging period (by 3.5 to 26.5 percent). Significantly lower values, however, were detected for only 4 of the 16 stations. The average maximum difference between dredging and either pre- or postdredging periods was 11.4 percent, which, within the range of temperature occurring during the dredging period (13° to 28° C), would equate to a reduction in DO of from 0.9 to 1.1 mg/ℓ. DO levels remained above 6.0 mg/ℓ throughout the study period, and considerable variation in DO and percent saturation was observed at most stations during each sampling period.

There was a concomitant increase in turbidity during the dredging and post-dredging periods (Table 3), ranging from 3.9 to 13.5 NTU. Significant differences were detected for 7 of 16 stations. In contrast to percent saturation of DO, turbidity levels remained elevated after dredging ceased.

Conclusions

The underlying differences between these models of DO reduction involve the timeframe over which DO reduction takes place and the associated substrates and chemical/biological processes which would act within that time-frame. For Model A, DO reduction is based on the action of biological agents acting on volatile solids over the course of days. On the other hand, Model B is based on the immediate oxygen demand created by the rapid (within seconds or minutes) oxidation of iron and sulfides which ends once all the material is oxidized and the suspended sediment moves away or settles. The second model's approach reflects a more realistic scenario of actual processes around an operating dredge where anoxic sediments (and associated reduced compounds) remain in suspension for only a short period of time. If, however, fine organic materials remain in suspension for a period of days, as suggested from monitoring of bay-wide turbidity (Table 3), Model A may explain longer term conditions (days).

Near-field DO conditions measured around a dredge (Table 1) are within the range predicted by Model B at the levels of turbidity measured (10 to 40 NTU = 26 to 140 mg/ℓ sediment). At these suspended sediment levels, Model B would predict DO depletion of from 0.1 (26 mg/ℓ) to 0.5 mg/ℓ (140 mg/ℓ). Actually, DO depletion ranged from 0 to 1.0 mg/ℓ with a number of measurements showing greater DO (up to 0.3 mg/ℓ). Mixing, not accounted for in the model, may have acted to

Table 3

Mean Values (Standard Deviation) of Optical Turbidity (NTU) at Weekly Transect Stations for Predredging (3 weeks), Dredging (5 weeks), and Postdredging (2 weeks) Periods

Transect	Station	Predredging	Dredging	Postdredging	Difference
16	WS*	4.5a** (4.5)	9.5ab (9.5)	12.5b (0.7)	8.0
	WNC*	4.7a (2.4)	9.8ab (1.8)	15.3b (0.4)	10.6
	MIDC*	5.8a (1.6)	9.9b (2.5)	14.0b (7.1)	8.2
	ENC	5.6 (2.9)	8.6 (8.6)	16.5 (10.7)	10.9
	ES	3.8 (1.5)	8.7 (3.5)	8.3 (0.4)	4.5
14	WS*	4.5a (1.6)	9.0b (1.7)	9.9b (1.6)	5.4
	WNC	4.8 (3.4)	10.6 (4.7)	17.2 (12.4)	12.4
	MIDC	6.2 (3.6)	11.6 (5.4)	14.5 (4.9)	8.3
	ENC*	4.2a (1.3)	8.7ab (3.3)	13.1b (6.9)	8.9
	ES	3.6 (1.3)	7.8 (3.6)	10.5 (3.5)	6.9
	FES	4.4 (0.7)	7.2 (3.0)	8.3 (1.0)	3.9
12	WS*	3.8a (0.5)	7.0ab (2.3)	9.4b (0.9)	5.6
	WNC*	4.6a (0.5)	8.6ab (1.0)	18.1b (12.6)	13.5
	MIDC	7.0 (3.6)	10.9 (7.1)	19.0 (12.7)	12.0
	ENC	5.1 (3.0)	8.7 (3.1)	14.5 (4.9)	9.4
	ES	4.1 (2.2)	7.0 (2.7)	10.0 (1.4)	5.9

Note: WS = western shoal, WNC = western natural channel, MIDC = midchannel, ENC = eastern natural channel, ES = eastern shoal, and FES = far eastern shoal.

* Significant Kruskal-Wallis test, H(0.05,5,3,2) = 5.25.

** a,b--means with no letters in common are significantly different (nonparametric Tukey test, Q(0.05,3) = 2.394).

lower observed DO levels. Overall, near-field monitoring suggested that dredge-induced DO reduction was minimal: generally less than 0.1 mg/ℓ with maximum mean reduction of no more than 0.2 mg/ℓ (Table 1).

Results of bay-wide monitoring suggested that the dredging activity resulted in slightly elevated turbidity (mean = 8.4 NTU, Table 3) and reduced DO saturation (mean = 11.4 percent, Table 2). As previously discussed, this drop in saturation represented a drop in DO of about 1 mg/ℓ (from about 7 to 6 mg/ℓ). While saturation levels rebounded after dredging ceased, turbidity increased. Elevated turbidity levels could be a function of the resuspension of fine-grained materials from the disturbed bottom in the wake of the dredge. The activity of a bucket dredge usually results in a pocketed bottom covered with a veneer of fine materials which could be easily resuspended by tidal or river currents.

A possible explanation for the concomitant reduction in DO could involve the scenario described in Model A, if the elevated levels of suspended material were organic (likely in the case of Haverstraw Bay sediments). The BOD resulting from the suspension of these materials would last only as long as new "unoxidized" materials were supplied and would, therefore, fall off after dredging ceased. Elevated turbidity could be expected to continue for a time after dredging ceased, until the bottom stabilized.

The results of this study suggested that the model of DO depletion, based on sediment concentrations of readily oxidizable compounds (ferrous iron, free sulfides), appeared to be a good predictor of DO reduction in the near-field around a bucket dredging operation. While predicted DO reduction was slightly greater than that observed, a liberal estimate of reduction is preferable, particularly in light of the highly variable conditions which characterize estuarine systems. While the model is simplistic, in that it requires few site-specific input variables, it provides a relatively accurate estimate of DO reduction. Since the basis of this model is similar to that which describes immediate oxygen demand (IDOD), field measurements of IDOD can replace measurement of iron and sulfide concentrations.

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Environmental Effects of Dredging Technical Notes

CORPS OF ENGINEERS INITIATIVE TO DEVELOP LONG-TERM MANAGEMENT STRATEGIES FOR NAVIGATION DREDGING PROJECTS: OVERVIEW AND FRAMEWORK

PURPOSE: This note describes a major US Army Corps of Engineers (USACE) policy initiative to define an appropriate and effective framework for developing and implementing the concept of a Long-Term Management Strategy (LTMS) within the national navigation dredging program. It presents a five-phase conceptual approach or framework for developing an LTMS with emphasis on "lessons learned" and a summary of selected field experiences.

BACKGROUND: Because of the multifunctional aspects of the LTMS initiative, the USACE established an LTMS steering committee to develop a general LTMS process framework and policy guidance, select appropriate LTMS pilot demonstration projects, and prepare "lessons learned" and technology transfer procedures for nationwide use. A concept paper that outlines national criteria and steps to be taken in developing an LTMS for Federal navigation dredging projects has been developed. This LTMS process is being evaluated in a series of field demonstration pilot projects before being implemented as national policy.

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Introduction

In 1978, the USACE Dredged Material Research Program concluded that long-term dredged material management plans would not only offer greater opportunities for environmental protection at reduced project costs, but would also meet with greater public acceptance once they are adopted and implemented (Saucier et al. 1978). More recently, a number of prominent scientific and engineering groups have strongly recommended that the USACE develop the concept of an LTMS for navigation projects (Klesch 1987). Presently, the USACE is defining an appropriate and effective management process, procedures, and policy guidance for developing and implementing an LTMS within the national dredging program (Francingues and Mathis 1989).

Why LTMS?

The long-term management of dredged material depends upon the ability to find suitable dredged material relocation sites. The US Congress, Office of Technology Assessment (1987) has identified this as the largest problem facing the USACE national navigation dredging program. Many dredging projects, and in some cases, the project beneficiaries, routinely rely on cycle-to-cycle location of relocation sites. This approach often results in significant project delays, increased costs, and sometimes recurring needs to invoke emergency dredging procedures for nationally sensitive navigation projects.

Presently, interactions occur in a highly complex legal and regulatory environment. Our projects are governed by over 30 major Federal environmental statutes, executive orders and regulations, and consistency in their implementation is difficult, if not impossible in some cases, to maintain. Personnel turnover within the USACE and other regulatory and review agencies responsible for implementing these complex environmental requirements has resulted in considerable problems in the way the regulations are interpreted and applied. Unfortunately, this problem has been the norm rather than the exception in the way dredging operations have been conducted over recent years. Finally, this is an era of increasing public awareness of our projects and a public that not only desires but insists on participating in the process of selecting long-term dredged material management solutions.

National Criteria for Developing An LTMS

The following criteria have been established for Corps-wide guidance.

- The LTMS must include all foreseeable new work, operations and maintenance (O&M), and permit activities. The basic premise is that it is not in the best public interest to construct a Federal project if there are no reasonable assurances that the project can be maintained and anticipated benefits accrued over the long term.
- Wherever possible, the LTMS should be for the anticipated project life. The LTMS scope should incorporate all anticipated Federal projects as well as project beneficiaries' dredged material management needs to

ensure long-term project viabilities. For new projects, this should in all cases be for the established 50-year project economic life. For existing projects, the same 50-year horizon should also be the established target or goal, while recognizing that project-specific circumstances may, in certain projects, dictate a shorter time frame.

- The LTMS must fully address both structural and nonstructural alternatives for maintaining navigation. Every effort should also be made to seek means of reducing dredging requirements and costs for the individual navigation projects.
- Unless specifically prohibited by Federal statute, the LTMS must incorporate the full and equal consideration of all dredging and dredged material management alternatives. No one management option can be considered a panacea for dredged material, nor can it be ruled out a priori in the initial plan formulation process for reasons other than sound economic, environmental, and engineering ones.
- The LTMS must be timely, technically feasible, cost-effective, and environmentally acceptable as dictated by established Federal standards, criteria, and regulations.

LTMS Framework

The USACE has developed a consistent, logical procedure by which LTMS alternatives can be identified, evaluated, screened, and recommended so that the dredged material placement operations are conducted in a timely and cost-effective manner. The framework for LTMS development is shown in Figure 1. This framework is a five-phase approach and each phase in Figure 1 consists of steps or essential activities that lead to a certain level of decision-making before continuing on to the next phase.

Phase I - Evaluate Existing Management Options

This phase is intended to serve as the first level of assessment and decision-making. It should be undertaken for all USACE navigation projects as a sound management practice. An expanded flowchart of the steps that comprise phase I is provided as Figure 2. The initial step is to establish appropriate operational boundaries for LTMS development. This means setting limits on project analysis areas to include both the geographical extent of the boundaries and the time frame(s) within which the analysis will occur, taking into consideration both Federal and non-Federal activities (new work, operations and maintenance, and permits).

Once the LTMS study boundaries are set, the next step is to identify the dredging needs in terms of volumes, dredging frequency, and dredged material

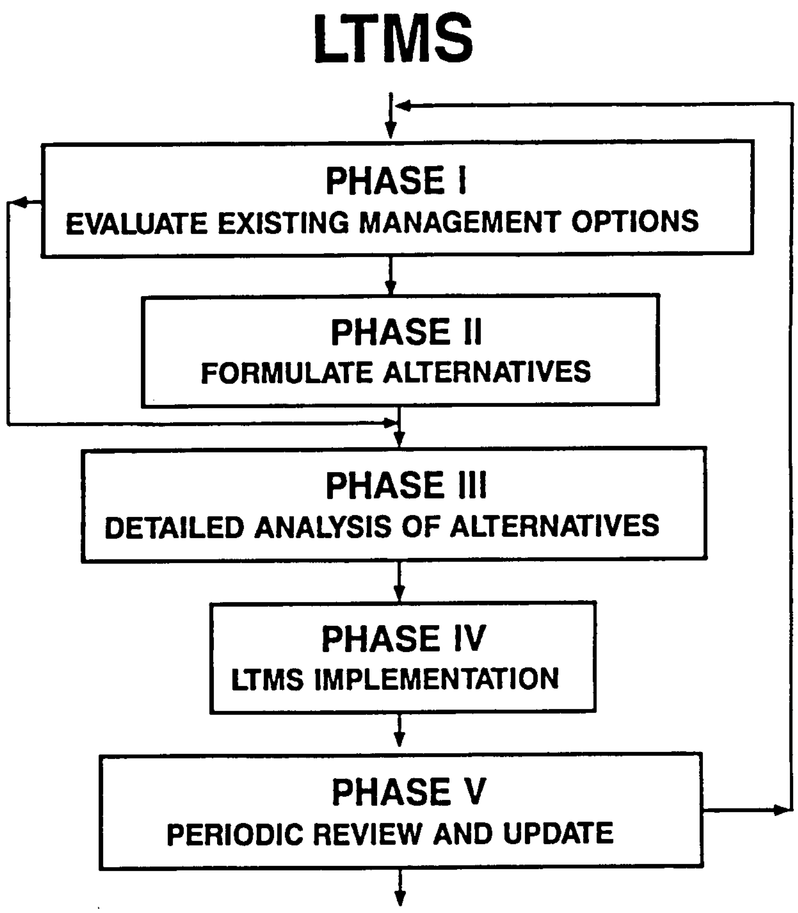

Figure 1. Phases of the LTMS process

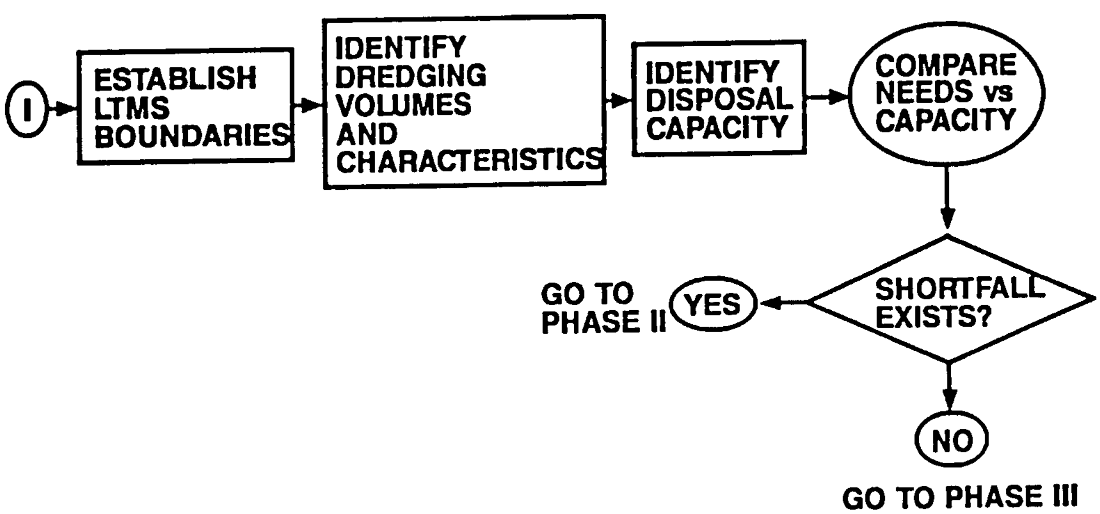

Figure 2. Phase I of the LTMS process

characteristics for the project or projects within the operational boundaries. Estimates should be made for existing and future work for both the Federal and non-Federal projects. Next, an identification and assessment of existing relocation site capacity should be made to allow for a comparison of needs versus existing capacities. A decision can be reached at this point as to whether there is a need to formulate management alternatives (Phase II) or to assess and document the long-term practicality of the existing management strategy (Phase III) prior to proceeding with implementation.

Phase II - Formulate Alternatives

The objective of Phase II is to systematically develop and retain all viable long-term management options that meet the study goals and objectives. To accomplish this, a series of steps have been identified and are presented in a flowchart (Figure 3).

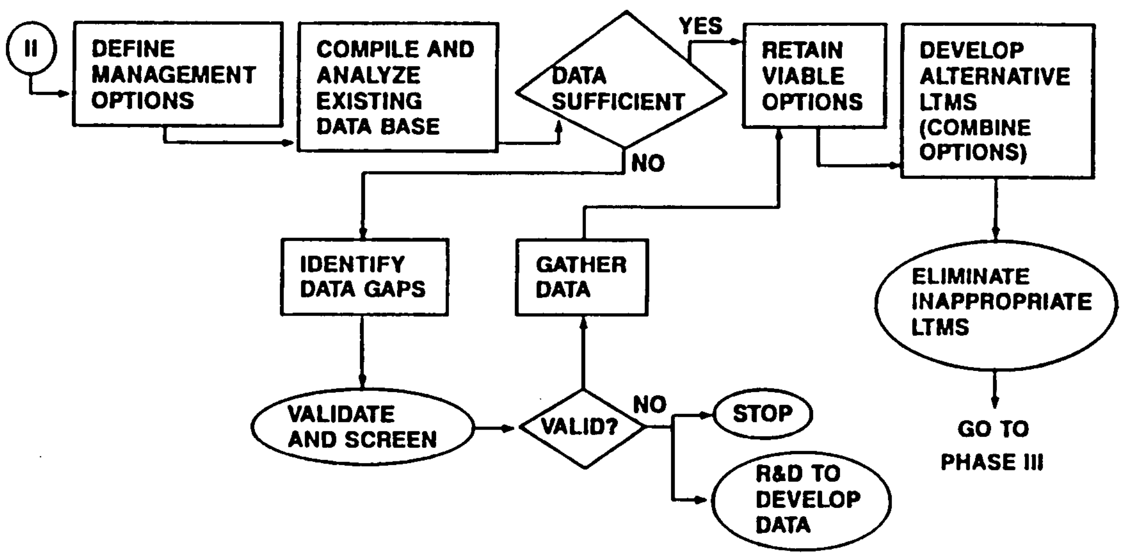

Figure 3. Phase II of the LTMS Process

Ideally, all available management options, including both structural and nonstructural alternatives, are defined consistent with the established LTMS goals and objectives. For example, a structural management option to reduce dredging volumes might include channel realignments and relocations or alternative measures such as the construction of wing dikes to reduce shoaling. An example of a nonstructural alternative could be a beneficial use such as beach nourishment or marshland creation. Equal consideration must be given to using all media (upland, wetland, intertidal, and open water).

To evaluate the feasibility of the management options, the next step is to compile and analyze existing data associated with the various management options. There is usually a wealth of information available from a variety of Federal and non-Federal sources. The intent is to minimize the need for additional data collection activities, so a decision is needed as to the sufficiency of the existing data for evaluating the suitability of the various management options. If the data are sufficient, then the next step is to retain those feasible options for further use. If the background information is not sufficient, data gaps must be identified, validated, and screened, based on various factors such as potential for development, and time and resources needed to fill the gaps. If the needs are valid, then a data collection effort must be planned. Unvalidated requirements result in either no further evaluation of the management options or in research and development. Once the validated data requirements have been met, the next step is to combine the viable management options into reasonably attainable alternatives. A next level of screening is then made to eliminate the impracticable alternatives, that is, those which are not compatible with the study objectives (e.g., providing dredged material disposal and/or reducing the dredging requirements).

Throughout Phase II, it is important to fully involve the appropriate Federal and state resource agencies and affected groups (ports, environmental organizations, and local citizens). These organizations should be included in the decision-making process. However, we should not overlook that the USACE must retain the lead responsibility for directing, developing, and implementing the LTMS process for Federal navigation projects.

Phase III - Detailed Analysis of Alternatives

This phase provides for a thorough operational analysis of existing dredged material management plans (if no shortfall is identified) and the detailed evaluation, screening, and selection of a preferred long-term dredged material management strategy if a Phase II analysis is required. As envisioned, it is a comparative assessment analysis that weighs and balances engineering, economic, and environmental factors and benefits (see Figure 4).

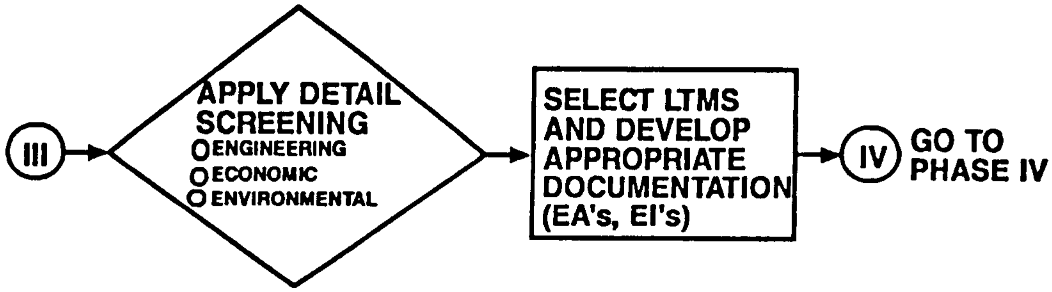

Figure 4. Phase III of the LTMS process

The purposes of Phase III are to select the most practicable strategy consisting of one or more alternatives for implementation and to provide the necessary in-house documentation needed to support this selection.

Phase IV - LTMS Implementation

The purpose of Phase IV is to develop the LTMS operations plan for implementing the selected LTMS. Consideration for this implementation plan development should include the administrative, procedural, management, and monitoring requirements (see Figure 5).

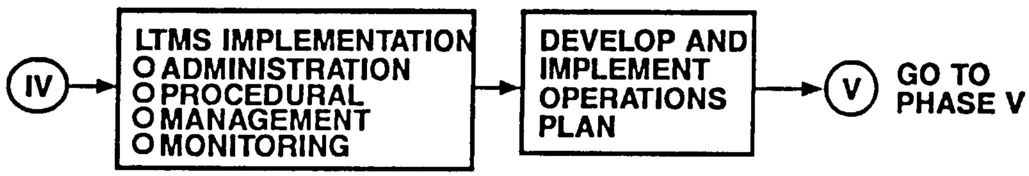

Figure 5. Phase IV of the LTMS process

Some operational considerations for implementation include:

- Environmental documentation for life of the plan.
- Long-term water quality certifications.
- Site-specific and regional permits/authorizations.
- Formalized regional mitigation strategies.
- Special Area Management Plans (e.g., regional plans with established zones favoring development versus resource protection).
- Implementation of site management requirements.

Phase V - Periodic Review and Update

The final phase in the LTMS process is a periodic reevaluation of the LTMS plan, based on changing regulations, economic and environmental conditions, and technological advances (see Figure 6).

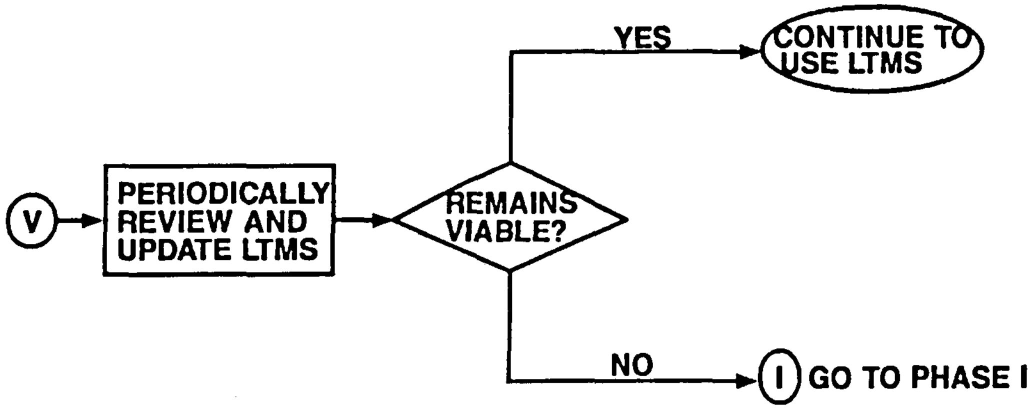

Figure 6. Phase V of the LTMS process

The intent of Phase V is to assure that decision-makers will maintain a viable implementation strategy which reflects changing times and project conditions, thereby avoiding the pitfalls of "crisis management." In the final analysis, the loop is closed, allowing the dredging manager to anticipate and accommodate changes in dredged material management needs and to document the validity of the technical, economic, and environmental long-term management decisions.

Pilot Demonstrations

Since 1987, two national LTMS demonstration studies have been initiated. The Maryland Port Administration (MPA), as the designated project sponsor, is developing a comprehensive Master Plan for long-term management of all dredged material from the Port of Baltimore. This Master Plan is funded solely by the MPA and was completed in October 1989. The study process being used by the MPA closely parallels that of the USACE LTMS conceptual process and provides a good basis for comparison with the second pilot study. This second study is being conducted by the US Army Engineer District, Portland, as a national USACE pilot demonstration. The LTMS study is being performed for the Federally funded maintenance program in the Columbia River Estuary.

Lower Columbia River Estuary LTMS

The Portland District is working cooperatively with the Port of Portland on a national pilot demonstration study involving an approximately 24-mile reach of the lower Columbia River near Astoria, OR. The study will address dredging and relocation annually of over 2.2 million cubic yards of sediment from the estuary portion of the Columbia and Lower Willamette River Federal navigation project. The study is limited to the 40-foot-depth main navigation channel (river mile 4.4 to 28.0) and will not include dredging at the entrance bar.

The LTMS study process was initiated in February 1988 and has proceeded through the completion of the Phase II study in September 1989. The study is patterned after the phased approach previously discussed and shown in Figure 1. Presently, the study is limited to completing three phases over a two-year period. The planning time frame for the LTMS is 50 years and will be based on alternative analysis, including development, comparison, and selection of alternatives for maintaining the project.

In June 1989, the Portland District published a report on its Phase I activities (US Army Engineer District, Portland 1989). Information pertinent to navigation, environmental issues, and dredging are documented, along with important studies and regulatory considerations to be used in subsequent analysis during later phases of the study. The Portland District is presently preparing a report on its Phase II activities.

Some of the anticipated LTMS project benefits already identified by the Portland District are:

- Reduced cost and time required for annual project maintenance.
- Increased efficiency in regulatory coordination and permitting.
- Improved implementation of environmental quality and beneficial use project features.
- Improved long-range planning by operations personnel in dredge scheduling and contracting.
- Enhanced potential for local sponsor agreements, agreements with resource agencies, and other cost-sharing agreements.

<u>Lessons Learned</u>

The final report on the lower Columbia River Estuary LTMS study will include a section on "lessons learned" that will evaluate study activities in terms of usefulness towards developing an LTMS. Some of the "lessons learned" to date are:

- The overall District dredging program should be prioritized by project for development of an LTMS. It should also consider needs and resources available to conduct an LTMS.
- There is a need to separate the short- and long-term problems at a project when conducting an LTMS, and to develop solutions that can be implemented for each condition.

- A funding mechanism is needed to address the multi-year requirements for conducting an LTMS study. The budget for studies should include money for baseline field assessments where data are not available.
- An interdisciplinary study team should be established to develop the LTMS. This team should include the project sponsor as a decision-sharing partner in the process.
- Continuity of team member participation in the LTMS process is a major concern. Team member alternates should be designated to attend meetings and/or to perform team duties if the primary team members are unable to participate.
- The Operations Division in the Portland District should be responsible for developing the LTMS, but a full-time study manager will be required to coordinate the in-house and outside agency input and activities, and to prepare the necessary reports.
- Local sponsor and other public obligations and interests should be clearly identified early in the LTMS process. Attempts to develop and implement long-range solutions without their input cannot succeed.
- Involve public agencies after the study team has firmly and clearly established its role and responsibilities. Early in Phase II of the LTMS process seems to be an appropriate point to solicit public agency participation.
- Initial public agency involvement should be educational and aimed at establishing a common level of knowledge and understanding of the goal, objectives, and scope of the LTMS effort. There are different levels of technical expertise and experience in the public agencies as well as there are in the Federal agencies.
- Field trips to the LTMS study area including dredging and disposal operations will help Federal, state, and local government agency personnel to understand the dredging issues, to establish a better appreciation for the LTMS effort, and to develop a rapport with team members.
- It is important to document the results of the study team's efforts as the LTMS process proceeds. A technical summary report should be made available as soon as possible during Phase I of the study.
- When developing potential long-term management solutions, the consideration of beneficial uses of the dredged material has become a major driving force in gaining acceptance.
- There is a need to clearly define when to initiate the formal National Environmental Policy Act (NEPA) process in conjunction with formulation of alternatives developed for the LTMS study.
- Good cost estimation and economic assessments are essential components of the LTMS process. Both the District's economist and dredging estimators need to be involved early in development of the LTMS.
- Education is a major ingredient in developing an LTMS and this requires funding to host public meetings, workshops, technical seminars, and field trips. Support for these activities must be formalized as part of the LTMS budget.

Perhaps the most important "lesson learned" to date by the Portland District has been the need to clearly identify early in the process local sponsor and other public obligations and interests.

Summary of Selected Field Experiences

Based on the collective experience of USACE professionals and others during the past three years, there have been both successful and unsuccessful attempts to incorporate and implement the various elements of the LTMS process within their dredging management programs. Some of the more pertinent "lessons learned" can be grouped under the basic category of study methodology. A list of questions and answers relevant to study methodology was developed to present selected results of USACE field experiences.

- Is the USACE LTMS process framework a viable one?

  The overwhelming response is yes. The Norfolk, New York, Mobile, Charleston, and St. Paul Districts have used approaches similar to the USACE LTMS process framework. In fact, the Port of Baltimore Master Plan development study is a good example of where the LTMS concept appears to be working with a great deal of success.

- How do you decide when to conduct an LTMS study?

  Most long-term dredged material management studies have resulted from the shortage of approved relocation sites either due to changes in laws or implementing environmental regulations making certain sites impossible to find or use. Also, many Districts were finding that they were spending too much time and resources to obtain permits, rights of way, and public acceptance on one-time site-use operations. This problem, along with complications in budgeting and scheduling dredging projects, has made it extremely difficult to maintain certain navigation projects.

  The bottom line for several Districts was that an LTMS for many projects is becoming a way of doing business, either by voluntary acceptance or through mandated court decisions. The New York Harbor long-range dredged material management study and plan is a direct result of a court-ordered requirement.

- Who should develop an LTMS?

  As a matter of good business practice, the USACE and, for the most part, the port authorities and local sponsors should be active partners in developing long-range dredged material management plans. The USACE should take an active lead technical role in developing the LTMS where there is a definite Federal interest. In some cases, however, certain port authorities may need to assume this responsibility. For example, the Maryland Port Administration has assumed the lead role in developing the Master Plan for the Port of Baltimore. Whatever the arrangement is, one thing is certain, the USACE should be involved in the LTMS process.

- What management structure has worked best when conducting the LTMS study?

  There is a clear consensus within the USACE that the LTMS study should be accomplished by an interdisciplinary study team consisting of all USACE affected elements (planning, engineering, operations, regulatory and real estate) involved in the navigation program. There should also be a clear point of contact within the Study Team and District to direct the study and provide consistency in the implementation of the selected LTMS. Finally, it became obvious that the use of coordinating committees or advisory groups made up of various Federal, state, and local governments, private interest groups, and citizens is essential to developing a successful LTMS with the best chance for implementation.

- How long should it take to develop an LTMS?

  While there was no prescribed time frame for developing a viable LTMS, most USACE study managers agreed that an average of about two years had been their experience. There were studies, however, where the issues and scope were so complex that two years was too short. These cases are particularly true where highly complex environmental issues have to be addressed. There was a common theme, however, that the USACE needed to "develop good long-term dredged material management plans, not long-term planning studies."

- What is considered to be long-term?

  Long-term has different meanings to various groups. Some Corps Districts view long-term as three to five years, whereas, others use ten to fifty years. Most agree that USACE dredging regulation guidance (33 CFR 337.9 - Identification and Use of Disposal Areas) encouraging District Engineers "to identify and develop dredged material disposal management strategies that satisfy the long-term (greater than ten years) needs for USACE projects" is a good definition of "long-term."

- What are the sponsor's role and responsibilities in developing an LTMS?

  The sponsor should play an important role in developing an LTMS. Responsibilities, however, will vary with the language of each project authorization. For example, in Norfolk District, in cases where the sponsor furnishes all lands, easements, and rights of way, this role should become a major one. The local sponsor must be willing to participate and assume responsibilities; otherwise, the USACE should not attempt to develop and implement the LTMS alone.

- Is the LTMS concept acceptable to local sponsors?

  The general response is yes. The practice of short-term fixes usually results in navigation projects not being properly maintained and potentially impacts the local economy. In Norfolk, several District Engineers have refused to request O&M dredging unless long-term dredged material management requirements were met, which provided additional incentive to the local sponsor. The experience in the Norfolk District has shown that local sponsors have benefited greatly from the District's long-term management policy because it has resulted in properly maintained channels.

Summary

Achieving dredged material relocation in a timely, technically feasible, cost effective, and environmentally responsible manner continues to be the major management problem facing the USACE national navigation program. The serious shortage of relocation sites, particularly upland, combined with traditional cycle-to-cycle dredging and relocation management practices, requires the development and implementation of long-term dredged material management strategies.

To address this difficult problem, the USACE has begun a major national policy initiative to define an appropriate and effective management process and framework for implementing the concept of an LTMS for the national dredging program. The framework for conducting an LTMS study has been developed and presented in this paper, along with a description of the pilot LTMS demonstration studies, with emphasis on the Columbia River Estuary LTMS study. A summary of "lessons learned" from this pilot study has also been presented.

A recommendation resulting from several meetings with USACE professionals is that if the LTMS conceptual process is to be a viable one, it must fully involve all affected program management elements including the USACE and individual port authorities as cost-sharing and decision-sharing partners in constructing and maintaining the Federal navigation system. Also, it must fully involve the Federal and state resource agencies and public and private sector groups, as appropriate, throughout the process with the USACE assuming a lead role responsibility for Federal projects.

There have also been a number of preliminary findings and institutional issues identified as a result of the USACE LTMS study initiative. Some of these can be summarized as follows:

- Project authorization may be the critical limiting factor in implementing LTMS plans.
- Program consistency is essential to the development of an LTMS; however, under existing laws, the USACE is unable to maintain a preferred level of program management consistency.
- Site management, both upland and open water, is essential to successful implementation of individual LTMS plans. The ownership and liabilities associated with materials placed upland are key issues needing more attention and USACE policy guidance.

- Cost sharing and funding of LTMS development are factors requiring resolution and/or clear guidance prior to agency-wide implementation of the LTMS process.
- Finally, whether the USACE has the ability to effectively implement individual LTMS plans is a major question that needs to be answered to assure a viable LTMS process that can be institutionalized. No doubt, there is considerable room for innovation in the area of LTMS plan implementation.

The effective resolution of the issues already identified, as well as those that will surely become evident in the future, is critical to the success of the LTMS initiative of the USACE. Plans are presently being made to hold a series of workshops to provide a forum for exchange of pertinent "lessons learned" by the USACE and others and to share experiences in solving long-range dredged material management problems.

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Environmental Effects of Dredging Technical Notes

PRELIMINARY GUIDELINES AND CONCEPTUAL FRAMEWORK FOR COMPREHENSIVE ANALYSIS OF MIGRATION PATHWAYS (CAMP) OF CONTAMINATED DREDGED MATERIAL

PURPOSE: The purpose of this note is to present the conceptual groundwork for the Comprehensive Analysis of Migration Pathways (CAMP). The conceptualization process for CAMP is discussed and available techniques for implementing CAMP are examined. Disposal of contaminated dredged material in a confined disposal facility is used to benchmark conceptual development. Case studies that illustrate analysis of selected migration pathways are also described.

BACKGROUND: The US Army Corps of Engineers performs a variety of mission-related activities that require analysis of the movement of chemicals in soil, water, and air. One of these activities involves dredging and disposal of contaminated sediments. The need to evaluate dredged material disposal alternatives has prompted the development and continued improvement of procedures and supporting laboratory tests for evaluating disposal alternatives (Francingues et al. 1985; Lee et al. 1985; Cullinane et al. 1986). These effects-based procedures do not always fully resolve the relative merit of disposal alternatives when contaminated sediments are involved. CAMP is being developed as an internally consistent set of procedures for comparing the containment efficiency of disposal alternatives and as such to provide supporting documentation for evaluating alternatives. CAMP is intended to interact with, but is not a substitute for, the existing effects-based procedures.

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Introduction

Many environmental regulatory agencies are beginning to emphasize assessment of total mass losses of contaminants through all pathways in their evaluation of dredged material disposal alternatives. Existing procedures such as the Corps of Engineers (CE) management strategy (Francingues et al. 1985), the decisionmaking framework (Peddicord et al. 1986), and the dredged material alternative selection strategy (DMASS) (Cullinane et al. 1986) incorporate independent analysis of contaminant migration pathways to estimate effects. Estimated effects are compared to criteria established by regulatory authorities to arrive at decisions regarding the suitability of an alternative, including the need for restrictions. When acceptable combinations of restrictions cannot be identified, however, no guidelines exist for objectively evaluating trade-offs between alternatives, including the no-action alternative. Development of a comparative assessment methodology that interacts with effects-based assessments to provide additional guidance for evaluating disposal alternatives is therefore needed.

Basic CAMP Concept

CAMP is structured around the time-honored engineering concept of a materials balance. The rate of contaminant mass into a control volume minus the rate of contaminant mass out of the same control volume is the rate of contaminant mass containment for the control volume. Containment efficiency (CEF) for an alternative is defined as follows:

$$\text{CEF} = \sum_{i=1}^{n} \sum_{j=1}^{m} \frac{(\text{Rate of Mass In})_{i,j} - (\text{Rate of Mass Out})_{i,j}}{(\text{Rate of Mass In})_{i,j}}$$

where i is the contaminant index, j is the pathway index, n is the number of contaminants included in the analysis, and m is the number of pathways included in the analysis. Estimated materials balances provided by CAMP can be used to compare various disposal alternatives. If rate of contaminant reentry into the environment can be determined for the no-action alternative, then dredging and disposal alternatives can be compared to the no-action alternative on the basis of rates of contaminant flux to the environment. This will involve combining estimates of the rate of contaminant mass loss for various disposal alternatives with estimates of the rate of contaminant mass loss for dredging operations to arrive at an overall rate of contaminant loss for a proposed project.

Thus, the basic concept of CAMP is very simple. Pathways are routes by which contaminants enter and/or exit a control volume. The rates at which contaminant masses are transported along pathways determine containment efficiency. Implementation of this simple concept presents three types of challenges: definition of the spatial scale for a control volume, estimation of contaminant migration rates along pathways, and definition of the temporal scale for conducting an analyis.

The spatial scale over which to conduct a materials balance is relatively straightforward for confined disposal facilities (CDFs) and other disposal alternatives involving confinement. The spatial scale for a CDF is the confining dikes, the interface between foundation soils and dredged material, and the surface of the CDF. Similarly, the spatial scale for an alternative that involves treatment is the treatment process unit. The appropriate spatial scale for the no-action alternative is site specific and sometimes difficult to determine. It might be the boundaries of a harbor or of the Federal project.

Estimation of contaminant mass flux along pathways for which predictive methods are unavailable or unverified is likely to introduce a high degree of uncertainity into CAMP. For some pathways, established procedures can be adapted to estimation of contaminant mass flux. For example, the modified elutriate test (Palermo 1988) can be used to estimate contaminant mass flux associated with discharge of an effluent during hydraulic disposal. For pathways such as volatile emissions, theoretical models are the only tools available for estimating contaminant mass flux (Thibodeaux 1989). For other pathways such as those involving uptake by biota that move into and out of a control volume, predictive methods may not be available.

The temporal scale for conducting a comprehensive materials balance is not as easily defined as the spatial scale. First, the relative importance of various pathways varies in time. For example, discharge of water during filling operations is an important pathway during filling of a CDF. After the CDF is filled, discharge associated with filling ceases. Thus, the time dependency of contaminant fluxes must be incorporated into CAMP. Further, the overall time scale must be considered. Most disposal alternatives for contaminated sediments and other residues are permanent or at least permanently maintained. The appropriate magnitude of the time scale for CAMP has not yet been determined.

CAMP Information Needs/Objectives

The following list of questions are typical ones that need to be answered for the development of CAMP as a useful tool. The list also indicates the types of questions that an application of CAMP should answer. The list has been specifically prepared for CDFs.

1. What is the relative significance of each pathway during each phase of the existence of a CDF (filling, between filling operations, partially vegetated, and filled)?

2. How does pathway significance relate to site management and/or application of control technologies?

3. What is known (and not known) about mechanisms and rates for each pathway? Are computational procedures available? What research is required to develop needed computational procedures?

4. What are the relationships among pathways?

5. How do changing physicochemical conditions and biological processes in the CDF affect contaminant mobility?

6. What is the appropriate temporal scale for evaluating long-term release of contaminants from CDFs?

CDF Pathways

Brannon et al. (in preparation) identified key contaminant mobility processes and pathways and, where possible, methods for estimating contaminant mass exit rates for CDFs. Available information of contaminant migration, cycling, and mobilization pathways is summarized in Table 1. Pathways involving movement of large masses of water, such as CDF effluent and discharge through permeable dikes, have the greatest potential for moving significant quantities of contaminants out of CDFs. Pathways such as volatilization may also result in movement of substantial amounts of volatile organic chemicals at certain stages in the filling of a CDF. The relative importance of contaminant cycling and mobilization in a CDF to net mass balance has not been determined.

Table 1 indicates the importance of basing CAMP on an understanding of the mass balances that are established as chemicals are transported along migration pathways. Apparently, calculation of materials balances for CDFs will involve application of multimedia models for many pathways. Advances in the use and

Table 1

Status of Available Information on Contaminant Migration, Cycling, and Mobilization Pathways*

Pathway	Status
CDF Effluent	Empirical methods exist for assessing CDF effluent
Water Transport Through Permeable Dikes	Methods for making crude estimates that do not account for many of the variables affecting this pathway have been used
Leaching	Methods are under development
Volatilization	Unverified predictive equations have been formulated
Surface Runoff	Empirical methods have been developed
Degradation of Organic Contaminants	No information is available for CDFs, but much work has been conducted in soils and sediments
Microbial Transformations of Metals	Importance in a CDF environment has not been shown
Mobilization by Microorganisms	Almost no information is available
Plant Uptake	Predictive models are being developed for metals under certain conditions; limited information is available in the literature for organic contaminants
Animal Uptake	Limited information is available for CDFs; no predictive models are available for CDFs

* From Brannon et al. (in preparation)

acceptance of multimedia environmental models were reviewed by Bird (1988), and the applicability of multimedia models to CDFs was reviewed recently by Martin and McCutcheon (in preparation). Public domain models are available that may have applicability to CDFs as follows:

1. MINTEQ (Felmy, Girvin, and Jenne 1984) calculates aqueous equilibrium speciation of metals. This model may be useful for estimating metal mobility under the various physicochemical conditions that occur in CDFs.

2. HELP (Schroeder et al. 1984) calculates seepage from landfills and provides information needed for developing liner specifications. This model, as discussed in a later section, has been used in conjunction with data from sediment leaching tests to estimate contaminant migration by leachate seepage from CDFs.

3. TOXI4 (Ambrose et al. 1988) simulates chemical transport in surface water and includes sediment-water column exchange. TOXI4 has been modified, as discussed in a later section, to model exposure concentrations and releases from CDFs (Martin, Ambrose, and McCutcheon 1988).

4. PRZM (Carsel, Smith, and Mulkey 1984) is an agricultural model that consists of hydrology and chemical transport components that simulate runoff, erosion, plant uptake, leaching, decay, foliar washoff, and volatilization of pesticides. PRZM may be useful for estimating percolation and runoff from exposed surfaces in CDFs.

5. FGETS (Barber and Suarez 1989), WASTOX-PART II (Connolly and Thomann 1984), and TEEAM (Dean et al. 1988) are organic chemical biouptake and bioaccumulation models that might be useful in assessing biological processes involved in internal cycling of contaminants that ultimately exit CDFs.

In addition, theoretical volatile chemical emission models (Thibodeaux 1989) and numerous groundwater models (Janandel, Doughty, and Tsang 1984) are available for application to CDFs. Although no single presently available model considers all of the myriad of processes and pathways in a CDF, some combination of the models available may be sufficient to provide first-order evaluations.

Much work is needed before models can be adopted for routine application to CDFs since model application to CDFs is largely unvalidated. Additional model development as well as supporting field and laboratory data are required to develop fully predictive tools. Additional discussions of available computational procedures and research needs for comprehensive analysis of migration pathways in CDFs can be found in Brannon et al. (in preparation) and Martin and McCutcheon (in preparation).

Example Case Studies

Estimates of contaminant losses from CDFs are being made in spite of the fact that some of the laboratory tests and computer models that are used have not been field proven (Myers, Miller, and Snitz 1988). Some case studies are briefly described below. The reader should consult the references for more detailed descriptions.

Chicago District activities

The Chicago District often uses mechanical dredging and disposal in CDFs. Region V of the US Environmental Protection Agency requested estimates of dissolved contaminant losses through dikes from existing and proposed CDFs in the

Chicago District. The District developed in-house models for this purpose (US Army Engineer District, Chicago 1986). The models simulate formation of dredged material deltas during disposal and the impacts of delta formation on the release of interstitial water and dike seepage. Equilibrium partitioning concepts are used to estimate interstitial water concentrations. Interstitial water that is released from the sediment is mixed with overlying water and transported through the dikes without attenuation.

Everett Harbor, Washington

The US Navy proposed to establish a homeport for a carrier battle group at Everett, Washington, and requested the Seattle District to provide technical assistance in developing a dredging and disposal plan for sediment that would have to be relocated. The Seattle District in turn requested technical assistance from the US Army Engineer Waterways Experiment Station (Palermo et al. 1989). One interesting aspect of the evaluation of dredging and disposal alternatives was estimation of total contaminant mass loss for both dredging and disposal. A containment performance goal of 95 percent of total contaminant mass in the in-place sediments was used to judge the relative merit of dredging and disposal options. The containment efficiency for confined aquatic disposal (CAD) using clamshell dredging with surface release from bottom dump barges met the performance criterion and was better than that for hydraulic dredging and disposal in CDFs (Palermo et al. 1989).

New Bedford Harbor, Massachusetts

New Bedford Harbor is a Superfund site in southern Massachusetts. Proposed remedial actions involve dredging and disposal of contaminated sediments in the Acushnet River estuary. Averett et al. (1988) calculated polychlorinated biphenyl (PCB) and heavy metal releases for various CDF disposal alternatives using hydraulic dredging. PCB mass releases for selected CDF alternatives are shown in Figure 1. Alternative A1 is an unlined CDF with earthfill (low hydraulic conductivity) dikes. The effluent associated with filling operations is not treated in Alternative A1. Alternative A2 includes treatment of the effluent for suspended solids removal. Alternative A3 includes treatment of the effluent for suspended solids removal and dissolved PCB removal using activated carbon. Alternative D is a lined CDF with effluent treatment for suspended solids and dissolved PCB removal.

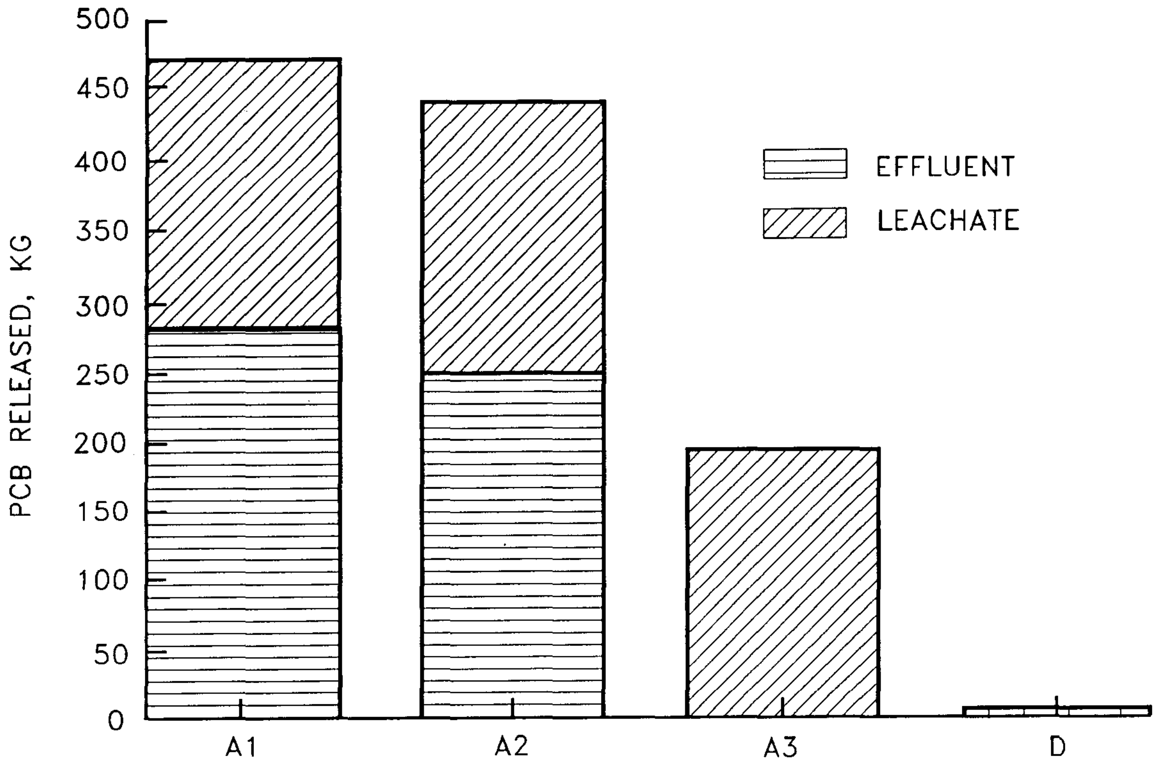

Figure 1. PCB release estimates for selected New Bedford Harbor CDF alternatives (from Averett et al. 1988)

The estimation techniques used by Averett et al. (1988) are too involved to describe in detail in this technical note. Noteworthy aspects of the calculations are summarized as follows:

1. Analysis of the CDF contaminant migration pathways included water discharged during hydraulic filling and leachate seepage. Runoff and volatilization were not pathways of concern because the CDF alternatives included capping.

2. PCB release during filling was calculated directly from suspended sediment and dissolved contaminant concentrations observed in the modified elutriate test and dredge flow rate.

3. Long-term (30 years) PCB migration via leachate seepage was analyzed by combining leachate quality data obtained in laboratory leach tests with percolation estimates from a version of the HELP model set up specifically for dredged material.

4. Short-term PCB migration via leachate seepage was estimated by analyzing consolidation and release of pore water using the PCDDF model (Cargill 1985).

TOXI4 application

Martin, Ambrose, and McCutcheon (1988) modified selected algorithms in the TOXI4 model (Ambrose et al. 1988) to model PCB transport through permeable dikes. Application of the model to a proposed in-lake CDF at Indiana Harbor, Indiana, showed that contaminant transport through permeable dikes at in-water CDFs is affected by the type of filling (hydraulic or mechanical), sorption properties of the dike material, and hydraulic pumping. Hydraulic pumping is the movement of lake water into and out of the dikes due to fluctuation in lake levels that occurs between filling operations. Hydraulic pumping was modeled as dispersion.

The estimates provided by TOXI4 (Table 2) for mechanical filling of the Indiana Harbor CDF were close to previous estimates developed by the Environmental Laboratory (1987) when significant partitioning of PCB to dike materials was simulated and flux due to hydraulic pumping (dispersion) was not included in the estimate. PCB flux due to hydraulic pumping exceeded advection losses for all simulations, including those conducted for hydraulic filling. TOXI4 estimates of combined advection and hydraulic pumping for hydraulic filling were, however, lower than those developed by the Environmental Laboratory (1987) for hydraulic filling.

Table 2

TOXI4 Estimated Releases of PCBs (kg) from the Proposed Indiana Harbor CDF (from Martin, Ambrose, and McCutcheon 1988).

		Loss Through Permeable Dike			
		Low Partitioning		High Partitioning	
Dredging	EL*	A*	D*	A	D
Hydraulic	6.3	0.37	1.9	0.03	0.5
Mechanical	0.0003	--	--	0.004	0.2

*Note: EL: loss estimates provided in Environmental Laboratory (1987).
A: advective loss due to flow through the dike.
D: dispersive loss due to hydraulic pumping.

CAMP Research and Development Needs for CDFs

Established procedures are available for estimating contaminant mass flow over weirs during hydraulic filling, the major contaminant migration pathway during hydraulic filling of CDFs with low permeability dikes. Existing procedures for other pathways are not fully developed and are probably suitable for reconnaissance-level estimation only.

Contaminant migration pathways requiring additional work include transport through dikes, leachate seepage, volatilization, and surface runoff. Research is also needed on the release of contaminants from mechanically dredged material during disposal, biodegradation of toxic organics, chemical and biological transformations of contaminants, and plant and animal uptake in CDFs. Pathways involving movement of water have the greatest potential for moving significant quantities of contaminants out of CDFs and, therefore, should have first priority.

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January 1995

Environmental Effects of Dredging Technical Notes

The Automated Dredging and Disposal Alternatives Management System (ADDAMS)

Purpose

This technical note describes the current capabilities and availability of the Automated Dredging and Disposal Alternatives Management System (ADDAMS). ***This technical note replaces the earlier Technical Note EEDP-06-12, which should be discarded.***

Background

Planning, design, and management of dredging and dredged material disposal projects often require complex or tedious calculations or involve complex decision-making criteria. In addition, the evaluations often must be done for several disposal alternatives or disposal sites. ADDAMS is a personal computer (PC)-based system developed to assist in making such evaluations in a timely manner. ADDAMS contains a collection of computer programs (applications) designed to assist in managing dredging projects. This technical note describes the system, currently available applications, mechanisms for acquiring and running the system, and provisions for revision and expansion.

Additional Information

For additional information regarding ADDAMS, contact the authors of this technical note, Dr. Paul R. Schroeder, (601) 634-3709, or Dr. Michael R. Palermo, (601) 634-3753, or the EEDP program manager, Dr. Robert M. Engler, (601) 634-3624. Points of contact for technical questions relating to various ADDAMS applications are provided in Appendix A of this technical note and on-screen in ADDAMS.

Description of ADDAMS

Objective

The Automated Dredging and Disposal Alternatives Management System (ADDAMS) is an interactive personal computer (PC)-based design and analysis system for dredged material management. ADDAMS is composed of individual modules or applications, each of which has computer programs designed to assist in the evaluation of a specific aspect of a dredging project. The creation of the system was in response to requests by Corps field offices for tools to rapidly evaluate dredged material management alternatives. The objective of the ADDAMS is to provide state-of-the-art computer-based tools that will increase the accuracy, reliability, and cost-effectiveness of Corps dredged material management activities in a timely manner.

Available Applications

Reflecting the nature of dredged material management activities, the applications and their methodologies contained in ADDAMS are richly diverse in sophistication and origin. The contents range from simple algebraic expressions, both theoretical and empirical in origin, to numerically intense algorithms spawned by the increasing power and affordability of computers.

Figure 1 shows the currently available applications of ADDAMS. A summary description of each ADDAMS application, including a listing of capabilities and technical points of contact, is found in Appendix A of this technical note. As applications are updated or new applications are added, Figure 1 and Appendix A will be updated by changes to this technical note.

Documentation and User's Guide

Each ADDAMS application has documentation describing how to run that application, how that application functions, and how it is programmed. This technical note is intended to serve as the user's guide and documentation for the overall ADDAMS system. All files for ADDAMS are provided to users on floppy diskettes. A detailed list of references is provided both in this technical note and directly on-screen within the applications including those concerned with the technical background and theory involved and documentation for the programming as appropriate. Points of contact for each application are also listed directly on the screens for answering questions regarding the respective applications.

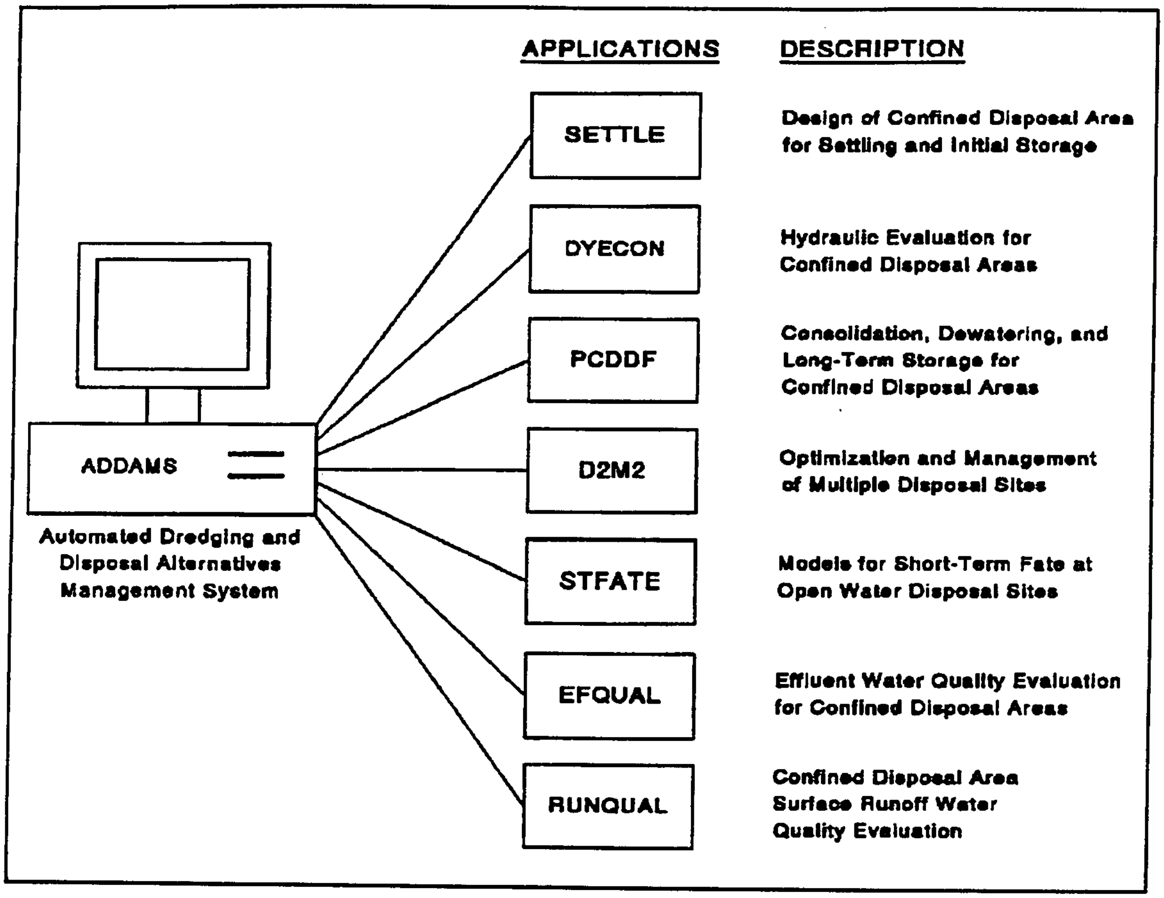

Figure 1. Current applications in ADDAMS

General Instructions

Target Hardware Environment

The strong preference of Corps field offices is for the system to reside in a desktop hardware environment commonly available. The system is therefore designed for a current base of PC-AT (including compatibles) class of personal computers resident at many Corps field offices, though some applications require a less powerful computer and others would be best run on a more powerful computer. Future versions of the various ADDAMS applications are expected to take advantage of the more powerful hardware technologies becoming commonly available, while maintaining some compatibility with lesser hardware. In general, the system requires a math coprocessor, 640 kilobytes of RAM, and a hard disk. In addition, an Enhanced Graphics Adapter (EGA) and color monitor are recommended. ADDAMS applications are written primarily in FORTRAN 77. However, some of the higher level operations and file management operations are written in BASIC, and some of the screen control operations are performed using an assembly language utility program.

Installation and Start-Up

It is recommended that the ADDAMS files be saved in a directory on the hard disk dedicated for the ADDAMS system, for example, C:\ADDAMS. The files are archived on the disks and must be de-archived prior to running the applications. To de-archive the files on each disk, copy the files from the disk onto the hard drive, type README, and follow the instructions. To begin a session, make the ADDAMS directory the current default directory, and type ADDAMS. Menus will then be displayed.

User Interface

ADDAMS employs a menu-driven environment and supports full-screen data entry. Single keystrokes (usually the F1-F10 function keys, number keys, Esc key, cursor keys, and the Enter key) select menu options in the system.

Cursor keys highlight input fields (displayed in reverse video) much like a spreadsheet program. To enter alphanumeric data, the user moves the cursor to the cell of interest using the up or down arrows to move vertically, and the Tab and Shift-Tab keys to move horizontally. The enter key moves forward through the cells. The left and right arrow keys can be used to move the cursor within a selected cell in order to edit the cell's contents. The Backspace key deletes characters in a cell. The space bar inserts spaces in a cell. The Delete and Insert keys, respectively, delete and insert a row of data on a screen of tabular data.

Page Down moves the cursor to the next screen of data entry and the Page Up key moves the cursor to the previous screen of data entry. The End key or Esc key permits the user to quit data entry and exit the application without saving the data. The Home key exits from the current data entry activity screen to the activity selection menu for the application and retains the entered data in memory.

Results from computations are generally displayed in tabular or graphic format on the screen or written to print files or devices.

Applications and File Management

Each ADDAMS application consists of one or more stand-alone computer programs or numerical models to perform a specific analysis. ASCII files hold input data from previous runs and are used to store output of results.

ADDAMS displays an initial menu of applications. Once an application is selected, an activity selection menu will be displayed at several levels for entering and editing data, executing the application, printing the results, performing file operations, and exiting the program.

The File Manager is accessible within each application. The File Manager acts only on data files for the selected application. The File Manager can select, name, or copy files, or display a directory listing the files.

Printing

Opportunities are provided to print a hard copy of input data, output of results, data files, and file directories. The DOS commands Control-Print Screen and Shift-Print Screen can also be used to print, respectively, all information written to the screen or currently on the monitor.

Ending

Normal termination is recommended at all times to avoid data loss. Data entry should be terminated by paging from the data entry screens or hitting the Home key to return to the activity selection menu. Hitting the Esc key or the function key for file operations will save the data, and then the Esc key is used to exit each menu to successively higher menu levels, and ultimately, back to DOS. During execution of a particular application's program, the user must wait until the sometimes lengthy computations are completed before exiting. The program can also be terminated by a Control-Break or by turning off the computer, but these methods of ending are not recommended because loss of data may occur.

Availability of ADDAMS on Diskettes

The ADDAMS system and applications are available on floppy diskettes. A request form for obtaining the ADDAMS diskettes is provided as Appendix B.

Revisions, Updates, and Workshops

The ADDAMS applications will be revised and updated as new technical approaches become available, and new applications will be developed to address additional management needs. Each application is designed as a module so that revisions or the addition of new applications can be easily accomplished. New users are provided with the most current version of each respective application. Version numbers are displayed on-screen for the ADDAMS system and the various applications. Periodically, a new version of the entire system may be required.

Announcements of revisions to specific applications and for the entire system will be published in the Environmental Effects of Dredging Programs' (EEDP) information exchange bulletin. Changes to this technical note will also provide information on new applications. In addition, workshops are held on an as-needed basis to familiarize Corps personnel with use of the ADDAMS system. Requests for additions to the mailing list for the EEDP bulletin or the technical note series and inquiries regarding the scheduling of ADDAMS workshops should be sent to the following address:

U.S. Army Engineer Waterways Experiment Station
ATTN: CEWES-EP-D
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Appendix A: Description of ADDAMS Applications

SETTLE Application

Title

Design of Confined Disposal Facilities for Suspended Solids Retention and Initial Storage Requirements (SETTLE)

Description

Confined disposal facilities (CDFs) must be designed to provide both the storage volume required for the dredged solids and the hydraulic retention time for removal of suspended solids from the effluent discharged from the area during hydraulic filling operations. Various settling processes occurring in the CDF control the initial storage during filling, clarification, and effluent suspended solids. Engineer Manual (EM) 1110-2-5027 (Headquarters, U.S. Army Corps of Engineers 1987) provides design guidance for CDFs. This application provides a computer program to assist users in the design of a CDF for solids retention and initial storage in accordance with the design procedures in the EM. Laboratory column settling tests are an integral part of these design procedures, and the data from these tests are required in order to use this application. The SETTLE application analyzes laboratory data from the settling tests and calculates design parameters for CDFs.

Major Capabilities

1. Analyzes laboratory settling test data for zone, flocculent, and compression settling for CDFs.

2. Determines the maximum allowable in situ volume that can be dredged and placed in a CDF with a given available storage volume.

3. Determines the maximum allowable dredge size (or inflow rate) that can be used with a given CDF surface area and ponding volume to obtain clarification and maintain satisfactory retention of suspended solids.

4. Determines the required CDF surface area and volume to accommodate a given dredge size and a given in situ volume to be dredged.

5. Determines the required weir crest length for a given dredge size.

Current Version

3.00 updated July 1993

Points of Contact

Dr. Paul Schroeder, CEWES-EE-A, (601) 634-3709
Dr. Michael Palermo, CEWES-EE-P, (601) 634-3753

Selected References

Hayes, D. F., and Schroeder, P. R. 1992. "Documentation of the SETTLE Module for ADDAMS: Design of Confined Disposal Facilities for Solids Retention and Initial Storage," *Environmental Effects of Dredging Technical Notes* EEDP-06-18, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Headquarters, U.S. Army Corps of Engineers. 1987. "Confined Disposal of Dredged Material," Engineer Manual 1110-2-5027, Washington, DC.

Palermo, M. R., Montgomery, R. L., and Poindexter, M. E. 1978. "Guidelines for Designing, Operating, and Managing Dredged Material Disposal Areas," Technical Report DS-78-10, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Thackston, E. L., and Palermo, M. R. 1988. "Refinement and Simplification of Column Settling Tests for Design of Dredged Material Containment Areas," *Environmental Effects of Dredging Technical Notes* EEDP-02-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

PCDDF Application

Title

Evaluation of Primary Consolidation and Desiccation of Dredged Fill for Determining Long-Term Storage Requirements (PCDDF)

Description

This application provides a mathematical model to estimate the storage volume occupied by a layer or layers of dredged material in a confined disposal facility (CDF) as a function of time. Management of CDFs to provide maximum storage capacity is becoming more necessary as both the storage capacity of existing sites and availability of land for new sites decrease. Maximum site capacity is achieved through densification of the dredged material by removal of interstitial water. The volume reduction, and the resulting increase in storage capacity, is obtained through both consolidation and desiccation (drying) of the dredged material. The PCDDF model relies on the results of laboratory consolidation tests to estimate the magnitude and rate of consolidation and on climatic data for estimation of the rates of drying at a given site. The predictive procedures are described in Engineer Manual (EM) 1110-2-5027 (Headquarters, U.S. Army Corps of Engineers 1987).

Major Capabilities

1. Determines the final or ultimate thickness and elevation of multiple lifts of dredged material placed at given time intervals.
2. Determines the time rate of settlement for multiple lifts and therefore the surface elevation of the dredged material fill as a function of time.
3. Determines the water content, void ratio, total and effective stress, and pore pressure for multiple lifts as a function of time.

Current Version

1.2 updated October 1993

Points of Contact

Dr. Paul Schroeder, CEWES-EE-A, (601) 634-3709
Dr. Michael Palermo, CEWES-EE-P, (601) 634-3753

Selected References

Headquarters, U.S. Army Corps of Engineers. 1987. "Confined Disposal of Dredged Material," Engineer Manual 1110-2-5027, Washington, DC.

Poindexter-Rollings, M. E., and Stark, T. D. 1989. "PCDDF89 - Updated Computer Model to Evaluate Consolidation/Desiccation of Soft Soils," *Environmental Effects of Dredging Technical Notes* EEDP-02-10, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Stark, T. D. "Program Documentation and User's Guide: PCDDF89, Primary Consolidation and Desiccation of Dredged Fill," Instruction Report D-91-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

DYECON Application

Title

Determination of Hydraulic Retention Time and Efficiency of Confined Disposal Facilities (DYECON)

Description

This application provides a computer program to determine mean hydraulic retention time and hydraulic efficiency of a confined disposal facility (CDF) from a dye tracer slug test. Determination of retention time of ponded water is an important aspect of CDF design. Dye tracer studies may be undertaken to provide retention time data for large sites or those with unusual characteristics. Procedures for conducting such dye tracer tests are presented in Engineer Manual (EM) 1110-2-5027 (Headquarters, U.S. Army Corps of Engineers 1987). In the absence of dye tracer data, the hydraulic efficiency can be estimated empirically.

Major Capabilities

1. Determines the theoretical and mean retention times of a CDF and the resulting hydraulic efficiency.

2. Determines the mean and maximum dye concentrations, time of peak dye concentration, and related characteristics of the dye concentration curve.

Current Version

3.00 updated July 1993

Point of Contact

Dr. Paul Schroeder, CEWES-EE-A, (601) 634-3709

Selected References

Hayes, D. F., and Schroeder, P. R. 1992. "Documentation of the DYECON Module for ADDAMS: Determining the Hydraulic Retention and Efficiency of Confined Disposal Facilities," *Environmental Effects of Dredging Technical Notes* EEDP-06-17, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Headquarters, U.S. Army Corps of Engineers. 1987. "Confined Disposal of Dredged Material," Engineer Manual 1110-2-5027, Washington, DC.

D2M2 Application

Title

Optimization of Long-Term Operation and Expansion of Multiple Disposal Sites Incorporating Dredging Sites, Disposal Sites, Transportation Facilities, and Management Restriction (D2M2)

Description

This application provides the Dredged-Material Disposal Management Model (D2M2), developed by the U.S. Army Engineer Hydrologic Engineering Center (HEC), a simulation-optimization model for systematic analysis of long-term operation and expansion of multiple disposal sites. The model provides a means of determining the optimum usage of multiple disposal areas to meet the dredging requirements at multiple dredging sites, for example, along the length of a navigation channel. D2M2 uses a linear-optimization approach in determining the optimum usage based on input data for dredging volumes, location, frequencies, transportation facilities, and associated costs.

Major Capabilities

1. Determines the optimum usage of multiple disposal sites to meet dredging requirements at multiple dredging locations.

2. Identifies the minimum-net-cost short-term operation policy for a system of disposal sites and dredging areas.

3. Analyzes disposal capacity expansion alternatives and determines the minimum cost disposal site acquisition schedule.

Current Version

3.00 updated October 1989

Points of Contact

Hydrologic Engineering Center, CEHEC, (916) 551-1748
Dr. Paul Schroeder, CEWES-EE-A, (601) 634-3709

Selected References

Ford, D. T. 1984 (Jan). "Dredged-Material Disposal Management Model," *Journal of the Water Resources Planning and Management Division*, American Society of Civil Engineers, Vol 16, No. 1, pp 57-74.

Hydrologic Engineering Center. 1984. "Dredged-Material Disposal Management Model (D2M2) User's Manual," U.S. Army Engineer Water Resources Support Center, Davis, CA.

STFATE Application

Title

Short-Term Fate of Dredged Material Disposal in Open Water (STFATE)

Description

This application provides mathematical modeling of the physical processes determining the short-term fate of dredged material disposed at open-water sites, that is, within the first few hours after disposal. STFATE was developed from the DIFID (DIsposal From an Instantaneous Dump) model. In STFATE, the behavior of the material is assumed to be separated into three phases: convective descent, dynamic collapse, and passive transport-dispersion. The model provides estimates of receiving water concentrations of suspended sediment and dissolved constituent and the initial deposition of material on the bottom. Estimates of water column concentrations are often needed to determine mixing zones; whereas, the initial deposition pattern of material on the bottom is required in long-term sediment transport studies that assess the potential for erosion, transport, and subsequent re-deposition of the material. This model can also serve as a valuable aid in field monitoring programs. STFATE can be used in evaluating water column effects of open-water disposal of dredged material in accordance with section 103 of the Marine Protection, Research, and Sanctuaries Act and section 404(b)(1) of the Clean Water Act.

Major Capabilities

1. Estimates receiving water concentrations of suspended solids, dredged material liquid and suspended phases, and dissolved contaminants as a function of time and location and compares contaminant concentrations with water quality standards.

2. Estimates the percentage of suspended solids deposited on the bottom as a function of time and location and the thickness of deposition.

3. Estimates mixing zone requirements to meet water quality standards.

Current Version

5.00 June 1993

Points of Contact

Dr. Billy Johnson, CEWES-HE, (601) 634-3725
Dr. Paul Schroeder, CEWES-EE-A, (601) 634-3709
Dr. Michael Palermo, CEWES-EE-P, (601) 634-3753

Selected References

Brandsma, M. G., and Divoky, D. J. 1976 (May). "Development of Models for Prediction of Short-Term Fate of Dredged Material Discharged in the Estuarine Environment," Contract Report D-76-5, U.S. 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, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

U.S. Environmental Protection Agency/U.S. Army Corps of Engineers. 1991. "Evaluation of Dredged Material Proposed for Ocean Disposal - Testing Manual," EPA-053/8-91/001, Office of Water, Washington, DC.

U.S. Environmental Protection Agency/U.S. Army Corps of Engineers. 1994. "Evaluation of Dredged Material Proposed for Discharge in Inland and Near Coastal Waters - Inland Testing Manual (Draft)," Office of Water, Washington, DC.

EFQUAL Application

Title

Analysis of Modified Elutriate Test Results for Prediction of Chemical Effluent Quality and Dilution Requirements for Confined Disposal Facilities (EFQUAL)

Description

This application provides a computer program to analyze the results of modified elutriate tests and predict the chemical quality of effluent discharged from confined disposal facilities (CDFs) during hydraulic filling operations. Such predictions are necessary to evaluate the acceptability of the effluent discharge under section 404 of the Clean Water Act. The effluent may contain both dissolved and particle-associated contaminants. The modified elutriate test was developed for use in predicting both the dissolved and particle-associated concentrations of contaminants in the effluent. Results of the modified elutriate and column settling tests may be used to predict the total concentrations of contaminants for a given set of CDF operational conditions.

Major Capabilities

1. Computes predicted dissolved, particle-associated, and total concentrations of contaminants of the effluent.

2. Compares predicted concentrations with given water quality criteria and standards and determines the required dilution, if any, in a mixing zone to meet the standards.

Current Version

3.00 updated October 1991

Points of Contact

Dr. Michael Palermo, CEWES-EE-P, (601) 634-3753
Dr. Paul Schroeder, CEWES-EE-A, (601) 634-3709

Selected References

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

Lee, C. R., and others. 1991. "General Decisionmaking Framework for Management of Dredged Material: Application to Commencement Bay, Washington," Miscellaneous Paper D-91-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Palermo, M. R. 1985. "Interim Guidance for Predicting Quality of Effluent Discharged from Confined Dredged Material Disposal Areas," *Environmental Effects of Dredging Technical Notes* EEDP-04-1 through 04-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Palermo, M. R., and Schroeder, P. R. 1991. "Documentation of the EFQUAL Module for ADDAMS: Comparison of Predicted Effluent Water Quality with Standards," *Environmental Effects of Dredging Technical Notes* EEDP-06-13, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

RUNQUAL Application

Title

Comparison of Predicted Runoff Water Quality with Standards (RUNQUAL)

Description

This application provides a computer program to analyze the results of surface runoff quality tests and to predict the chemical quality of the surface runoff discharged from confined disposal facilities (CDFs). Such predictions are necessary to evaluate the acceptability of the surface runoff under section 404 of the Clean Water Act. The surface water runoff may contain both dissolved and particle-associated contaminants. Results of the surface runoff quality tests and the column settling tests may be used to predict the dissolved and total concentrations of contaminants for a given set of CDF operational conditions.

Major Capabilities

1. Computes predicted dissolved and total contaminant concentrations in the surface runoff discharged from a confined disposal site using surface runoff quality test data.

2. Compares predicted surface runoff concentrations with specified water quality standards.

3. Computes required dilutions of surface runoff discharge to meet specified water quality standards, considering background concentrations in the receiving water.

Current Version

1.00 August 1993

Points of Contact

Dr. Charles R. (Dick) Lee, CEWES-ES-F, (601) 634-3585
Dr. Paul Schroeder, CEWES-EE-A, (601) 634-3709

Selected Reference

Schroeder, P. R., Gibson, A. C., and Dardeau, E. A., Jr. 1995. "Documentation of the RUNQUAL Module for ADDAMS: Comparison of Predicted Runoff Water Quality with Standards," *Environmental Effects of Dredging Technical Notes* EEDP-06-19, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Appendix B: Request Form for ADDAMS

Please send the ADDAMS diskettes to:

Name and Title ____________________
Mailing Address ____________________
and Office Symbol____________________
____
Telephone Number____________________
Anticipated uses of ADDAMS ____________________
____

Requests for ADDAMS must be sent with *formatted* floppy disks. Please circle the applications desired and the number and type of diskettes enclosed.

Requested Modules	**Number of diskettes enclosed (all DS)**			
	5.25 in. 360 kb	**5.25 in. 1.2 Mb**	**3.5 in. 720 kb**	**3.5 in. 1.44 Mb**
ADDAMS (all modules)	26	14	16	9
ADDAMS DEMO	6	3	3	2
SETTLE	2	1	1	1
DYECON	2	1	1	1
PCDDF	2	1	1	1
D2M2	1	1	1	1
STFATE	10	4	6	3
EFQUAL	1	1	1	1
RUNQUAL	1	1	1	1
EXECUTIVE SHELL	1	1	1	1

Signed____________________Date____________________

MAIL THE COMPLETED REQUEST FORM AND FORMATTED DISKETTES TO:

U.S. Army Engineer Waterways Experiment Station
ATTN: CEWES-IM-DS (Naylor)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

EEDP-06-13
November 199

Environmental Effects of Dredging Technical Notes

Documentation of the EFQUAL Module for ADDAMS: Comparison of Predicted Effluent Water Quality with Standards

Purpose

This technical note describes a technique for comparison of the predicted quality of effluent discharged from confined dredged material disposal areas with applicable water quality standards. This note also serves as documentation of a computer program called EFQUAL written for that purpose as part of the Automated Dredging and Disposal Alternatives Management System (ADDAMS).

Background

The quality of water discharged from confined dredged material disposal areas during filling operations (effluent) is a major environmental concern associated with such disposal. Techniques for predicting effluent quality are presented in Technical Notes EEDP-04-1 through EEDP-04-4 (Palermo 1985). These notes describe the use of modified elutriate tests and column settling tests to predict the quality of the effluent discharged. Guidance for calculating the size of mixing zones is found in Technical Note EEDP-04-5 (MacIntyre 1987). Before calculations of the size of the mixing zone are made, the required dilution of each contaminant of concern to meet its respective water quality standard must be determined. This technical note presents a technique for comparing contaminant concentrations in the elutriate with water quality standards and documents a computer program which calculates the required dilutions considering all pertinent factors.

Guidelines have been published to reflect the 1977 Amendments of Section 404 of the Clean Water Act (US Environmental Protection Agency (EPA) 1980). Proposed testing requirements define dredged material according to four categories. Category 3 includes potentially contaminated material proposed for confined disposal that has "potential for contamination of the receiving water column only." The proposed testing requirements call for evaluation of short-term water column impacts of disposal area effluents. Under Section 401 of the Clean Water Act, a water quality certification is required from the state in which the discharge occurs. The certification may include water quality standards for contaminants of concern and should specify the geometric limits of a mixing zone for initial dilution in the vicinity of the discharge where receiving water quality standards may be exceeded.

Additional Information

Contact the authors, Dr. Michael R. Palermo, (601) 634-3753, or Dr. Paul R. Schroeder, (601) 634-3709, or the manager of the Environmental Effects of Dredging Programs, Dr. Robert M. Engler, (601) 634-3624.

EFQUAL Application of ADDAMS

Requirements

The quality of water discharged from confined dredged material disposal areas during filling operations (effluent) is a major environmental concern associated with such disposal. Modified elutriate tests and column settling tests are used to predict the quality of the effluent discharged. The predicted concentrations can be used with appropriate water quality standards to determine the mixing zone required to dilute the effluent to an acceptable level. Before calculations of the size of the mixing zone are made, the required dilution of each contaminant of concern to meet its respective water quality standard must be determined.

Comparison of the predicted effluent concentration with the water quality standard and, if necessary, calculation of the dilution required to meet the water quality standard must be determined for each contaminant of concern. For some projects, the number of contaminants of concern can easily exceed a hundred. The predicted effluent concentration, the water quality standard, and the background concentration of the contaminant in the receiving water all influence the dilution required. Further complicating the process is the fact that any of these three concentrations may exceed the others and that some of the concentrations may be below the detection limit of the chemical analysis used to predict the effluent concentration. The computational effort and data management effort required for such an evaluation can be substantial. Therefore, a computer program has been developed to efficiently perform the required calculations and present the data in a manner which can be easily interpreted.

EFQUAL Capabilites

The computer program for effluent quality described in this note has been developed as a module of the Automated Dredging and Disposal Alternatives Management System (ADDAMS) and can be run on a personal computer (PC). The module is entitled EFQUAL.

ADDAMS is an interactive computer-based design and analysis system for dredged material management. The general goal of the ADDAMS is to provide state-of-the-art computer-based tools that will increase the accuracy, reliability, and cost-effectiveness of dredged material management activities in a timely manner. The ADDAMS is described in more detail in Technical Note EDDP-06-12 (Schroeder and Palermo 1990).

EFQUAL has the following capabilities:

- Compute predicted dissolved and total contaminant concentrations in the effluent from a confined disposal site using modified elutriate test data.
- Compare predicted effluent concentrations with specified water quality standards.
- Compute required dilutions of effluent to meet specified water quality standards, considering background concentrations in the receiving water.

Using the EFQUAL Module

The EFQUAL module of ADDAMS uses a menu-driven environment with a full-screen data-entry method. The initial menu contains options for entering/editing input data, selecting existing data files or performing file management operations, selecting/entering/editing water quality criteria, performing calculations, printing output, and exiting the EFQUAL module. In general, single keystrokes are required to select menu options displayed on the screen. Cursor keys are used to select between highlighted input fields much like a spreadsheet program. Results from computations are generally displayed in tabular format on the screen, saved in ASCII files, or sent to a printer. Detailed assistance is available on-line by pressing the F2 key for help.

Input/Output

The main data requirements for the EFQUAL module include modified elutriate test conditions and results, background receiving water concentrations, and water quality standards for contaminants of concern. Other data describing the samples and parameters used in the modified elutriate tests can also be entered for documentation purposes. The final output of the module consists of tabular summaries of modified elutriate data, predicted effluent quality concentrations, and water quality standards; absolute and statistical comparisons of predicted effluent water quality with standards; and computed dilutions required to meet the standards. Table 1 lists the necessary input parameters with their corresponding units. Instructions for data entry and additional descriptive information for some parameters are provided directly on the EFQUAL input screens or are available from the on-line user guide.

Table 1 EFQUAL Input Parameters	
Parameter	**Units**
For each evaluation: Descriptive title Number of modified elutriate replicates	
For each modified elutriate replicate: Slurry concentration (optional) Retention time (optional) Total suspended solids (TSS) concentration	 g/L hr mg/L
For each contaminant of concern: Detection limit Test sediment concentration (optional) Test water concentration (optional) Background water concentration Water quality standard	 µg/L mg/kg µg/L µg/L µg/L
For each contaminant of concern and each modified elutriate replicate: Modified elutriate dissolved concentration Modified elutriate total concentration (required only if total concentrations used for comparison to standards)	 µg/L µg/L
For each evaluation: Estimated effluent TSS concentration (required if total concentrations used for comparison to standards) Percentage increment above background and dilution calculations (used when standards are below or very close to background)	 mg/L percent

Considerations in Comparing Predictions with Criteria

Contaminants of Concern and Water Quality Standards

Before entering water quality standards or elutriate test data, the user must build a list of all contaminants of concern. The list must contain the names of all contaminants measured in the modified elutriate tests or listed in any water quality criteria set of interest, such as the EPA acute toxicity water quality criteria, the Federal drinking water standards, or state water quality standards. The EFQUAL module comes with a list of contaminants for the Federal acute toxicity water quality criteria. To update the list, the user should select the water quality criteria set option of the EFQUAL module and then choose the criteria set of interest or build a new criteria set (up to a maximum of 12 sets). The program will display the current list of contaminants and provide instructions for adding or deleting contaminants from the list.

When building or editing the list of contaminants, the user should also enter the value of the water quality standard for all contaminants having that data available. Entry of the standard is made on the same screen in a column adjacent to the entry of the contaminant name. Many of the contaminants initially listed on the screen may not have standards for the selected criteria set but may have values in other criteria sets. A criterion value equal to or less than zero will be treated as a missing value. Contaminants having missing values in the selected set should not be deleted from the list since the contaminant may be used for other criteria sets.

EFQUAL allows comparisons to be made using any of the several sets of criteria or standards which are stored in a file of criteria sets. The EPA acute water quality criteria for protection of freshwater or saltwater aquatic life are initially available as choices. It should be noted that chronic criteria are technically inappropriate because water column effects are considered short-term. As noted earlier, EFQUAL allows the user to build additional sets of water quality standards (for example, state standards specified under Section 401 water quality certifications), which can then be permanently stored in the table of standards for use in future evaluations. The water quality standards may be left blank if a standard does not exist for a particular contaminant. If no water quality standard for a given contaminant is specified in the set of standards selected for comparison, EFQUAL displays N/A blanks for the standard and comparison results.

Modified Elutriate Test Description

Modified elutriate test results and related information are the majority of data that must be entered. When new data are entered, a text description of the samples used for the tests can be entered for documentation purposes.

The modified elutriate procedure calls for the test to be performed with a minimum of three replicates. Up to nine replicates can be entered in EFQUAL. Separate sets of replicates of the modified elutriate test may be analyzed for classes of contaminants, for example, metals or organics. Therefore, the definition of a replicate for purposes of EFQUAL is any separate sample analyzed for chemical concentrations and for which a separate total suspended solids (TSS) determination is made. The slurry concentration used in the test, the retention time prior to sample extraction, and the TSS concentrations for each replicate are then specified.

Test Data

EFQUAL displays a table of the contaminants of concern for purposes of entering the modified elutriate and other data for specific contaminants. The test data can be entered for any contaminant listed on the displayed table of contaminants by a menu selection. EFQUAL marks those contaminants with an asterisk on the displayed table for which data has been entered. All data previously entered for a contaminant can be deleted by pressing the delete key after highlighting the contaminant.

Once a specific contaminant has been selected for data entry, EFQUAL presents an input screen for that contaminant. Data from the modified elutriate test procedure (see Technical Note EEDP-04-2) includes dissolved concentrations of contaminants, total concentrations of contaminants, and the TSS concentration. This allows a contaminant fraction of the TSS to be calculated so that a prediction of the total concentration of contaminants in the effluent can be determined for any effluent TSS loading (see Technical Note EEDP-04-3). The EFQUAL module automatically performs the needed data reduction and displays the results.

The test sediment concentrations and test water concentration for the contaminant may be entered for documentation purposes, but these parameters are not used in any calculations. The detection limit, the background water concentrations, and the dissolved and total modified elutriate concentrations for the contaminant are required for the computations. EFQUAL displays the TSS concentration for all replicates to aid in replicate identification for each contaminant of concern. Care should be exercised in assigning the contaminant concentrations to the correct replicate when entering the data, since this will directly affect computations of total contaminant concentrations.

Once the dissolved and total concentrations for a replicate are entered, the EFQUAL program calculates and displays a value for the contaminant fraction of the TSS. If the contaminant concentration for a replicate as determined by the test is below detection, a zero may be used for ease of data entry; however, the value of the detection limit with a less than (<) sign is displayed by the program. If the entered value of the dissolved concentration for any replicate exceeds that for the total concentration (a possibility considering variability and low concentrations), a value of zero is displayed for that contaminant fraction. After any replicate data is entered or edited, the program calculates and displays values of the mean and standard deviation for the dissolved and contaminant fractions data. No statistics are displayed for the modified elutriate total concentrations, because their mean has little value since the suspended solids concentration may vary among the replicates.

Detection Limits

The detection limit entered for each contaminant of concern plays a potentially important role in later computation of dilutions. The value entered should be the detection limit for chemical analysis of the modified elutriate samples. If elutriate concentrations of all replicates analyzed are below detection, the mean is assumed to be zero, and zero is used in subsequent computations. If one or more of the replicates is above the detection limit, the detection limit is assumed for any replicates with values below detection in computing the mean. This approach is conservative in that the predicted effluent concentrations will be higher than if zero were assumed for replicates below detection.

Background Concentrations

The value of background concentration for each contaminant is used for later computation of dilutions. This value must be determined by a separate chemical analysis of the receiving water. In some cases, the receiving water and the test water used in the modified elutriate test (water from the dredging area) are the same. If the background water or test water concentrations are below detection, a value equal to the detection limit is used in the computations of required dilution. This assumption is conservative in that the required dilution will be greater than if zero were assumed for the background concentration.

Predicted Effluent Concentrations

The EFQUAL module computes both predicted dissolved and total effluent discharge concentrations. The predicted dissolved concentrations are equal to the mean of the modified elutriate dissolved concentrations. If the total effluent concentrations will be used in the evaluation, a value of the anticipated effluent discharge TSS concentration must be given to compute the total concentrations. Column settling test results (see Technical Note EEDP 04-2) should be used to determine the effluent TSS concentration. The total contaminant concentrations are computed using the dissolved modified elutriate test concentrations, the computed contaminant fractions in the TSS, and the specified effluent TSS concentration (see Technical Note EEDP-04-3). Either the dissolved or total effluent discharge concentrations can be used for comparison with specified water quality standards and in computing required dilutions to meet standards.

Evaluation of Results

Comparison of Effluent Discharge with Standards

The output from the EFQUAL module of most interest is the comparison of predicted effluent discharge concentrations with specified water quality standards. The user has an option to choose either the dissolved or total effluent discharge concentrations and one of several sets of standards for the comparison. Any water quality standards imposed as part of a Section 401 water quality certification should be based on potential for environmental impact. The standards are usually set in terms of dissolved concentrations, but could be set in terms of total concentrations. Care should be exercised in selecting the appropriate predicted effluent discharge concentration (dissolved or total) for comparison to the standards. For example, if the standards are equivalent to or are based on the EPA acute water quality criteria, comparison of dissolved effluent discharge concentrations is technically appropriate. This is because the EPA criteria were developed using effects data for exposure of organisms to dissolved concentrations of contaminants.

Whenever the predicted effluent concentration and a standard can possibly be compared and data for multiple replicates are available, the mean of the replicate data and the standard are statistically compared considering the variance of the replicate data. The statistical test performed is a two-tailed Student's t-test (Miller and Freund 1985). The test consists of efforts to reject the null hypothesis, that is, that the two values are equal. The test does not produce a proof, but produces various confidence levels that the result is correct. The confidence level in percent that the predicted concentrations exceeds the standard (P > S _ %) or that the standard exceeds the predicted concentration (S > P _ %) is computed for each parameter. If the confidence level is less than 50 percent, then the test results indicate that the two values are essentially equal (that is, the null hypothesis cannot be rejected). Expressed another way, the confidence level of asserting that the two values are not equal is less that 50 percent ($P \neq S < 50$ percent).

Calculation of Dilution Factor

If the predicted effluent discharge concentration exceeds the standard and the standard exceeds the background concentration, a value for dilution to meet the standard is calculated. However, if both the effluent and background concentrations exceed the standard, neither the standard nor the background concentration can be met by dilution. For this case, the user specifies a percentage above the background concentration for which a dilution will be calculated (110 percent of the background or 10 percent above background is recommended for this value). Similarly, if the background concentration is less than but very close to the standard, very large dilution would be required for effluents to meet the standard. Consequently, dilution to the percentage above the background is also computed for this condition. If the background concentration is below detection, the detection limit is used for the background concentration. Use of the detection limit for background under this condition is conservative and will result in the largest dilution that could be required for the given standard and effluent concentration.

The EFQUAL module computes dilution factors for each contaminant of concern using the following equation whenever the effluent concentration is greater than the standard to be met:

$$D = \frac{P - S}{S - B} \qquad (1)$$

where

- D = dilution factor required to dilute the contaminant of concern to the appropriate water quality standard, S, volume, of background water/volume of effluent
- P = concentration of the contaminant of concern in the effluent discharge, µg/L
- S = receiving water quality standard for the contaminant of concern, µg/L (or a concentration equal to the specified percentage above background concentration)
- B = background concentration of the contaminant of concern in the receiving water, µg/L

Three concentration variables are used in the above equation. When the detection limit and a specified percentage above background are considered, there are five concentrations that can possibly be used in the comparison. Sixty different conditions are possible, considering every possible combination of the relative magnitude of the five concentrations. However, many of the conditions result in the same conclusion with respect to the interpretation of the comparison and dilution factor required, leaving only eight meaningful cases. These eight cases are illustrated in Figure 1. Additional discussion of each of the eight cases is given

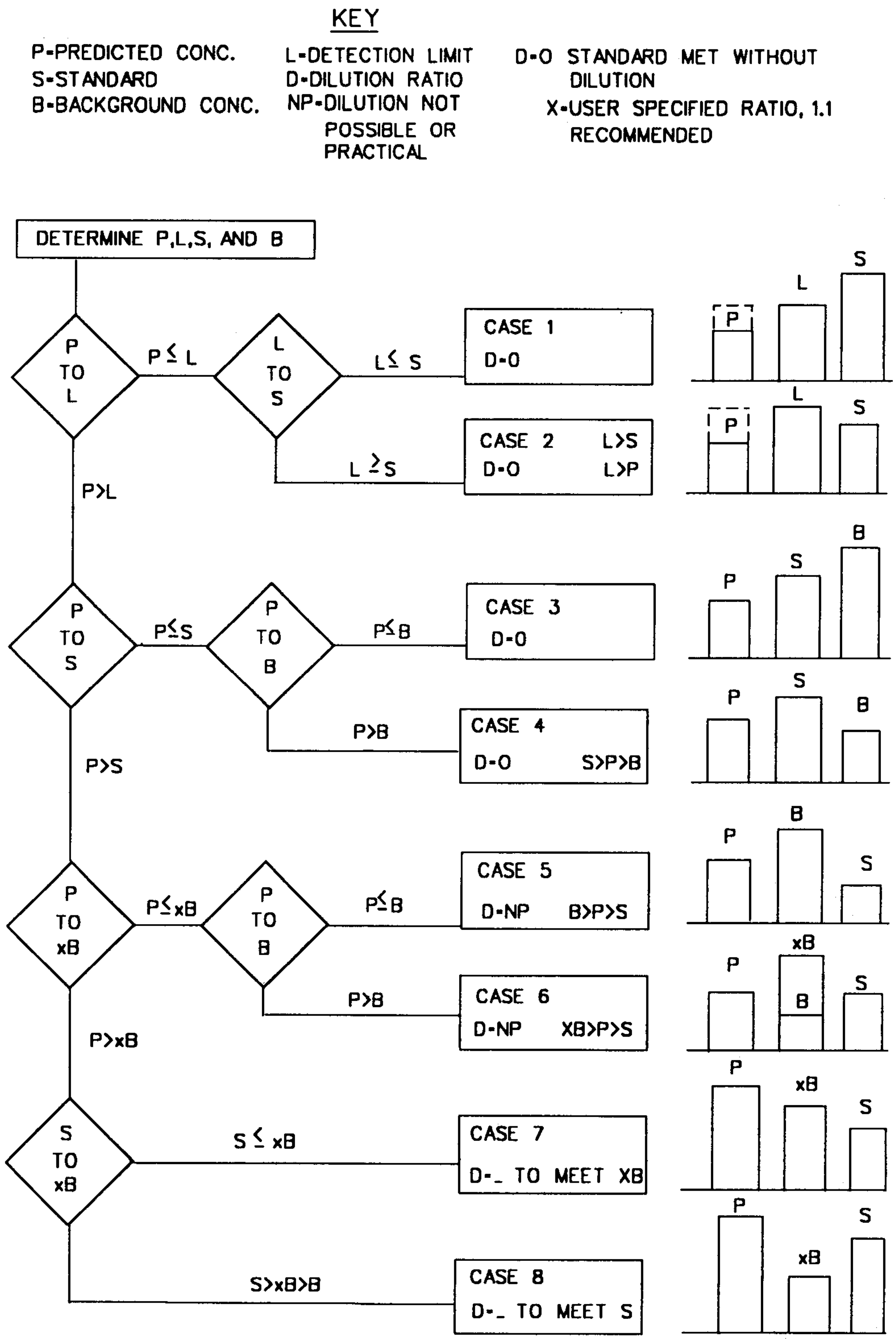

Figure 1. Possible conditions for comparison of effluent concentrations with standards

below. In addition to the symbols D, P, S, and B defined above, the following symbols are used in the descriptions of the cases:

> xB = concentration equal to a multiple, x, of the background, equivalent to S in Equation 1 when S <= xB
>
> L = detection limit for tests, used in B in Equation 1 if L > B

Case 1: S > L > P. For this case, the predicted concentration is less than the detection limit and the detection limit is less that the standard. The standard is met with no dilution, and the EFQUAL program displays the comment "D = 0" for the dilution required.

Case 2: L > (S,P). The predicted concentration and standard are both less than the detection limit. The test results do not clearly indicate that the standard is met since the exact concentration of the effluent is unknown, so the EFQUAL program displays the comment "D = 0, L > (S,P)" for the dilution required.

Case 3: (S,B) > P > L. All concentrations are greater than the detection limit, and the predicted concentration is less than the standard and the background. Under these conditions the effluent discharge is cleaner than the background receiving water for the contaminant of concern. The standard is met with no dilution, and the EFQUAL program displays the comment "D = 0" for the dilution required.

Case 4: S > P > (B,L). The predicted concentration and standard are greater than the detection limit; the predicted concentration is less than the standard; but the predicted concentration is greater than the background. The standard is met with no dilution, and the EFQUAL program displays the comment "D = 0 S > P > B" for the dilution required. This indicates that an acceptable deterioration of the background receiving water occurred.

Case 5: B > P > (S,L). The predicted concentration and background are greater than the detection limit and the standard, but the predicted concentration is less than background. Under these conditions, the standard is less than the background, and the receiving water is already in violation of the standard. Since the predicted concentration is less than the background, the receiving water will be improved for the contaminant of concern. No dilution is possible, and the EFQUAL program displays the comment "D = NP B > P > S" for dilution required.

Case 6: xB > P > (B,S,L). The predicted concentration exceeds the detection limit, the standard, and the background, but the predicted concentration is less than the specified percentage above background. Under these conditions, the predicted concentration is only slightly above the background; therefore dilution is not practical. In addition, the receiving water is already or nearly in violation of the standard. Since the predicted concentration exceeds the background, some degradation of the receiving water will occur. No dilution is practical, and the EFQUAL program displays the comment "D = NP xB > P > S" for dilution required. If B is less than L, L is used in place of B to compute xB.

Case 7: P > xB > (S,L). The predicted concentration exceeds the detection limit, the standard, and the specified percentage above background, and the specified percentage above background exceeds the standard. Under these conditions, the receiving water is already or nearly in violation of the standard. Since the predicted concentration also exceeds the background, degradation of the receiving water will occur. Dilution to meet the specified percentage above background is calculated, since the background exceeds or is very close to the standard. The EFQUAL program displays the comment "D = __ to meet xB," entering the calculated value for dilution. If B <= L, L is used in place of B to compute xB, xB is used as S in Equation 1, and L is used as B in Equation 1.

Case 8: P > S > (xB,L). The predicted concentration exceeds the detection limit, the standard and the specified percentage above background, and the standard exceeds both the background and the specified percentage above background. The dilution to meet the specified standard is calculated, and EFQUAL enters the comment "D = __ to meet S," entering the calculated value for dilution. If B is less than L, L is used in place of B in Equation 1.

Summary

These procedures provide a consistent, rational, and conservative approach to compare predicted effluent water quality with water quality standards. In addition, the approach computes dilution requirements which are needed to evaluate mixing zones.

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EEDP-06-14
February 1993

Environmental Effects of Dredging Technical Notes

Evaluating Environmental Effects of Dredged Material Management Alternatives — A Technical Framework

Purpose

This Technical Note presents a brief description of a joint U.S. Army Corps of Engineers (USACE) and U.S. Environmental Protection Agency (USEPA) Technical Framework for the identification of environmentally acceptable alternatives for the management of dredged material. *This Technical Note replaces the earlier Technical Note EEDP-06-14, which should be discarded.*

Background

The USACE and USEPA have developed a consistent Technical Framework for their agencies' personnel to follow in identifying environmentally acceptable alternatives for the management of dredged material (USACE/USEPA 1992). The USACE had previously developed a Management Strategy (Francingues and others 1985) for evaluation of dredged material alternatives, which focused on contaminant testing and controls. USEPA later initiated development of a similar management strategy focusing on environmental considerations of disposal alternatives. A USACE/USEPA work group was subsequently formed for the purpose of developing the joint Technical Framework, which has been endorsed by both agencies.

The Technical Framework is intended to serve as a consistent "road map" for USACE and USEPA personnel in evaluating the environmental acceptability of dredged material management alternatives. Specifically, its major objectives are to provide:

- A general technical framework for evaluating the environmental acceptability of the full continuum of dredged material management alternatives (open-water placement, confined (diked) placement, and beneficial uses applications).

- Additional technical guidance to supplement present implementation and testing manuals for addressing the environmental acceptability of available management options for the discharge of dredged material in both open-water and confined sites.
- Enhanced consistency and coordination in USACE and USEPA decision-making in accordance with Federal environmental statutes regulating dredged material management.

Additional Information

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Introduction

Dredged material placement is regulated by the Marine Protection, Research, and Sanctuaries Act (MPRSA), also called the Ocean Dumping Act, and the Federal Water Pollution Control Act Amendments of 1972, also called the Clean Water Act (CWA). The requirements of the National Environmental Policy Act (NEPA) and its implementing regulations must also be considered in evaluating alternatives. The Technical Framework is designed to meet the procedural and substantive requirements of NEPA, CWA, and MPRSA in a technically consistent manner.

The Technical Framework described herein is intended to be applicable to all proposed actions involving the management of dredged material. This includes both the new work construction and navigation project maintenance programs of the USACE as well as proposed dredged material discharge actions regulated by the USACE. Further, the document addresses the broad range of dredged material, both clean and contaminated, and the broad array of management alternatives — confined (diked intertidal and upland) disposal, open-water (aquatic) disposal, and beneficial use applications.

Application of the Technical Framework will allow for consistency in decision-making across statutory boundaries and consideration of the full continuum of dredged material discharge options. For example, application of the Technical Framework will help ensure that open-water discharge does not hinder the development and use of other options, such as confined upland sites. The guidance established by the Technical Framework should reduce confusion by both regulators and the regulated community in all future evaluations.

Overview of Technical Framework

The Technical Framework for determining environmentally acceptable placement alternatives for dredged material can be applied nationwide and is relatively general, but comprehensive. It addresses a wide range of dredged material characteristics, dredging techniques, and management alternatives. Because the Technical Framework provides national guidance, flexibility is necessary. It should not be followed rigidly; rather, it should be used as a technical guide to evaluate the commonly important factors to be considered in managing dredged material in an environmentally acceptable manner. The Technical Framework is consistent with and incorporates the evaluations conducted under NEPA, CWA, and MPRSA and consists of the following broad steps:

- Evaluation of dredging project requirements.
- Identification of alternatives.
- Initial screening of alternatives.
- Detailed assessment of alternatives.
- Alternative selection.

Detailed Assessments

For both open-water and confined placement alternatives, the detailed assessment of alternatives includes the following broad steps:

- Determining the characteristics of disposal sites.
- Evaluating direct physical impacts and site capacity.
- Evaluating contaminant pathways of concern.
- Evaluating control measures.
- Retaining environmentally acceptable alternatives.

This technical note focuses in detail on the evaluation of contaminant pathways of concern.

Contaminant Pathways

Any contaminant testing should focus on those contaminant pathways where contaminants may be of environmental concern, and the testing should be tailored to the available disposal site. For aquatic sites, contaminant problems may be related to either the water column or benthic environment. For confined sites, potential contaminant problems may be either water quality related (return water effluent, surface runoff, groundwater leachate), contaminant uptake related (plant or animal), or air related (gaseous release).

Design of a testing program for the sediment to be dredged depends on the pathways of concern for the alternative being evaluated. Protocols have been developed to evaluate all contaminant pathways of concern and consider the unique nature of dredged material and the physicochemical conditions of each placement site under consideration.

The testing guidelines that have been developed jointly by the USEPA and USACE generally incorporate a tiered approach and a scientifically based decision process that uses only the level of testing necessary to provide the technical information needed to assess the potential chemical and biological effects of the proposed discharge of dredged material.

Management Actions or Control Measures

In cases where results of tests and assessments indicate that the MPRSA Impact Criteria or CWA Guidelines for a given pathway will not be met, management actions may be considered to meet the Criteria or Guidelines. Possible controls for open-water alternatives include operational modifications, use of submerged discharge, treatment, lateral confinement, and capping or contained aquatic disposal. Possible controls for confined placement include operational modifications, treatment, and various site controls (for example, covers or liners).

Retention of Environmentally Acceptable Alternatives

With the completion of detailed testing and assessments and the consideration of management and control measures for the respective alternatives, a determination of environmental acceptability is made. This determination must ensure that all applicable standards or criteria are met. If control measures are considered, a determination of the effectiveness of the control measure in meeting the standards or criteria must be made. If all standards or criteria are met, the alternative can be considered environmentally acceptable. At this point in the Technical Framework, socioeconomic, technical, and other applicable environmental considerations must be evaluated before selecting a management alternative.

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EEDP-06-15
December 1991

Environmental Effects of Dredging Technical Notes

Risk Assessment: An Overview of the Process

Purpose

This technical note provides a nontechnical overview of the risk assessment process. A companion technical note regarding risk assessment terminology will be published in the near future.

Background

In November 1989, Chief of Engineers LTG Henry J. Hatch convened the Environmental Advisory Board (EAB) to discuss the Dredging Program and its potential impact on wetland development and coastal erosion protection. The EAB is a blue-ribbon panel of outside experts which normally meets every 6 months to hear discussions and develop recommendations on any environmental topic of concern to the Chief of Engineers. At the November meeting, personnel from the US Army Engineer Waterways Experiment Station briefed the EAB on topics such as the Long-Term Management Strategy (LTMS), inshore versus offshore placement of dredged material, effects-based testing of dredged material, and research and development needs to support the Dredging Program. A central theme emerged in the EAB's response to these topics for the Chief of Engineers. The Corps must more fully use the risk assessment process, its concepts and procedures. LTG Hatch's response was positive: "Risk assessment should be much more fully utilized in dealing with both contaminated and uncontaminated dredged materials." LTG Hatch also called for additional research on risk assessment in response to the EAB recommendation. This technical note represents the initial effort by the Dredging Program in Headquarters, US Army Corps of Engineers to implement the EAB recommendations.

Additional Information

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Historical Perspective

The foundation of contemporary risk assessments began some 40 years ago in the US Food and Drug Administration (FDA). The FDA is charged, in part, with ensuring food products in interstate commerce are "safe." To assess the risks posed by man-made chemicals the FDA adopted an approach using safety factors. That is, the "safe" level of a chemical was some fraction (usually 0.01) of the lowest concentration shown in laboratory studies to have an adverse effect. This approach was satisfactory for a while.

In 1958, Congress passed the Delany Amendment to the Food, Drug, and Cosmetic Act. Although well intentioned, this legislation prohibited the presence of *any* chemical in *any* product regulated by the FDA shown to cause cancer in *any* test under *any* circumstance. This total prohibition was based on the belief subscribed to by most scientists at the time that no safe level of exposure to a carcinogen could be established. The impact of the Delany Amendment was not fully felt until the mid-1960s when chemists began detecting more and more contaminants at lower and lower concentrations virtually everywhere they looked.

Advances in analytical chemistry, in particular high-resolution gas chromatography, lowered detection limits greatly, often by orders of magnitude. In addition, an increasing number of biological tests were indicating that many chemicals in common everyday use were causing cancer in laboratory animals.

The combined impact of these events created a significant scientific, legal, and economic dilemma. On one hand, the Delany Amendment mandated zero risk in FDA-related products. On the other, strict enforcement would literally shut down interstate commerce and have severe economic effects nationwide.

To solve this dilemma, the FDA adopted a *de minimis* policy. This basically said that chemicals at very low concentrations posed inconsequential human health risk. (*De minimis* is a shortened form of *de minimis non curat lex* — a legal doctrine which indicates that the law does not concern itself with trifles.) Although the FDA was criticized by many for taking this approach, the scientific community could provide no reasonable alternative.

At this same time the public and other Federal agencies were becoming more aware and concerned about pollutants in the workplace (for example, benzene and vinyl chloride), the environment (for example, mercury and DDT) and the home (for example, formaldehyde and radon). In 1981, the FDA asked the National Academy of Sciences (NAS) to review the science supporting the evaluation of human health risks posed by man-made chemicals. The NAS was also asked to recommend to Federal departments and agencies a sound consistent approach for assessing those chemical risks. The result was a watershed document, the NAS "Red Book." In it the NAS proposed a general approach for assessing human health risks (National Research Council 1983). This paradigm has been the blueprint for virtually all risk assessments conducted since that time. The US Environmental Protection Agency (EPA) vigorously embraced the NAS risk assessment paradigm and has used it extensively to evaluate human health risks at hazardous and toxic waste (HTW) sites under its Superfund program.

Overview of the Risk Assessment Process

There are four elements in the risk assessment process: hazard identification, dose-response assessment, exposure assessment and risk characterization. Each step is summarized below.

Hazard Identification

This is the process of showing *causality*, that is, does a chemical cause cancer (a carcinogen) or induce some other adverse effect such as reproductive dysfunction or birth defects (a teratogen)? If this causality can be demonstrated, the chemical is referred to as a "hazard." In theory, hazard identification yields a quantal yes-or-no answer to the causality issue. In practice, the available evidence generally does not permit an unequivocal answer to the causality question. Consequently, when deciding whether a chemical is a hazard, the total weight of the evidence as well as the strength of the relationship are evaluated using guidance such as Hill's criteria (Hill 1965). Types of evidence considered in hazard identification include laboratory toxicity studies for both carcinogens and noncarcinogens, epidemiological studies, clinical case studies, and quantitative structure-activity relationships.

Dose-response Assessment

While hazard identification decides whether a chemical is toxic, the dose-response assessment determines the magnitude of the toxic response. This is almost always accomplished experimentally in the laboratory. Rats or mice or some other mammal acting as human surrogates are exposed to high concentrations of the chemical hazard and some effect (for example, incidence of tumors) is monitored over time. Results are typically expressed in dose-response curves, that is, the quantitative relationship between the administered chemical dose and observed biological response. To use these data in assessing environmental risks, results must be extrapolated from high dose to low environmentally realistic exposures and from surrogate test species to human beings. These extrapolations can be the source of considerable uncertainties.

In dose-response assessment, a clear distinction is made between carcinogenic and noncarcinogenic chemicals. For carcinogens, it is currently assumed that no "safe" concentration or threshold exists. All the data from the laboratory experiment are used to calculate the slope of the dose-response curve. The upper-bound 95 percent confidence limit of the slope (slope factor) reflects the chemical's cancer potency. In contrast, a threshold concentration is assumed to exist for noncarcinogens. Below this threshold concentration no adverse effects can be expected to occur. Concentrations just above and below the threshold are called the lowest-observed-adverse-effect level (LOAEL) and the no-observed-adverse-effect level (NOAEL), respectively. The LOAEL and NOAEL are used to calculate the toxicity or reference dose (RfD).

Exposure Assessment

In exposure assessment, the magnitude, frequency, and duration of chemical exposure relative to the target receptor(s) are determined. This process is model-intensive with both descriptive and quantitative models being used. Here, a distinction is made between pathways and routes. A pathway is where the chemical travels between the initial source of contamination and the ultimate biological receptor. A route is how the chemical enters the receptor (for example, ingestion, inhalation, or dermal adsorption). EPA currently uses a reasonable maximum exposure (RME) for most exposure calculations. The RME is defined as the upper 95 percent confidence limit of every exposure parameter.Exposure is generally assumed to occur over a full lifetime (70 years) or a working lifetime (30 years).

Risk Characterization

Outputs from the dose-response assessment and exposure assessment are brought together to produce a numerical estimate of chemical risk. For noncarcinogens, this risk is expressed as a hazard quotient (HQ) or the ratio between RME and RfD. Chemical risks increase as the HQ approaches unity. For carcinogens, risks are expressed as the upper bound (95 percent confidence limit) estimate of number of humans developing cancer. The *de minimis* risk most often cited is 10^{-6} or one in a million individuals. It is crucial to remember that the numerical estimate of risk is an upper-bound calculation and that the true risk lies somewhere between zero and this upper-bound estimate. EPA has provided recent guidance indicating that upper-bound lifetime cancer risks between 10^{-4} and 10^{-6} are acceptable at Superfund sites following remediation (EPA 1990). Finally, the uncertainties associated with the risk assessment process are addressed during the risk characterization stage.

Risk Management

Once the chemical risk has been assessed, it must then be managed. This is the job of the risk manager. Management alternatives range from no action to extensive (and expensive) remediation. Chemical risks are almost always managed by controlling the potential for *exposure.* The intrinsic toxicity or dose-responsiveness of a chemical can rarely, if ever, be altered. In developing a management plan, the risk manager considers not only the results of the risk assessment, but factors such as applicable laws and regulations, engineering feasibility, potential benefits, costs, economic impacts, and the socio-political decision environment. Clearly, this process is very similar to the one undertaken by District Engineers and their staffs in evaluating the potential environmental impacts of dredging operations.

The NAS strongly recommended that risk management be a discrete activity clearly separate from the risk assessment process. It was felt that the assessment of chemical risks should be carried out independently, free from potential biases such as political pressures or remediation costs. While this compartmentalization may increase the technical purity of the risk assessment, the risk assessor and risk manager must communicate at some point early in the process if the technical results are to be useful.

Risk Communication

Risk communication is a dialogue, not a monologue. It occurs at two levels. The first is between the risk assessor and the risk manager. In practice, this usually occurs during risk characterization when the assessor communicates technical findings to the manager. The manager must be provided a clear and accurate picture of the results including an appreciation for the limits and uncertainties. If this does not occur, then the next level of risk communication, risk manager to the public, will be unsuccessful. At this step, the public includes not only the general public, but also all other interested parties such as resource agencies, other Federal agencies, special interest groups as well as the human population which may be at risk.

Risk Analysis

Risk analysis is a broad, inclusive term encompassing the processes of risk assessment, risk management, and risk communication, as well as any field verification or monitoring activities. Field verification includes studies carried out to determine the accuracy of laboratory observations and predictions. Field monitoring (in the context of risk assessment) is undertaken to ensure that steps taken to manage the chemical risks have been successful. Risk analysis and its component parts are shown in Figure 1.

Uncertainties in the Risk Assessment Process

Assessing risk will *always* involve uncertainty. If there were no uncertainties, there would be no risk and answers to questions would be known with precision and accuracy. The uncertainties associated with numerical estimates of chemical risk can be quite large. Some of the more important sources of uncertainty include the classification of chemicals as carcinogenic versus noncarcinogenic, extrapolating dose-response data from laboratory animals to humans and from high dose to low dose, selection of appropriate exposure models, and parameter inputs for those models. To cope with these potentially large uncertainties, conservative assumptions and safety factors are used throughout the risk assessment process. While this greatly diminishes the possibility of underestimating risks, it can also lead to very unrealistic, some would say, unusable answers. Uncertainty analysis, error propagation, safety factors, and the appropriate use of conservative

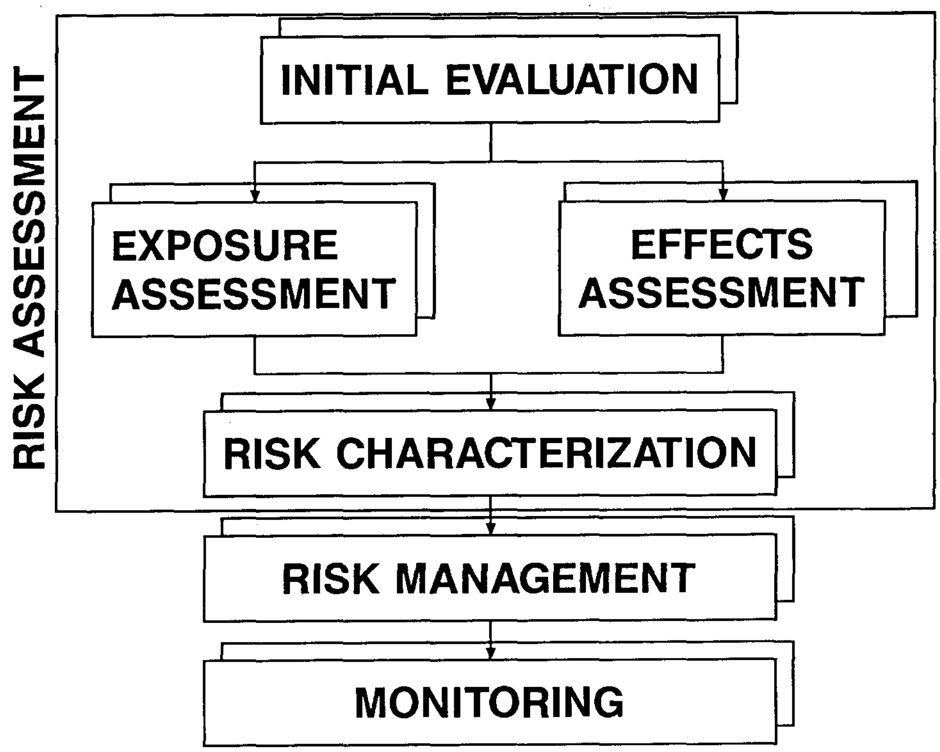

Figure 1. Risk Analysis

assumptions are now receiving greater attention by policy makers and the technical community.

Nonhuman Target Receptors

Traditionally, risk assessments have focused almost exclusively on human beings as the target receptor for man-made chemicals. Methods and data bases have all been developed from the human health perspective. Only now are approaches being considered to assess chemical risks to nonhuman target species. Some methods will probably be modifications to technologies used now for human health risk assessments. However, new and innovative procedures will undoubtedly need to be developed. For example, what are the appropriate test species? In human health assessment, many mammalian species are used when there is only one receptor species of concern. In assessing risks to nonhuman species there may be many target receptor species. What suite of test animals is most appropriate? What type of extrapolation is required? Human health risk assessments are chemical specific. While this may be appropriate for nonhuman target species, an effects-based approach may be more desirable especially when exposure is to complex mixtures such as contaminated sediments. Another issue to resolve is endpoint selection. In human health risk assessment, the only endpoints have been carcinogenesis and teratogenesis. When nonhuman target receptors are of concern, the number of potential endpoints is virtually limitless. These and other issues will require considerable time and effort to resolve.

Potential Application of the Risk Assessment Process to Corps Dredging Operations

Before discussing *how* risk assessment could be applied to Corps dredging operations, a more fundamental and legitimate question to ask is *why* should it be considered at all. The incentives for seeking risk-based solutions are found in the current decision-making environment for dredging operations:

- Regulatory decisions are always made in the absence of complete and certain data.
- Achievement of zero risk is impossible.
- Achievement of near-zero risk may be cost-prohibitive.
- Everyone will accept a certain amount of risk.

Using a risk-based approach in this decision-making environment has political, managerial, and technical advantages. Some of these are described below.

- Environmental risk assessment is the only approach currently available for quantifying chemical risks which has broad acceptance in the scientific and regulatory communities. It is not perfect and has its critics, but a logical, technically sound alternative for estimating chemical risks has yet to emerge. Risk assessments have been and will continue to be conducted by individuals and agencies within and outside the Federal government. Using an approach that is used and recognized by major portions of the scientific and regulatory communities (EPA, for example) will help ensure that Corps technical results and regulatory decisions are more readily accepted.
- The risk assessment process treats uncertainties explicitly. This eliminates the need for worst-case testing scenarios. When properly designed and conducted, risk assessments yield a continuous solution as opposed to a discrete yes-or-no answer. This solution is expressed in the form of *probability distributions*. While some managers (and scientists) will feel uncomfortable with this type of technical output, it offers considerable flexibility for the type of weighing and balancing that must be done in implementing Congressionally-mandated programs.
- Regulators are charged with making decisions, not finding scientific truths. The risk assessment process is commensurate with this charge because it deals with probabilities, not absolute truths.
- Risk assessments are, by their nature, highly conservative. Therefore, if projected chemical risks are found to be acceptable (for example, excess lifetime cancer risks of 10^{-4} to 10^{-6}), the risk manager and the manager's constituency can be assured that the actual risk is quite low. This is because the highly conservative process yields upper-bound risk estimates.

- If projected risks are not acceptable (for example, excess lifetime cancer risks $\geq 10^{-4}$), the risk assessment process offers a means of identifying where the problems are and how they can be corrected. Sensitivity analysis is the manager's tool for pinpointing these critical elements. Once the important forcing functions have been identified, supporting data and assumptions may be more closely scrutinized. If the data associated with these elements is poor or nonexistent, the risk manager has the option of collecting additional information. If the knowledge domain is sufficient, sensitivity analysis will help focus the risk management activities to the most critical elements.

- Large uncertainties can be partially ameliorated by conducting *comparative* or *incremental* risk assessments. In this approach, the quantitative *difference* associated with various scenarios is examined rather than the *absolute* risk of each. Many conservative assumptions and large uncertainties are common to each scenario and, thus, become moot. For example, one could calculate the incremental risk associated with relocating dredged material in a waterway versus taking no action. Conservative assumptions and large uncertainties common to both actions become irrelevant. It is the *difference* between the two which is important.

- Finally, using a risk-based approach has a distinct managerial advantage. Risk assessments identify what is important, what is unimportant, and what is unknown. This permits managers to allocate critical and usually limited resources to areas of greatest need. It provides an objective way for the manager to identify knowledge gaps and direct resources in such a manner that will facilitate the future conduct of his or her job.

Applications to Navigation Dredging

The Corps' statutory authority for disposal or discharge of dredged material into the ocean or waters of the United States comes, respectively, from Section 103 of the Marine Protection, Research, and Sanctuaries Act of 1972 (PL 92-532) and Section 404(b)(1) of the Federal Water Pollution Control Act of 1972 (Public Law 92-500), as amended. Both laws specify that there shall be "no unacceptable adverse impacts" on the environment as a result of dredging operations. It is important to note that the law permits some "adverse impacts" as long as they are not "unacceptable." This statutory language strongly suggests a risk-based technical evaluation.

The Corps uses a tiered testing effects-based approach for assessing dredged material. Bioassays are conducted to determine the toxicity of project sediment to appropriate sensitive animals and to determine the bioaccumulation potential of sediment-associated contaminants. Results are compared to a reference sediment which represents the disposal environs in the absence of disposal activities. The procedure is technically sound, enjoys wide acceptance, and reflects a judicious marriage of state-of-the-art and the requirements for routine testing in a regulatory program. In most instances, however, this approach yields a qualitative yes-or-no answer. That is, dredged material is found to be either acceptable or not acceptable for unrestricted disposal. Current procedures do not permit the manager to quantitate how "acceptable" or "unacceptable" the project sediment is. This is where a risk-based assessment procedure could more fully used.

Historically, most sediments have been found to be "acceptable." Those considered marginal or "unacceptable," while representing a small volume of total material dredged, consume a disproportionately large share of limited resources. These costs, expressed as time, money, and productivity, are initially borne by the Corps and permit applicants. Ultimately, they are passed on to the consumer and taxpaying public. The lack of technically sound procedures for assessing the *probability* of adverse impacts associated with dredging operations is a major reason additional testing is always requested. To the manager or permit applicant the evaluation and testing probably seem to go on forever. If risk-based procedures were available to Corps Districts and Divisions, they would be able to balance potential environmental impacts with other factors (for example, costs) in a more technically defensible manner. These procedures would also provide the risk manager with a quantitative means of comparing the risks associated with different disposal options (for example, diked containment or upland confined disposal facility) including the no-action alternative. Corps Districts and Divisions carry out this weighing and balancing now, but the process is subject to criticisms of subjectiveness, bias, and inconsistency. Formal procedures for determining the degree of "unacceptable adverse impacts" of dredged material disposal would help mute these criticisms and signal a significant technical step forward. It would also likely increase the Corps' credibility among local agencies, the public, and the courts.

Applications to Environmental or Clean-up Dredging

Sediments tend to act as sinks for environmental contaminants. In some lakes, rivers, harbors, and waterways, nonnavigational dredging may be considered as a means of cleaning up or remediating sites which are highly contaminated and pose substantial risk to human health and the environment. This environmental or clean-up dredging may be conducted under four separate authorities. The oldest, but least used is Section 115 of the Federal Water Pollution Control Act of 1972 (PL 92-500). This section authorized the EPA Administrator, acting through the Secretary of the Army, to remove and appropriately dispose of in-place toxic pollutants from harbors and navigable waterways. To date, only one Section 115 action has been carried out — dredging in 1974 of spilled polychlorinated biphenyls in the Duwamish River in Seattle, WA.

The second, more familiar authority under which environmental dredging can occur is the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Superfund. In 1980, Congress authorized $1.6 billion for CERCLA for over five years to clean up hazardous materials at sites across the country. Many of these sites contain highly contaminated soils and sediment. One such site, New Bedford Harbor, MA, was the focus of a recent interagency study evaluating the environmental and engineering feasibility of dredging and dredged material disposal alternatives (Averett 1990).

The third authority is the Department of Defense's (DOD) Defense Environmental Restoration Program (DERP). DERP is analogous to the civilian Superfund program, but is specific to active and formerly used DOD installations. The two programs are so inextricably linked that when the CERCLA was reauthorized in 1986 (Superfund Amendments and Reauthorization Act (SARA) (PL 99-499)), DERP was included as Section 211 of this Act. Under DERP, the Secretary of Defense, in consultation with the Administrator of EPA, may carry out investigations and clean-up activities at DOD facilities in a manner consistent with the same procedural and substantive requirements used at civilian sites under the Superfund program. The Corps has been assigned the responsibility for Army sites involved in DERP activities. Human health risk assessments are conducted by contract and reviewed by the US Army Environmental Hygiene Agency prior to approval by the US Army Surgeon General. In both the Superfund Program and DERP, the US Army Engineer Division, Missouri River has the lead for remedial design and action.

The fourth and final authority for clean-up dredging is also the most recent. Under Section 312 of the Water Resources Development Act of 1990 the Corps was authorized to conduct environmental dredging in association with civil works navigation projects within certain spatial, financial, and sponsorship limitations. Field guidance for this authority is currently being prepared by Headquarters, US Army Corps of Engineers.

Under all four authorities, risk assessment can be used to establish effects-based clean-up goals for environmental dredging. It answers the question, "How clean is clean?" This is critical because clean-up to background, while desirable, is often not possible. For example, what constitutes "background" is often not clear. Risk assessment allows one to specify clean-up goals that are risk-based. Since outputs are expressed as probabilities, one can balance benefits achieved (that is, risk reduction) with other factors such as clean-up costs. This is a particularly attractive feature since costs associated with clean-up dredging typically run 1-2 *orders of magnitude* above navigation dredging ($1-$5/cu yd).

Applications to other Corps Operations

Could the risk assessment paradigm be applied to Corps operations other than dredging; for example, the management of wetlands, lakes, reservoirs, and watersheds? There is no reason not to think so. The risk assessment process can be applied whenever there is uncertainty regarding a particular action or activity. The only obstacle would be the appropriate technical tools for assessing exposure and effects.

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Environmental Effects of Dredging Technical Notes

Long-Term Management Strategy (LTMS) National Forum: Corps of Engineers Summary and Findings

Purpose

This Technical Note summarizes the National Forum on Implementation Strategies of Long-Term Management of Dredged Material held January 28-31, 1991, at Baltimore, MD. The findings of the Forum have been documented in a report to be published by the Environmental Effects of Dredging Programs (EEDP) in FY 92. The information gained from the Forum participants is also being incorporated into proposed policy and technical guidance to help direct, develop, and implement Long-Term Management Strategy (LTMS) studies and plans by the US Army Corps of Engineers (USACE).

Background

The USACE needs long-term dredged material management solutions to properly and efficiently maintain the Federal navigation program. Locating and retaining environmentally and economically acceptable dredged material disposal sites is a major management problem facing the national dredging program today (US Congress, Office of Technology Assessment 1987).

The USACE headquarters has received from its field offices a considerable number of high-priority funding requests to develop individual LTMS plans for Federal navigation projects with strong national economic implications. The broader scoped, regional or geographically based studies such as San Francisco Bay and Upper Chesapeake Bay/Baltimore Harbor are the focus of attention because of their scope, controversy, and economic and potential environmental impacts. The need also encompasses the nation's future ability to maintain a number of recently constructed deep-draft harbors. The need is equally evident for several national defense ports, where, unfortunately, emergency dredging is the norm rather than the exception due to the present inability to establish feasible long-term dredged material management solutions. However, the greatest need relates to providing dredged material disposal site capacity for individual project reaches. In many cases, this has resulted in the inability to achieve the maximum intended project benefits, and, in some cases, continued project viability itself has been jeopardized.

To respond to this need, the USACE began a major new initiative to develop the appropriate management process, procedures, and policy guidance for incorporating the concept of LTMS as a management tool into the USACE national dredging program (Francingues and Mathis 1989). Considerable progress has been made in refining the LTMS concept to more effectively and efficiently address the Nation's diverse dredging needs. As part of this refinement process, the Corps hosted the National Forum to exchange information, views, experiences, and lessons learned concerning LTMS and to identify innovative procedures, tools, and impediments to implementing LTMS plans. The Forum was attended by approximately 170 representatives of a very diverse cross-section of Federal, State, and local governmental agencies, port authorities, environmental groups, private consultants, and concerned citizen groups.

Additional Information

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Long-Term Management Strategy (LTMS) National Forum

The National Forum on Implementation Strategies of Long-Term Management of Dredged Material was held in Baltimore, MD, January 28-31, 1991. It was sponsored by the US Army Corps of Engineers (USACE). The meeting was organized by EA Mid-Atlantic Regional Operations, EA Engineering, Science, and Technology, Inc., Sparks, MD, under contract with the US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS.

MG Patrick Kelly, Director of Civil Works, and Dr. Tudor Davies, Director of the US Environmental Protection Agency's (USEPA) Office of Marine and Estuarine Protection, presented their Agency's views on LTMS development, current status, and future direction. Panel presentations were made on a variety of pertinent issues; five illustrative case studies and eight poster presentations were also given.

Overview of LTMS - the Process

The LTMS process developed and presented by the USACE at the Forum consists of five phases to help guide LTMS studies and plan development and implementation. Each phase consists of essential activities before proceeding to the next appropriate phase. The process is described in detail in *Environmental Effects of Dredging Technical Notes* EEDP-06-10 (Francingues and Mathis 1990), which was provided to each meeting participant at registration. A brief description of the five phases follows.

Phase I is a comparison of disposal needs versus available capacity and is extremely important in defining the needs and required scope of the study and LTMS plan.

Phase II is the systematic development and retention of all viable long-term management options that meet the specific study goals and objectives developed during Phase I. This includes, where appropriate, in-water, upland, ocean, and beneficial use options.

Phase III is the selection of the most practicable LTMS plan consisting of one or more alternatives for implementation and the necessary in-house documentation needed to support this selection.

Phase IV, plan implementation, and Phase V, periodic plan review and update, are specific steps that have been lacking in many previous applications of the LTMS concept. These phases require the dredging manager to face head-on the major unknown question with the LTMS concept—how to effectively implement an LTMS plan once agreed to by all parties concerned, while simultaneously providing appropriate review and updating to ensure the continued long-term viability of the established plan. These two components are intrinsically interrelated, and both are essential for effective LTMS plan implementation.

LTMS Objectives

Some of the objectives for LTMS include:

- Reduction of cost and time for Operations and Maintenance (O&M) dredging.
- Increased regulatory and permit efficiency.
- Improved long-term planning.
- Potential for local sponsor agreements.
- Avoidance of crisis management.

Scope and Criteria for LTMS

The scope of individual LTMS plans should be flexible and may involve single projects or project reaches or groups of projects with common dredged material management needs or geographic boundaries. The following national criteria have been established for developing an LTMS:

- The LTMS must include all foreseeable Federal new-work, O&M, and non-Federal project-related dredging activities. The basic premise is that it is not in the best public interest to construct a Federal project if there are no reasonable assurances that the project can be maintained and intended project benefits accrued over the long-term.

- Whenever possible, the LTMS should be for the anticipated project life. The target goal is to plan for 50 years into the future, but in no case for less than 10 years.

- The LTMS should fully address both structural and nonstructural alternatives for maintaining navigation. Every effort should be made to seek means of reducing dredging requirements and costs for the individual navigation projects.

- The LTMS must consider all practicable dredging and dredged material management alternatives. No one option can be considered a panacea for dredged material disposal, nor can it be ruled out in the initial planning process for other than sound economic, environmental, and engineering reasons.

- Beneficial uses of dredged material are to be incorporated whenever practicable.

- Site management, both upland and open water, is essential and required for successful implementation of LTMS plans.

- The LTMS plan must provide for periodic review, revision, and update, and must incorporate, whenever appropriate, new improvements in dredging equipment and dredged material management technologies.

What is LTMS?

Essentially LTMS is a process for providing reasonable assurances that navigation projects can be effectively maintained and anticipated benefits can be accrued over the long-term (for example, the economic life of the project). In short, LTMS can be viewed as:

- A USACE process rather than a program, and not a process funded separately from new work construction or O&M navigation dredging.

- A five-phase process that incorporates long-range solutions to navigation dredging needs consistent with existing USACE planning, engineering, construction, and O&M programs.

- A potential mechanism to focus and facilitate the use of existing and innovative procedural and regulatory instruments (for example, special area management, advanced identification of sites, and general and regional permits) for implementing comprehensive dredged material management plans.

- A potential mechanism to provide information/technology transfer to other agencies and the public.

- A forum to assist better coordination, foster cooperation, and to provide consensus-building opportunities to achieve preferred dredged material management consistent with USACE authorities, regulations, and established policies.

What LTMS is Not

Because of the misconceptions conveyed by several of the Forum participants and for clarification, it is important to highlight clearly features which LTMS is not presently intended to provide. Therefore, LTMS is not:

- A formally institutionalized, new program with a major new authorization and appropriation.

- The source of funds to pursue environmental initiatives not clearly established by present authorities for the USACE at the expense of the national navigation program.

- An environmental habitat restoration program.

- A contaminated sediment cleanup program.

Corps Assessment of Forum Findings

Most of the Forum participants, including the regulatory agencies, were very receptive and supportive of the LTMS concept. Many expressed a desire and willingness to fully cooperate in developing and implementing long-term solutions to the problem of managing dredged material.

The Forum findings have been categorized for presentation according to the following broad topics: implementation; beneficial uses of dredged material; contaminated sediments; public awareness, communication, and education; and recommendations.

Implementation

- Partnerships and participation in developing and implementing LTMS plans received considerable discussion concerning roles and responsibilities of various participants in the LTMS process.

- Federal implementation instruments can only be fully effective where there is a sponsoring local agency to reflect local needs and issues (for example, balancing development and resource conservation/protection). This will require greater consensus on what constitutes technically defensible priority habitats and values.

- Procedural instruments are presently available and workable for the effective implementation of LTMS plans. There are no major procedural impediments to using existing instruments; however, there may be different geographical considerations in the use of various instruments. The LTMS process should, in fact, help to focus or serve as a catalyst to facilitate the use of existing procedures or processes.

- The regulatory community must play a major role in LTMS plan implementation. The benefits will not only result in fully implementable solutions but also in reducing the overall regulatory workload.

- The states often have an essential role in effective LTMS plan implementation through Coastal Zone Management (CZM), land-use planning/zoning, and long-term certifications.

- LTMS implementation requirements and procedures are equally applicable to navigation and habitat restoration projects.

- Implementation of long-term management plans specific to dredged material received less discussion and attention than was originally envisioned. This was attributed primarily to confusion concerning the apparent hierarchy of related environmental management issues that tended to overshadow the objectives of the Forum. This hierarchy of issues includes resource management (for example, National Estuary Program and Coastal America), sediment management to include contaminated sediments and source reduction, and dredged material management for navigation and beneficial uses.

Beneficial Uses of Dredged Material

- Beneficial use of dredged material was identified by many participants as their option of first choice. In fact, this item led to considerable discussion of the Federal Standard concept versus the "least-cost, environmentally acceptable beneficial use alternative."

- As emphasized by Forum participants, establishing priority environmental resources and values must be a focus. The need is critical in developing long-term resource management plans for appropriately locating future dredged material disposal sites, guiding future beneficial use applications of dredged material, using mitigation strategies to include related instruments such as mitigation banking and, in light of new USACE authorities, incorporating future fish and wildlife habitat restoration projects.

- The fact that dredged material is a valuable resource and the many potential beneficial uses of dredged material must be clearly demonstrated to the public. Unfortunately, the public has the misconception about the volume of sediment that is actually contaminated because of the focus on noxious types of waste dumping activities (for example, sludge and municipal refuse).

Contaminated Sediments

- Contaminated sediments received considerable discussion time. Participants were concerned about how much material was contaminated and where was it located; how to define contaminated sediments; how to test it; which procedures were acceptable; and what methods were available to manage highly contaminated sediments.

- The reduction and control of sources of sediment load and contamination to navigation projects were highlighted as a major need. USEPA is developing a Contaminated Sediment Management Strategy in which the USACE should play a significant role, in light of the USACE's new authorities for environmental dredging and the potential applicability of the LTMS concept for managing contaminated sediments.

Public Awareness, Communication, and Education

- There is a need for more effective communication with, and better education and involvement of, the public in finding solutions to the problem of long-term management of dredged material. Some at the Forum suggested that LTMS would be an excellent medium for this purpose.

- It is also important to educate USACE and other Agency staff about how other long-term solutions to dredging problems have effectively involved the public to increase the probability of success on each new project(s) considering an LTMS.

Recommendations

- Environmental and economic factors dictate that the USACE proceed with developing policy and procedural guidance to implement the LTMS concept for the existing navigation program and within the existing funding authorities.

- LTMS policies and procedures should remain sufficiently flexible to allow the pursuit of related sediment management objectives (for example, management of highly contaminated bottom sediments). This should be done in conjunction with individual LTMS studies where it is in the best public interest and cost effective to do so and where supplemental funding sources can be identified and are provided.

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Environmental Effects of Dredging Technical Notes

Documentation of the DYECON Module for ADDAMS: Determining the Hydraulic Retention and Efficiency of Confined Disposal Facilities

Purpose

This technical note describes procedures for determining mean hydraulic retention time and efficiency of a confined disposal facility (CDF) from a dye tracer slug test. These parameters are required to properly design a CDF for solids retention and for effluent quality considerations. Detailed information on conduct and analysis of dye tracer studies can be found in Engineer Manual 1110-2-5027, "Confined Dredged Material Disposal" (Office, Chief of Engineers (OCE), U.S. Army 1987). This technical note documents the DYECON computer program which facilitates the analysis of dye tracer concentration data and computes the hydraulic efficiency of a CDF as part of the Automated Dredging and Disposal Alternatives Management System (ADDAMS).

Background

Confined disposal facilities detain and store sediment dredged from navigation channels, estuaries, lakes, and other waterways. Conventional hydraulic dredging processes add large volumes of water to facilitate pipeline transport, resulting in a liquid slurry mixture being discharged into the CDF. This disposal process requires that the CDF provide sufficient hydraulic retention time for removal of suspended solids to meet local and state effluent quality standards.

Solids retention depends heavily on the hydraulic retention time within the CDF. Thus, accurately determining the mean hydraulic retention time is an important aspect of CDF design. Hydraulic efficiency is a convenient parameter for describing the hydraulic characteristics of a CDF since mean hydraulic retention time varies with inflow rate and volume of ponded surface water.

Hydraulic efficiency, defined as the ratio of the mean hydraulic retention time to the theoretical hydraulic retention time, remains reasonably constant over a wide range of inflow rates and ponded volumes. Once the hydraulic efficiency of a CDF is determined, it can be used to evaluate the effects of flow and ponded volume variations during future disposal activities.

Additional Information

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DYECON Application of ADDAMS

Introduction

Slug dye tracer studies are commonly used to determine the mean hydraulic retention time for ponds, lakes, rivers, and other water bodies. Procedures for performing slug dye tracer studies are very similar and are described in detail in EM 1110-2-5027 (OCE 1987). One can compute the theoretical hydraulic retention time for a CDF using the equation

$$T = \frac{V_p}{Q} \qquad (1)$$

where

T = theoretical hydraulic retention time, sec

V_p = ponded water volume in CDF, cu ft

Q = average inflow rate into CDF, cu ft/sec

Unfortunately, the actual hydraulic retention is often much smaller than the theoretical hydraulic retention time due to the nonideal dispersion resulting from short-circuiting and dead zones. Actual mean hydraulic retention time can be determined for a CDF, or any other water body, by instantaneously injecting a known mass of dye at the inflow point, then measuring the dye concentration in the outflow. The mean hydraulic retention time occurs when 50 percent, by mass, of the dye has exited. Since some dye is always lost to unknown sources, the mean hydraulic retention time is normally taken as the time when 50 percent of the total mass of dye recorded at the outflow has exited the water body. Figure 1 shows an idealized plot of the retention time distribution for a CDF.

Slug dye tracer studies are an effective means for determining the mean hydraulic retention time and hydraulic efficiency only for an existing CDF during

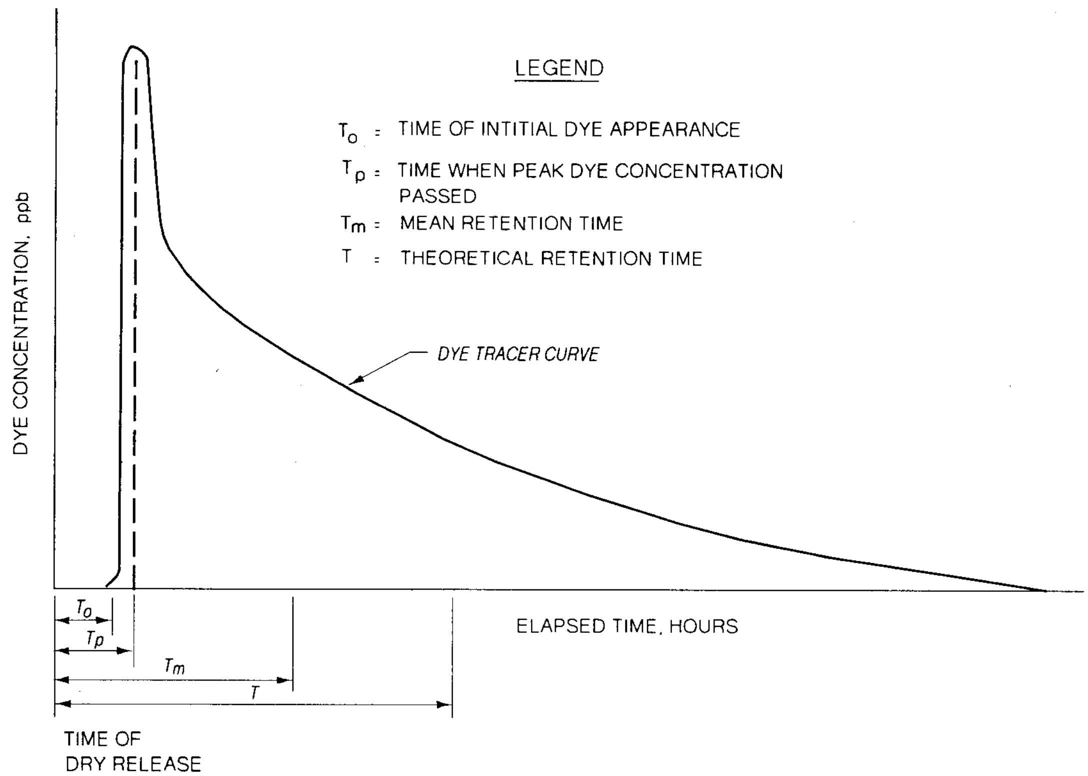

Figure 1. An idealized plot of the retention time distribution for a CDF

an operating disposal project. However, hydraulic retention time and efficiency are also necessary to perform design calculations for constructing new CDFs; similarly, these parameters may be required for an existing CDF at times when it is not in operation. Fortunately, hydraulic efficiency can also be estimated based upon the geometric configuration of a water body or, in this case, a CDF. These methods are not routinely as reliable as direct measurement, but they do facilitate design calculations which would otherwise be impossible.

Capabilities

DYECON is a computer program and module of the Automated Dredging and Disposal Alternatives Management System (ADDAMS). The general goal of ADDAMS, an interactive computer-based design and analysis system for dredged material management, is to provide state-of-the-art computer-based tools that will increase the accuracy, reliability, and cost-effectiveness of dredged material management activities in a timely manner. *Environmental Effects of Dredging Technical Notes* EEDP-06-12 (Schroeder and Palermo 1990) describes ADDAMS in more detail.

The DYECON module of ADDAMS has the following specific capabilities:

- Analyze and reduce slug dye tracer data.
- Calculate the hydraulic efficiency of an existing CDF based upon test data.
- Estimate hydraulic efficiency of a CDF based upon geometric characteristics.

Availability

DYECON as well as the other modules of ADDAMS is available through the Information Technology Laboratory of the U.S. Army Engineer Waterways Experiment Station. See Appendix A for an order form.

Using DYECON

DYECON may be started from the ADDAMS executive shell by selecting the DYECON program (option 2) or started separately by typing DYECON at the DOS prompt. The preferable method for starting DYECON depends upon your familiarity with the DOS operating system, available RAM, system configuration, and the existence of other ADDAMS modules. It is primarily a matter of personal preference, however, since DYECON operates the same regardless of how it is initiated.

General Operation

DYECON operates in a user-friendly, menu-driven environment and facilitates data entry and editing by using a full-screen editor approach. A central menu called the *DYECON Activity Selection Menu* allows the user to select the desired operation such as enter/edit slug dye tracer data, perform hydraulic efficiency calculations, perform file management operations, and set the hardware configuration for the DYECON graphics. All menu selections are numbered and the user may select an option by pressing the number of the desired option. The user may also choose to cycle through the menu options using the up arrow (↑) or down arrow (↓) key and then select the highlighted option by pressing the ENTER key.

Each selection from the *DYECON Activity Selection Menu* provides the user with a full-screen editor for data entry and editing. Most editing screens describe several required data items with the current value for the data item displayed. Editing focuses on the highlighted data item or question. A description of the data item and options are usually located to the left of the cell; units are displayed to the right of the cell. The user may enter a new value in the cell or modify the value in the cell. Moving to another data item on the current screen requires pressing either the ENTER key, the TAB key, or one of the vertical arrow keys. Page Down and Page Up keys display the next and previous screens, respectively. DYECON presents the results of design computations on descriptive screens similar to the full-screen data editor. DYECON will also print the results to ASCII output files or directly to the printer.

Getting Started

The user should establish the proper hardware configuration prior to any other use of DYECON. Hardware configuration can be established or modified by selecting menu item 5, perform hardware configuration for graphics. DYECON uses the stored configuration to display and print graphics. Modifications to the hardware configuration are not required after the initial setup unless the available hardware changes or the configuration data file is lost.

After the initial hardware configuration, later uses of DYECON should begin by selecting (or making "active") the desired data file. DYECON recalls the data file from the previous session and initially makes it the "active" data file. A new or different existing data file can be activated by using the ADDAMS File Manager. The File Manager is initiated by selecting menu item 4, perform data file selection and operation; the ADDAMS File Manager and its operation are discussed in detail by Schroeder and Palermo (1990). When the File Manager returns control to DYECON, it reads the active data file, if it exists, and assigns values to variables as appropriate. If the file does not exist, the File Manager will initialize the active data file. Note that DYECON does not offer an option to change the name of the active data file after it has been read. Thus to modify an existing data file and retain the original file, the user must change the active file name to the desired name for the modified file before saving the data. This operation is performed using the ADDAMS File Manager, but must be done before modifications are saved to prevent loss of the original data.

On-line Help

On-line comprehensive help messages are available to DYECON users by pressing F1 or Alt-F1. Pressing the F1 key provides general assistance on the current menu and information regarding choices the user needs to make. Detailed assistance for the currently highlighted data item is available on-line by simultaneously pressing the Alt and F1 keys. These context-sensitive messages provide detailed information about the user's options at the current position and/or describe data to be entered or edited at the current cursor position. Help messages may also provide default values or typical ranges.

Hardware Requirements

DYECON requires a MS-DOS based personal computer with at least 640 kilobytes of RAM, a hard disk with 2 megabytes of free space, and a CGA, EGA or higher resolution color video card and compatible monitor.

Determining Mean Hydraulic Retention Time and Efficiency

Mean hydraulic retention time and hydraulic efficiency are required for proper CDF design. DYECON computes the mean hydraulic retention time from dye concentration or fluorescence in the CDF effluent as a function of elapsed time and background concentration or fluorescence in the effluent. DYECON requires the theoretical hydraulic retention time of the CDF to compute the hydraulic efficiency. DYECON assumes that the flow is nearly constant during the conduct of the test; therefore, flow measurements are not required. Calculations for mean hydraulic retention time and efficiency are based upon procedures described in EM 1110-2-5027 (OCE 1987).

Entering/Editing Dye Tracer Data

Option 1 of the *DYECON Activity Selection Menu*, Enter/edit dye concentration data, initiates a series of screens for data entry and edit. These screens allow the user to enter or edit the data required to compute the mean hydraulic retention time and efficiency; these data are described in Table 1.

Table 1. Summary of DYECON Input Parameters

Parameter	Units
Background dye concentration	Fluorescence readings or ppb
Theoretical retention time	Hours
Elapsed time of sample	Hours
Dye concentration of sample	Fluorescence readings or ppb

The first screen under this option requests the background dye concentration, in parts per billion or fluorescence readings, and theoretical retention time in hours. The second screen allows the user to enter the elapsed time in hours and the measured dye concentration in the effluent, in parts per billion or fluorescence. Control returns to the original menu after the concentration versus time data are entered. Actually, any consistent set of units for concentration or time can be used. The user would only have to substitute his units of concentration for parts per billion in the results and his units of time for hours.

Analyzing Dye Tracer Data

Selecting Option 2, Analyze dye tracer data, prompts DYECON to compute the statistical parameters associated with the effluent slug dye tracer data. The calculations occur quickly, and a screen summarizing the results is displayed. Table 2 lists the parameters displayed on this screen. DYECON also provides an option for generating a plot of dye concentration versus elapsed time. The graph may be displayed on the screen or printed on an attached printer or plotter.

Table 2. Summary of DYECON Output Parameters

Parameter	Units
Theoretical retention time, T	hr
Hydraulic efficiency	percent
Mean retention time, T_m	hr
Background concentration (fluorescence)	ppb
Mean concentration (fluorescence)	ppb
Maximum concentration (fluorescence)	ppb
Time of initial dye appearance, T_0	hr
Time to when 10 percent of the dye has passed, T_{10}	hr
Time to when 50 percent of the dye has passed, T_{50}	hr
Time to when 90 percent of the dye has passed, T_{90}	hr
Time of last observation when dye concentration was greater than 10 percent of the maximum observed concentration	hr
Time when peak dye concentration passed, T_p	hr
Morrill index, T_{90}/T_{10}	hr

Estimating Hydraulic Efficiency from Site Geometry

Proper CDF design for solids removal requires an estimate of the hydraulic efficiency of the proposed site. DYECON can estimate hydraulic efficiency for a given site geometry based upon the relative length along the flow path to the width normal to the flow path. Selecting option 3 displays a screen describing how these lengths should be determined and allows the user to enter values for both lengths. When both lengths are entered, DYECON calculates the estimated hydraulic efficiency and displays it in the lower portion of the screen. Hydraulic efficiency is displayed as a percent corresponding to the size of mean retention time relative to the theoretical hydraulic retention time.

Hardware Setup for Graphics

Graphics are an integral part of the design process using DYECON. Displaying, printing, and plotting the graphics require the user to specify the hardware configuration. Selecting option 5, perform hardware configuration for graphics, from the *DYECON Activity Selection Menu* provides the user with a screen for selecting the plotter, printer, and video hardware from a list of available choices. The user will also need to specify the desired resolution for each hardware device.

Computational Procedures

The computational procedures employed by DYECON are essentially those described in EM 1110-2-5027 (OCE 1987) for determining the mean hydraulic retention time and hydraulic efficiency of a CDF. The procedures are described below.

Hydraulic Retention Time

DYECON calculates the mean hydraulic retention time (sometimes referred to as the average residence time), Morrill Index, and other statistical parameters used to evaluate CDF performance with regards to hydraulic efficiency (Deaner 1970, Rebhun and Argaman 1965, and Morrill 1932). DYECON first calculates the centroid of the area under the dye concentration versus time curve from the data entered by the user. The mean retention time is the first moment of this area about the origin and is equal to the x-coordinate of the calculated centroid (Rich 1973, and Beer and Johnston 1977). The y-coordinate of the centroid is the mean dye concentration and can be used to estimate the effective dye recovery if the effluent discharge rate remained constant during the test.

Hydraulic Efficiency

DYECON calculates hydraulic efficiency using Equation 1 based upon the results of the slug dye tracer data and the theoretical retention time entered by the user. This method is preferable but requires an existing site which is operating to conduct the field test.

DYECON also provides a method for estimating hydraulic efficiency of a CDF based upon site geometry. The method is described in EM 1110-2-5027 and based upon the equation:

$$e_h = \frac{T}{T_d} = 0.9\left[1 - e^{-0.3\frac{L}{W}}\right] \qquad \textbf{(2)}$$

where

e_h = hydraulic efficiency, dimensionless
T = mean hydraulic retention time, sec
T_d = theoretical hydraulic retention time, sec
L = length of the flow path, ft
W = width of CDF normal to flow path, ft

The length of the flow path is the distance travelled from the inflow point to the discharge point. This is the straight line distance between the discharge pipe and effluent weir if flow diversions or obstructions do not exist. Flow diversion or spur dikes can significantly reduce dead zones and increase the length of the flow path by forcing the flow path to change directions. The flow path then is the sum of the flow path lengths along the direction of flow.

The width, W, should reflect the average width along the flow path. This width should reflect flow restrictions imposed by flow diversions or obstructions. For example, in a long, rectangular CDF with equally spaced and equal length spur dikes in the longitudinal direction, the width specified should be the distance between spur dikes. Alternatively, the width could be estimated to be the result of the ponded area divided by the length of the flow path.

Summary

DYECON is an effective and efficient means of analyzing slug dye tracer results and calculating the hydraulic efficiency of a CDF. DYECON is easy to use and its procedures provide a consistent means for CDF analysis and design. It is an ADDAMS tool which facilitates proper dredged material management by encouraging the evaluation of an array of design alternatives.

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APPENDIX A: REQUEST FORM FOR ADDAMS

Please send the ADDAMS diskettes to:

Name and Title ______________________________
Mailing Address ______________________________
and Office Symbol ______________________________
____
Telephone Number ______________________________
Anticipated uses of ADDAMS ______________________________
____

Requests for ADDAMS must be sent with *formatted* floppy disks in a self-addressed mailing envelope. When ordering individual modules, also select the Executive Shell. Please circle the applications desired and the number and type of diskettes enclosed.

Requested Modules	Number of diskettes enclosed (all DS)			
	5.25 in. 360 kb	5.25 in 1.2 Mb	3.5 in. 720 kb	3.5 in. 1.44 Mb
ADDAMS (all modules)	13	9	9	8
SETTLE	2	1	1	1
PCDDF	2	1	1	1
DYECON	2	1	1	1
D2M2	1	1	1	1
DUMP	4	2	2	1
EFQUAL	1	1	1	1
WET	1	1	1	1
EXECUTIVE SHELL	1	1	1	1

Signed______________________________Date____________________

MAIL THE COMPLETED REQUEST FORM AND FORMATTED DISKETTES TO:

US Army Engineer Waterways Experiment Station
ATTN: CEWES-IM-MI-C (Naylor)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199