



DREDGED MATERIAL RESEARCH PROGRAM



MISCELLANEOUS PAPER D-76-17

ECOLOGICAL EVALUATION OF PROPOSED DISCHARGE OF DREDGED OR FILL MATERIAL INTO NAVIGABLE WATERS

INTERIM GUIDANCE FOR IMPLEMENTATION OF SECTION
404(b) (1) OF PUBLIC LAW 92-500 (FEDERAL WATER
POLLUTION CONTROL ACT AMENDMENTS OF 1972)

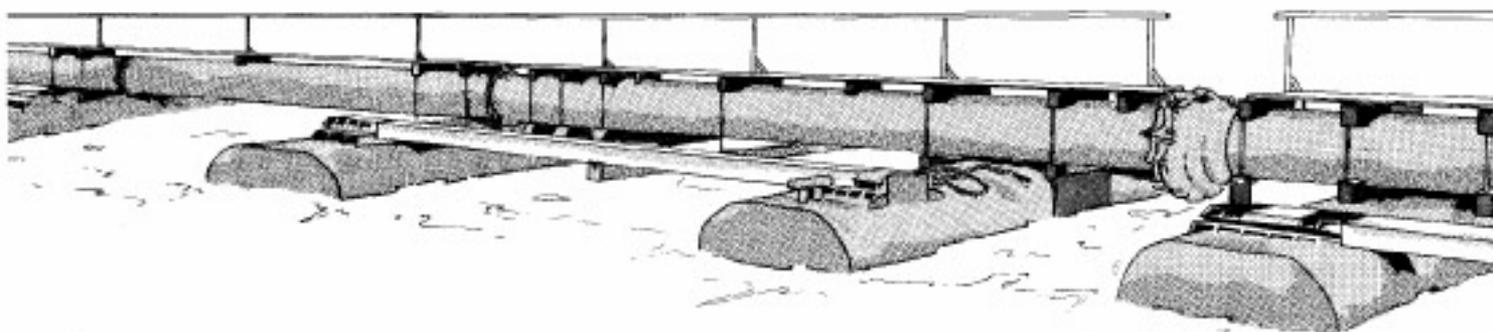
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May 1976

Final Report

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Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

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30 June 1976

SUBJECT: Transmittal of Miscellaneous Paper D-76-17

TO: All Report Recipients

1. In accordance with Section 230.4-1 of the Federal Register (Volume 40, No. 173, Friday, 5 September 1975, which will be referred to hereafter in this letter as the Register), the Environmental Protection Agency, in conjunction with the Corps, will publish a procedures manual. This manual will be used for the evaluation of proposed discharges of dredged or fill material into navigable waters as required in the implementation of Section 404(b) of the Federal Water Pollution Control Act Amendments of 1972. Pending publication of the procedures manual, District Engineers are to furnish interim guidance to permit applicants concerning the applicability of specific approaches or procedures to be used in the evaluation process.
2. The report transmitted herewith represents a multidisciplinary effort to develop interim guidance for the implementation of Section 404(b)(1) of Public Law 92-500 (Federal Water Pollution Control Act Amendments of 1972). Guidelines pursuant to implementation of Section 404(b)(1) published in the Register specify an ecological evaluation of proposed discharge of dredged or fill material in navigable waters. At the request of the Office, Chief of Engineers, the Environmental Effects Laboratory of the Waterways Experiment Station initiated development of interim guidance for District Engineers to use in evaluating permit applications according to Section 404(b).
3. In the developmental phases of the Dredged Material Research Program (DMRP), it became apparent that an understanding of the potential for ecological harm of the discharge of dredged material into wetland and aquatic areas required substantial state-of-the-art improvement in a number of fundamental aspects. Therefore, such state-of-the-art improvement was included in the DMRP tasks and work units of the Environmental Impacts and Criteria Development Project. The evaluation procedures as well as the discussions of the applicability and limitations of test results are indicative of several DMRP investigations both underway and completed. The procedures represent the current state-of-the-art in the dynamically evolving fields of aquatic and sediment chemistry and biology.

WESYV

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4. The procedures given in the interim guidance are applicable to evaluation of the ecological effects of discharges from hopper dredges, barges, scows, and hydraulic pipelines as well as the effects of effluent or runoff from contained land or water disposal areas. General approaches for ecological evaluation involve physical effects and chemical-biological interactive effects, both of which are discussed in the interim guidance. Procedures for alternate site comparisons are also presented. Detailed procedures include those for conducting an elutriate test, estimating a mixing zone, performing bioassays, conducting total sediment analyses, and evaluating biological community structure.

5. The interim guidance is not intended to establish standards or rigid criteria and should not be interpreted in such a manner. The document attempts to provide a balance between the technical state-of-the-art and routinely implementable guidance for using the procedures specified in the Register and is expected to provide a continuity among the Corps Districts' evaluation programs for Section 404 permit activities. The interim guidance is particularly important in forming a foundation to be augmented by more meaningful and comprehensive evaluation procedures and guidelines as these evolve from current and future DMRP and other related environmental research. It is anticipated that the interim guidance will be updated routinely as new and more implementable evaluation procedures are developed and verified. The interim guidance will remain in effect until promulgation of the procedures manual.



JOHN L. CANNON
Colonel, Corps of Engineers
Director

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20. ABSTRACT (Continued)

outlines the basic philosophy of the ecological evaluation of dredged and fill material discharges and outlines the general procedures to make this evaluation.

Important in an ecological evaluation are the selection of appropriate test(s) and interpretation of results for assessment of potential problems. General approaches for technical evaluation are partitioned into physical effects, chemical-biological interactive effects, and procedures for site comparison.

The Interim Guidance presents the general sequence of testing and evaluative procedures given in the Federal Register and presents detailed stepwise procedures for conducting an elutriate test, estimating a mixing zone, performing bioassays, conducting total sediment analyses, and evaluating biological community structure. These procedures contain all references and citations pertinent to the various evaluative procedures.

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PREFACE

According to Section 404(b) of Public Law 92-500 (Federal Water Pollution Control Act Amendments of 1972), any proposed discharge of dredged or fill material in navigable waters must be evaluated through the use of guidelines published by the EPA in the Federal Register, Vol. 40, No. 173, Friday, 5 September 1975. The Federal Register states that interim guidance to permit applicants concerning the applicability of specific approaches or procedures will be furnished by the District Engineers. This report, referred to as the Interim Guidance, contains those procedures considered applicable to the discharge of dredged or fill material in navigable waters as well as evaluative guidance with respect to the state-of-the-art of such procedures.

At the request of the Office, Chief of Engineers, the Environmental Effects Laboratory (EEL) of the Waterways Experiment Station (WES) initiated development of the Interim Guidance shortly after publication of the 5 September 1975 Federal Register. The Interim Guidance was prepared under the direction of Dr. Robert M. Engler with assistance of several EEL and Hydraulics Laboratory (HL) personnel. Parts I, II, and III and Appendix A were prepared by Drs. Engler, John W. Keeley, and Russel H. Plumb, Jr. Appendix B was prepared by Mr. M. B. Boyd and Dr. B. H. Johnson of the Mathematical Hydraulics Division (HL) and Dr. Plumb. Appendix C was prepared by Drs. Plumb, Richard K. Peddicord, and Peter J. Shuba. Appendix D was prepared by Dr. Plumb. Appendix E was prepared by Drs. Plumb, Peddicord, and Shuba. Technical review of the manuscript was conducted by Drs. John Harrison, Chief, EEL, Roger T. Saucier, Keeley, and Rex L. Eley and Mr. Boyd.

The Directors of WES during preparation and publication of the Interim Guidance were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. Customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	metres
square feet	0.09290304	square metres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
gallons	0.003785412	cubic metres
feet per second	0.3048	metres per second
cubic feet per second	0.02831685	cubic metres per second

PART I: INTRODUCTION

Background

1. Section 404(b) of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) specifies that any proposed discharge of dredged or fill material into navigable waters must be evaluated through the use of guidelines developed by the Administrator of the Environmental Protection Agency (EPA) in conjunction with the Secretary of the Army acting through the Chief of Engineers. The District Engineer must make the evaluation in accordance with guidelines published by EPA in the Federal Register, Vol. 40, No. 173, Friday, 5 September 1975 (hereafter referred to as the Register) placing special emphasis on Section 230.4 and 230.5 insofar as potential ecological effects are concerned.

2. Ecological impacts of the discharge of dredged or fill material can be divided into two main categories: physical effects and chemical-biological interactive effects, described in Sections 230.4-1(a) and (b) of the Register, respectively. Physical effects are often straightforward and evaluation may often be made (without laboratory tests) by examining the character of the dredged or fill material proposed for discharge and the sediments of the discharge area with particular emphasis on the principles given in Section 230.5 of the Register. On the other hand chemical-biological interactive effects resulting from the discharge of dredged or fill material are usually difficult to predict.

3. There are many concerns over the potential environmental consequences of various discharge operations. The principal concerns caused by open-water discharge of dredged or fill material that contains

chemical contaminants are the potential effects on the water column and benthic communities due to the presence of the contaminants.

a. Release of chemical contaminants from the sediment to the water column may best be simulated by use of an elutriate test.

b. To the extent permitted by the state-of-the-art, expected effects such as toxicity, stimulation, inhibition, or bioaccumulation may best be estimated by appropriate bioassays.

c. Comparison of and suitability of the proposed disposal sites may be evaluated by the use, where appropriate, of total sediment analysis or bioevaluation.

4. A mixing zone is also estimated for the disposal site, and the interim guidance for calculating the mixing zone will be supplied by the District Engineer. Sizing of the mixing zone requires consideration of elutriate concentrations compared to concentrations of the same constituents in disposal site water and other data such as the volume and rate of intended discharge, the type of discharge, and the hydrodynamic regime at the disposal site.

5. Considering the complexity of involved ecosystems, no single test can be used to evaluate all effects of proposed discharges of dredged or fill material. Consequently, the guidelines published in the Register provided options to be used in the technical evaluation of the proposed activities. Certain situations may require no testing of the dredged or fill material while other situations may require use of one or more of the testing procedures. Each procedure used should provide information about the proposed discharge activity. However, there are limitations associated with the use of the results obtained with each

procedure, and no one procedure should arbitrarily be relied upon to the exclusion of the others.

6. For example, total sediment analysis results cannot be used to assess water-quality effects and elutriate test results cannot be used to assess turbidity effects. Also, when it becomes necessary to perform bioassays as part of the evaluation procedure, experimental conditions should reflect the exposure times and exposure concentrations that would be expected in the field based on the dilution and dispersion at the proposed disposal site. Each of these limitations must be considered when selecting, conducting, and evaluating the results of the procedures in the Register.

Purpose and Scope

7. The EPA, in conjunction with the Corps of Engineers, is to publish a procedures manual that will contain summaries and descriptions of tests, definitions, sample collection and preservation procedures, analytical procedures, calculations, and references required for the evaluation of permits in accordance with the Register. Until publication of the manual, interim guidance concerning the implementation and applicability of specific approaches or procedures will be furnished to applicants by District Engineers.

8. This report has been prepared to serve District Engineers as proposed interim guidance for the evaluation of the effects of the discharge of dredged or fill material into navigable waters. This document, developed by the Environmental Effects Laboratory and the

Hydraulics Laboratory of the Waterways Experiment Station for the Office, Chief of Engineers, attempts to provide a balance between technical state-of-the-art and routinely implementable guidance for using the procedures specified in the Register. Evaluation of ecological effects consists of two phases: selection of the appropriate test(s) or evaluation procedure(s) and the interpretation of results for assessment of potential problems. This guidance defines the applicability of testing procedures specified in the Register and presents limitations in interpreting the results. In addition it follows the general order of test application and general priority of importance of testing and evaluation procedures given in the Register.

Applicability

9. This Interim Guidance is applicable to all activities involving the discharge of dredged or fill material into navigable waters [see Section 230.1(b)(1) and (2) of the Register]. The procedures presented herein are to be used to evaluate the discharge and overflow from hopper dredges; hydraulic pipeline discharges; the discharge and overflow from bottom and end dump barges and scows; and the runoff, effluent, or overflow from a contained land or water disposal area. For relevant definitions and additional inclusions and exclusions of the applicability of the evaluative guidelines given in the Register and the procedure presented herein, see Section 230.2 and Appendix A of the Register.

Definitions

10. The following terms are defined as used in this report. See Section 230.2 and Appendix A of the Register for a complete list of definitions.

Disposal site. Location within fixed geographic boundaries in which a discharge of dredged or fill material is proposed or has been undertaken. Includes the volume of water and the substrate over which such water volume lies, where applicable.

Dredged material. Any material excavated or dredged from navigable waters. (See exclusions in Appendix A of the Register.)

Dredging or excavation site. Site from which the dredged material is removed or excavated.

Constituents. Chemical substances, solids, and organisms associated with dredged or fill material.

Guidelines. Procedures and concepts published in the Register for the evaluation of the discharge of dredged or fill material.

Interim guidance. Specific, detailed procedures for evaluation of the discharge of dredged or fill material supplied for the use by the permit applicant.

Mixing zone. Smallest practical area within each specified disposal site, consistent with the objectives of the Register, in which desired concentrations of constituents must be achieved.

Fill material. Any pollutant used to create fill in the traditional sense of replacing an aquatic area with dry land or of changing the bottom elevation of a water body for any purpose. Fill material does not include the following:

a. Material resulting from normal farming, silviculture, and ranching activities, such as plowing, cultivating, seeding, and harvesting for the production of food, fiber, and forest products.

b. Material placed for the purpose of maintenance, including emergency reconstruction of recently damaged parts of currently serviceable structures such as dikes, dams, levees, groins, riprap, breakwaters, causeways, and bridge abutments or approaches, and transportation structures.

c. Additions to these categories of activities that are not fill will be considered periodically and the regulations amended accordingly.

Discharge of fill material. The addition of fill material into navigable waters for the purpose of creating fastlands, elevations of land beneath navigable waters, or for impoundments of water. The term generally includes, without limitation, the following activities in a navigable water: placement of fill that is necessary to the construction of any structure; the building of any structure or impoundment requiring rock, sand, dirt, or other pollutants for its construction; site-development fills for recreational, industrial, commercial, residential, and other uses; causeways or road fills; dams and dikes; artificial islands, property protection and/or reclamation devices such as riprap, groins, seawalls, breakwalls, and bulkheads and fills; beach nourishment; levees; sanitary landfills; fill for structures such as sewage treatment facilities, intake and outfall pipes associated with power plants, and subaqueous utility lines; and artificial reefs.

Discharge of dredged material. Any addition of dredged material,

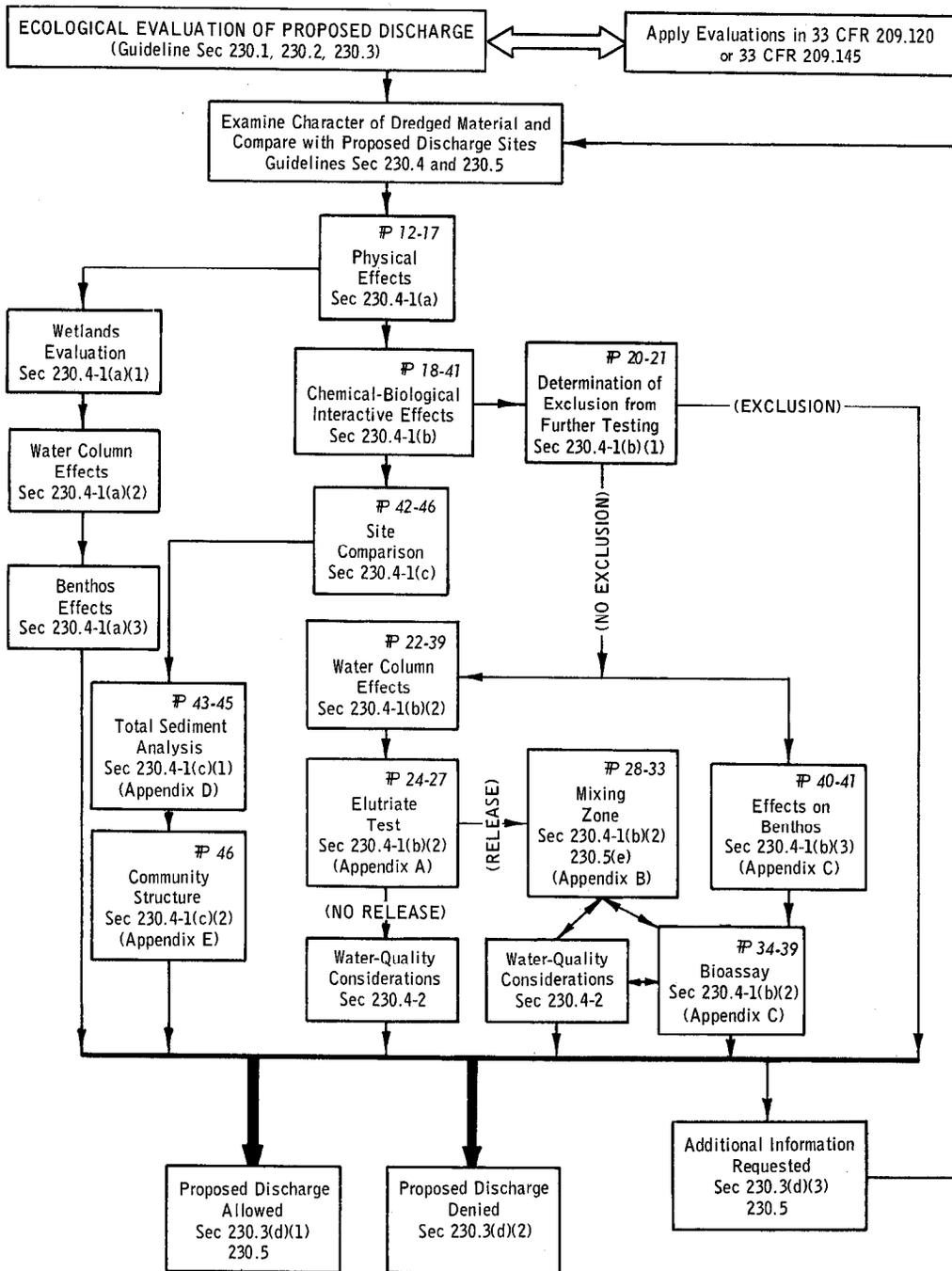
in excess of one cubic yard when used in a single or incidental operation, into navigable waters. The term includes, without limitation, the addition of dredged material to a specified disposal site located in navigable waters and the runoff or overflow from a contained land or water disposal area. Discharges of pollutants into navigable waters resulting from the onshore subsequent processing of dredged material that is extracted for any commercial use (other than fill) are not included within this term and are subject to Section 402 of the Federal Water Pollution Control Act even though the extraction of such material may require a permit from the Corps of Engineers under Section 10 of the River and Harbor Act of 1899.

PART II: GENERAL APPROACHES FOR TECHNICAL EVALUATION

11. The potential effect of the discharge of dredged or fill material on aquatic organisms and human uses of navigable waters may range from insignificant disruption to irreversible change at the disposal site. These changes can be categorized as resulting from physical effects and/or chemical-biological interactive effects of the discharge. In order to evaluate possible effects, the Register specifies procedures that can be used to assess physical effects, assess chemical-biological interactive effects, estimate volume and area of the required mixing zone, make excavation and/or discharge site comparisons, and evaluate contaminated fill material. These procedures are found in Section 230.4 and 230.5 of the Register. A diagrammatic representation of the sequence of testing and evaluation procedures is given in Figure 1.

Physical Effects

12. One of the most important potential physical effect considered by the Register is degradation or destruction of wetland resources. If the proposed discharge site is not considered a wetlands area, the technical evaluation should continue on to consider the water column effects and benthic effects as indicated in Figure 1. However, if the proposed disposal site is considered a wetlands area, the proposed operation should be evaluated by applying the principles presented in Sections 230.4-1(a)(1) and 230.5 of the Register prior to considering other evaluative procedures.



Note: Section numbers within the boxes refer to the Register.

Paragraph (¶) and appendix citations inside the boxes refer to this report.

Figure 1. Sequences of testing and evaluation procedures

Water column effects

13. The most obvious water column effects of open-water discharge of dredged or fill material are temporary aesthetically displeasing increases in turbidity and suspended solids levels. Also, the reduced light penetration resulting from the increased turbidity may have an adverse effect on the algal community. The increased suspended solids concentrations may also have an adverse effect on other aquatic organisms. A careful review of the technical literature does not indicate the level at which these potential effects become significant. It has, however, been noted in recent Dredged Material Research Program (DMRP) research that concentrations of suspended sediment that result in organism mortality have been much higher and have remained for a much longer duration than the concentrations observed with open-water discharges. In addition, it must be emphasized that disposal operations may produce high turbidity and suspended solids concentrations but that these concentrations only persist for short time periods, and there is little information available to assess the effects of short-term exposure.

14. Due to the small amount of available information, it is difficult at this time to predict the effects on a water column of turbidity and suspended solids increases resulting from dredged or fill material discharge. In order to evaluate the significance of turbidity and suspended solids increases at a proposed disposal site, it may be necessary to conduct bioassays with appropriate organisms as discussed later in this guidance. It is necessary that careful consideration be given to mixing and dilution at the proposed disposal site and to reproduce

expected conditions so that bioassay results will reflect anticipated exposure concentrations and exposure times.

Effects on benthos and other physical functions

15. Another obvious physical effect that can be anticipated at a proposed discharge site is a covering of part of the benthic community with a subsequent possible change in community structure or function and physical nature of the system. General guidance for evaluating this and other effects is found in Sections 230.4-1(b)(1), 230.4-1(c)(2), and 230.5 of the Register. When an aquatic or wetlands area is covered with dredged or fill material so as to permanently change the physical nature of the area (i.e., filling a lowland or open-water area for construction purposes), complete destruction of benthic and aquatic organisms communities is obvious. Recent DMRP studies have indicated that varying deposits of 2 to 100 cm of dredged material on substrate of similar physical characteristics (i.e., sand on sand and mud on mud) had minimal impact. Comparatively speaking, dredged material placed on a substrate of unlike physical characteristics has a maximum impact.

16. Filling may also permanently change the hydrography of an area with subsequent changes in circulation patterns and shoaling areas within the adjacent water body. Filling of lowland or wetland areas may have a profound effect on groundwater recharge and areas of nutrient and mineral cycling and may destroy natural areas of contaminant detoxification and fixation.

17. Judicious selection of the discharge site for dredged or fill material is imperative in minimizing physical impacts. Seasonal effects

of dredged or fill material discharge such as disruption of spawning patterns and movements of anadromous fish should be avoided.

Chemical-Biological Interactive Effects

18. No single test can be used to predict all of the ecological effects of proposed discharges of dredged or fill material. Consequently, the Register [Sections 230.4-1(b)(1), (2), and (3)] includes procedures that may be used in the chemical-biological interactive evaluation of the proposed activities: exclusions from testing procedures, elutriate test, and bioassay. In addition, a procedure is provided to estimate the amount of the aquatic environment that will be required as a mixing zone in order to dilute the proposed discharge. These tests and procedures are shown in Figure 1 and details are given in Appendices A-C of this report. For the convenience of the reader, each appendix is followed by a list of references cited in the appendix.

19. The release of dissolved solids from dredged material that may result in chemical changes in water quality at the discharge site may best be simulated by the use of an elutriate test, which is described in Appendix A. The procedure for determining the extent of the mixing zone is given in Appendix B. Expected effects such as toxicity, stimulation, inhibition, or bioaccumulation may best be simulated by appropriate bioassays; guidance for performing bioassays is given in Appendix C.

Exclusion from chemical and biological testing

20. There are obvious cases where dredged or fill material is not

considered chemically contaminated and would therefore cause negligible chemical pollution when discharged into an appropriate disposal site. Evaluative procedures for these cases are given in Section 230.4-1(b)(1) of the Register. Dredged or fill material may be excluded from the chemical-biological interactive procedures given in Section 230.4-1(b)(2) and (3) of the Register if it falls within any of the following categories.

a. The dredged or fill material is composed predominantly of sand, gravel, or any other naturally occurring sedimentary material with particle size larger than silt, characteristic of and generally found in areas of high current or wave energy such as streams with large bed loads or coastal areas with shifting bars and channels.

b. The dredged or fill material is for beach nourishment or restoration and is composed predominantly of sand, gravel, or shell with particle sizes compatible with material on receiving shores.

c. The material proposed for discharge is substantially the same as the substrate at the proposed disposal site; the site from which the material proposed for discharge is to be taken is sufficiently removed from sources of pollution to provide reasonable assurance that such material has not been contaminated by such pollution; and adequate terms and conditions are imposed on the discharge of dredged or fill material to provide reasonable assurance that the material proposed for discharge will not be moved by currents or otherwise in a manner that is damaging to the environment outside the disposal site.

21. However, the District Engineer may require testing of any

dredged or fill material after evaluating and considering any comments received from the EPA Regional Administrator. The Regional Administrator will state what additional information is needed and how the results of any proposed testing will be of value in assessing potential environmental effects.

Water column effects

22. Constituents contained in or associated with sediments are unequally distributed among different chemical forms depending on the physical-chemical conditions in the sediments and the overlying water.^{1,2} When contaminants introduced into the water column become fixed into the underlying sediments, they rarely if ever become part of the geological mineral structure of the sediment. Instead, these contaminants remain dissolved in the sediment interstitial or pore water, become sorbed to the sediment ion exchange portion as an ionized constituent, form organic complexes, and/or become involved in complex sediment oxidation-reduction reactions and precipitations.

23. The fraction of a chemical constituent that is potentially available for release to the water column when sediments are disturbed is approximated by the interstitial water concentrations and the loosely bound (easily exchangeable) fraction in the sediment. In order to estimate the impact of the release of dissolved constituents from dredged or fill material to the water column, an elutriate test will be used in conjunction with a mixing zone. General guidance for the elutriate test is given in Section 230.4-1(b)(2) of the Register; specific laboratory procedures are given in Appendix A of this report.

24. Elutriate test. The elutriate test is a simplified simulation of the dredging and disposal process wherein predetermined amounts of dredging site water and sediment are mixed together to approximate a dredged material slurry. The elutriate is the supernatant resulting from the vigorous 30-min shaking of one part bottom sediment from the dredging site with four parts water (vol/vol) collected from the dredging site followed by a 1-hr settling time and appropriate centrifugation and 0.45 μ filtration.

25. The elutriate is analyzed for major dissolved chemical constituents deemed critical for the proposed dredging and disposal site by the District Engineer (after considering comments received from the Regional Administrator) after taking into account known sources of discharges in the area and known characteristics of the dredging and disposal site. After calculating dilution at the disposal site using the mixing zone procedure given in Appendix B, the potential impact of the proposed discharge activity in the discharge area can be evaluated. When the elutriate test is used for mechanical dredging, concentration values can be considered very conservative and as worst-case values for water column impacts. Well-mixed slurries are rarely obtained in mechanical dredging and the majority of the material impacts the bottom seconds after release, often retaining its original physical structure.

26. Results of the analysis of the elutriate approximate the dissolved constituent concentration for a proposed dredged material disposal operation at the moment of discharge. These concentrations can be combined with appropriate and applicable water-quality standards

(Section 230.4-2 of the Register) and the mixing zone guidance given in Appendix B to calculate the volume of disposal site water necessary to dilute the dredged material discharge to an acceptable level. The proposed discharge can be evaluated based on the necessary volume and projected surface area of the calculated mixing zone compared to the total aquatic environment available.

27. Water-quality standards. Water-quality standards or criteria were generally developed and are usually expressed as the concentration of a soluble constituent that will produce an undesirable effect if maintained for 96 hr or longer. However, a dredged material discharge is usually rapidly diluted following disposal; therefore, the dissolved constituent concentrations approximated by the elutriate test must also be reduced by dilution in order to simulate as closely as possible what is actually happening in the field. Since the time required for this dilution will be short (generally minutes) compared to the 96-hr time period implicit in the water-quality standards, elutriate test concentrations should not be compared directly to water-quality standards to assess the possible environmental effects of the discharge. Elutriate concentrations should be modified to reflect the dilution or dispersion characteristics at the proposed discharge site prior to comparison with water-quality criteria or standards.

28. Mixing zone evaluation. A mixing zone is the smallest practical area within each specified disposal site, consistent with the objectives of the Register, in which desired concentrations of constituents must be achieved. An elutriate test provides an estimate of the

maximum concentration of dissolved constituents immediately after discharge and must be used in conjunction with a mixing zone provided for the sole purpose of mixing (diluting) the discharge to acceptable levels. If constituents of concern are not released in the elutriate test, mixing need not be considered. The use of the mixing zone concept, therefore, provides reasonable opportunity for diluting discharge concentrations by partially using the natural assimilative capacity of the receiving water. Sample problems using typical elutriate concentrations and various modes of discharge (i.e., hopper, barge, or pipeline) are given in Appendix B. General guidance for the mixing zone and selection of the discharge site is given in Sections 230.4-1(b)(2), 230.4-2, and 230.5(e) of the Register.

29. At this time, there are few uniform approaches that can be used to designate the size of a mixing zone required to accommodate a discharge into an aquatic system. However, there are several important concepts that should be considered in establishing a mixing zone. The size of a designated mixing zone should be limited, but each mixing zone should be tailored to a particular receiving water body and no attempt should be made to apply a single size limitation in any water body.³ In other words, a decision should be based on a case-by-case evaluation at each proposed disposal site and the beneficial use(s) (e.g. public water intake, shell fisheries) to be protected. Also, the designated mixing zone should be situated such that there is an adequate zone of passage for mobile organisms.^{3,4} In addition, a relatively larger mixing zone can be tolerated for intermittent dis-

charges (compared to continuous discharges) without having a significant impact on the receiving waters.^{5,6}

30. The approach to be taken is to calculate the volume of disposal site water necessary to dilute a proposed dredged material discharge to acceptable levels by using results of analyses of the elutriate test and disposal site water in conjunction with appropriate and applicable water-quality standards.

31. Prediction of the plume shape and areal coverage when the required dilution volume is achieved is a very difficult problem involving hydrodynamic and sediment transport considerations. Although developmental work by the DMRP is continuing on sophisticated numerical models that ultimately may provide this capability, there is no appropriate verified model that can be suggested for routine use at this time. Consequently, a simplified approach for calculating the projected surface area of the mixing zone is suggested in Appendix B. The approach is based on assuming particular geometrical shapes for the disposal plume depending upon the mode of discharge and the disposal site environment.

32. Use of the simplified approach will indicate the maximum portion (volume) of the total aquatic environment that would be considered necessary for the proposed discharge activities because it assumes that the dredged material discharge will be completely mixed at the disposal site and that chemical constituents measured in the standard elutriate will behave conservatively following disposal. Also, the calculated surface area projection of the proposed discharge can be

compared with the available surface area in an authorized discharge zone. Included in the discussion in Appendix B are methods for estimating the mixing zone for scow, hopper, and continuous pipeline discharges, as well as for several hydrodynamic conditions in the receiving water.

33. Several authors have defined mixing zones in terms of biological effects.^{3,4} However, the mixing zone calculated by the method described in Appendix B should not be equated with a zone of adverse biological impact. The basis for the recommended approach is the fact that the effects of a discharge are a function of exposure concentration and exposure time. Although appropriate and applicable water-quality standards are used to define the volume of water in which acceptable concentrations may be equalled or exceeded, the duration of mixing zone conditions cannot be easily quantified at this time. Therefore, the method should only be used to estimate the volume and surface area at a disposal site that will be significantly influenced by a given discharge.

34. Water column bioassay. When the District Engineer determines that further information will be necessary to assess the possible effects of dredged material on water quality at the disposal site, he may specify bioassays as described below. These bioassays should consider dilution and dispersion after discharge at the disposal site. General guidance for bioassay procedures is given in Section 230.4-1(b)(2) of the Register, and specific procedures for conducting marine and fresh-water algal assays are given in Appendix C of this report.

35. Bioassays are procedures that use living organisms to detect or measure the presence of available toxic, inhibitory, or stimulatory substances. The value of such biological testing is that it provides an estimate of the general suitability of conditions in the sample being studied for the test organism(s) being used. Thus, even though the sample being studied has not been completely analyzed chemically and the toxicity of each constituent (alone or in mixtures) is not known, bioassay results may provide an estimate of potential adverse effects on water quality. Also, when combined with appropriate chemical analysis, bioassay procedures can sometimes be used to determine the distribution of the biologically available and biologically unavailable form of a particular component; however, determination of this distribution in most cases exceeds the current state-of-knowledge of sediment-water-biological interactions.

36. In the evaluation of dredged material, the procedure requires exposure of test organisms to a sediment to be dredged or to an elutriate and then evaluation of the organism response. The type of effects may range from acute mortality to a chronic sublethal effect such as the inhibition of reproduction or a change in the respiration rate. The magnitude of response may range from death to no effect. Therefore, bioassays can provide information on whether constituents associated with dredged material are in a chemical form that can potentially affect organisms at a proposed discharge site.

37. Bioassay procedures are applicable to a wide variety of organisms. The species selected for testing should be native to the

proposed disposal site during the season of the operation and be compatible with the purposes for testing. For example, if the question of concern is the potential short-term effects of dissolved chemicals on eutrophication, an algal bioassay is appropriate. However, if there is concern over potential longer term effects of toxicant uptake, suggested organisms would include various species of fish and macroinvertebrates^{7,8} and, in some cases, algae and diatoms.

38. Major limitations on the use of bioassays are that they are generally more difficult, time consuming, and expensive than chemical analyses. For example, a healthy stock of potential test organisms must be maintained in the laboratory for use as needed. In addition, sufficient controls must be used during the actual bioassay testing procedure to ensure that the observed response(s) are caused by the material being tested and not by the condition of the organisms, the equipment being used, or any other artificial manifestation(s). Also, a relatively long time interval ranging from several days to several weeks or more may be required, depending on the organism and the responses being monitored, to conduct a bioassay. Each of these factors increases the space, time, and manpower requirements necessary to perform a bioassay as compared to most chemical analyses.

39. Extreme care must be exercised in extrapolating from the results of a laboratory bioassay in attempting to predict field effects because existing procedures do not adequately address the changing conditions that can be expected at a disposal site. Existing procedures generally examine the effects of different concentrations of a test

material for a constant but arbitrarily selected period of time.⁹ However, the effect of the test material is a function of the exposure concentration and the exposure time, although the importance of time is not generally understood or recognized. Since the exposure concentration and the exposure time for a given concentration are both altered continually at a discharge site due to dilution, existing procedures would most likely overestimate potential adverse effects at a disposal site. For this reason, mixing zone considerations (exposure times and concentrations) must always be incorporated into the final interpretation of water column bioassay results.

Effects on benthos

40. Summarizing Section 230.4-1(b)(3) of the Register, the bioevaluation or bioassessment of chemical-biological interactive effects of a proposed discharge activity on bottom-dwelling or benthic organisms is most difficult and is at the forefront of the current state-of-the-art. Bioassay by definition is a method of testing the potency or activity of a material through elicitation of a response (biochemical, physiological, or mortality) by a living organism. However, bioevaluation or bioassessment may involve much more subtle effects, such as uptake of a contaminant that may result in no apparent organism response, or it may involve longer term changes in the community structure of an array of benthic organisms at a given site due simply to avoidance or attraction mechanisms.

41. Routine and generally accepted benthic organism bioassays and biological assessments appropriate for evaluating dredged material are

not available at this time. However, there are instances where through proper conduct and interpretation and with an understanding of inherent limitations, the District Engineer may require use of an appropriate benthic assay to assess ecological effect and establish discharge conditions. General guidance may be found in Sections 230.4-1(b)(3), 230.4-1(c)(2), and 230.5 of the Register; additional discussion is found in Appendices C and E of this report.

Procedure for Comparison of Sites

42. When information is required for the selection of the most environmentally compatible disposal site, the District Engineer may require a total sediment chemical analysis or further biological assessment of the excavation and proposed disposal sites. A total sediment analysis will give an inventory of the total concentration of chemical constituents, including mineral and nonmineral fractions of a sediment. These constituents may be natural components of the Earth's crust and natural systems, contaminants that move to a sediment, or any combination or mixture thereof. Consequently, a total sediment analysis using a strong acid digestion procedure cannot be related in any way to the potential mobility or biological availability of sediment-contained constituents. Site comparisons using biological evaluation procedures such as community structure analyses require a significant field sampling program and a great deal of biological expertise to interpret findings. General guidance for these chemical and biological procedures are found in Section 230.4-1(c) of the Register with discussion in

Appendices D and E of this report.

Total sediment analysis

43. Representative sediment samples are digested over heat with concentrated strong acid, and the resulting solution is analyzed for those inorganic constituents deemed critical by the District Engineer. When organic compounds are included as critical constituents, an original sediment sample should be extracted with appropriate organic solvents, and the extracts analyzed for these materials. Analytical procedures are given in Appendix D of this report.

44. The results of these analyses will provide some indication of the general chemical similarity of the sediments to be dredged with the sediments at the proposed disposal site(s). The total composition of sediments, when compared with natural background levels at the site, will also, to some extent, reflect the inputs to the waterway from which they were taken and may sometimes be used to identify and locate point source discharges.

45. Since chemical constituents are partitioned among various sediment fractions, each with their own mobility and bioavailability, a total sediment analysis is not a useful index of the degree to which dredged material disposal will affect water quality or aquatic organisms. In addition, total sediment analysis results are further limited because they cannot be compared to any established water-quality criteria in order to assess the potential environmental impact of discharge operations. This is because the water-quality criteria are based on water-soluble chemical species. However, chemical constituents associated

with dredged material suspensions are generally in particulate solid-phase forms or mineralogical forms that have markedly lower toxicities, mobilities, and chemical reactivities than the solution-phase constituents. Consequently, little information is available about the biological effects of solid-phase and mineral constituents that make up the largest fraction of dredged material. This fact precludes the development of meaningful total sediment criteria at this time.

Benthic community structure and other biological assessments

46. A variety of methods exist for characterizing benthic community structure for the proposed dredging and discharge sites. These methods are described in a general fashion and literature references are provided in Appendix E. Basically these methods require a significant field sampling program and a great deal of taxonomic expertise to yield meaningful results. Even at best, due to the significant variation in natural biological abundance, sampling procedures, and evaluation methodologies, the results frequently would be difficult to interpret in a way that would be meaningful to decisionmaking. Analyses of benthic community structure are not recommended unless a full-scale ecological field study by competent biologists is deemed necessary for decisionmaking.

Contaminated Fill Material Restrictions

47. Guidance for this area is given in Section 230.5(d) of the Register. The specific procedures provided in this report and the general guidance found in Section 230.4 and 230.5 of the Register may

be used where appropriate in making an evaluation. Consideration should be given to the source of the fill material providing that the site of the proposed excavation is sufficiently removed from source(s) of contamination. Further consideration should be given to an adequate physical characterization of the fill material to facilitate selection of appropriate evaluation procedures provided in the Register and this report. To date little or no information is available concerning environmental impacts related to discharge of contaminated fill material other than the obvious physical impacts associated with such activities as completely filling a wetlands area.

PART III: EPILOGUE

48. This report was not intended or developed for the establishment of standards or extremely rigid criteria nor should it be interpreted in this manner. Rather, these evaluation procedures are suggested additional guidance for the District Engineer to use in evaluating permit applications for the discharge of dredged or fill material pursuant to Section 404(b) of the Federal Water Pollution Control Act of 1972. This report contains state-of-the-art evaluation procedures in the dynamically evolving fields of aquatic and sediment chemistry and biology and will be updated as newer, more meaningful evaluation procedures are developed. Ecosystem perturbation cannot be predicted nor described by any single test, standard, or discipline but must be the result of multidisciplinary evaluation.

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Note: Pertinent references are cited in and lists follow each appendix.

APPENDIX A: ELUTRIATE TEST PROCEDURE

Number of Samples

1. The number of sediment and water samples to be taken from the dredging site for replicate analyses must be carefully considered because of the extremely heterogeneous nature of samples of this type. Also, the necessary number of replicate analyses of composite disposal site water samples must be carefully considered because of the comparatively low background concentrations of some constituents in samples of this type.

Sample Collection and Preservation

Water

2. Collection should be made with appropriate noncontaminating water-sampling devices. Collect a 2-gal representative water sample at both the dredging site and the disposal site. If the samples are to be analyzed for trace organics or for a large number of constituents, a proportionately larger initial sample should be collected. The samples must be stored in plastic bottles or in glass storage containers if trace organic analyses are to be performed on the samples.

3. The samples should be stored immediately at 2 to 4°C. The samples should never be frozen. The storage period should be as short as possible to minimize changes in the characteristics of the water. It is recommended that samples be processed within one week of collection.

Sediment

4. Sediment samples from the dredging site should be taken with a grab sampler or corer in such a manner to ensure that their characteristics are representative of the proposed dredging site. Approximately 1 gal of sediment should be collected; if the samples are to be analyzed for trace organics or a large number of constituents, a proportionately larger initial sample should be collected. The samples should be placed in airtight plastic bags or jars or in glass storage containers if trace organic analyses are to be performed on the samples. Care should be taken to ensure that the containers are completely filled with sample and that air bubbles are not trapped in the container.

5. The samples should be stored immediately at 2 to 4°C. The samples must never be frozen. The storage period should be as short as possible to minimize changes in the characteristics of the sediment. It is recommended that samples be processed within one week of collection.

Apparatus

6. The following items are required. Prior to use, all glassware, filtration equipment, and filters should be washed with 5 to 10 percent (or stronger) hydrochloric acid (HCl) and then rinsed thoroughly with deionized water.

- a. Acid-rinsed plastic bottles for collection of water samples.
- b. Plastic jars or bags ("Whirl-Pak," plastic freezer containers, etc.) for collecting dredged or fill material samples.
- c. Laboratory shaker capable of shaking 2-litre flasks at

approximately 100 excursions/min. Box type or wrist-action shakers are acceptable.

- d. Several 1-litre graduated cylinders.
- e. Large (15 cm) powder funnels.
- f. Several 2-litre large-mouth graduated Erlenmeyer flasks.
- g. Vacuum or pressure filtration equipment, including vacuum pump or compressed air source, and an appropriate filter holder capable of accomodating 47, 105, or 155-mm-diameter filters.
- h. Membrane filters with a 0.45μ pore-size diameter should be used. The filters should be soaked in 5M HCl for at least 2 hr prior to use.
- i. Centrifuge capable of handling six 1- or 0.5-litre centrifuge bottles at 3,000 to 5,000 rpm. International Model K or Sorval Super Speed are acceptable models.
- j. Wide-mouth, 1-gal capacity glass jars with Teflon-lined screw-top lids should be used for sample containers when samples are to be analyzed for trace organics. (It may be necessary to purchase jars and Teflon sheets separately; in which case, the Teflon lid liners may be prepared by the laboratory personnel.)

Test Procedure

7. The stepwise test procedure is given below.
 - a. Subsample a minimum volume of 1 litre each of dredging site and disposal site water. If it is known in advance that a large number of measurements are to be performed, the size of each subsample

should be increased to meet the anticipated needs.

b. Filter an appropriate portion of the disposal site water through an acid-soaked 0.45 μ pore-size membrane filter that has been prerinsed with approximately 100 ml of disposal site water. The filtrate from the rinsing procedure should be discarded.

c. Analyze the filtered disposal site sample for the major constituents as soon as possible using acceptable procedures.^{1,2,3} If necessary, the samples may be stored at 2 to 4^oC after preservatives have been added. The filtered water samples may be frozen with no apparent destruction of sample integrity.

d. Repeat steps a, b, and c with dredging site water.

e. Subsample approximately 1 litre of sediment from the well-mixed original sample. Mix the sediments and unfiltered dredging site water in a volumetric sediment-to-water ratio of 1:4 at room temperature (22 \pm 2^oC). This is best done by the method of volumetric displacement.⁴ One hundred ml of unfiltered dredging site water is placed into a graduated Erlenmeyer flask. The sediment subsample is then carefully added via a powder funnel to obtain a total volume of 300 ml. (A 200-ml volume of sediment will now be in the flask.) The flask is then filled to the 1000-ml mark with unfiltered dredging site water, which produces a slurry with a final ratio of one volume sediment to four volumes water. If the volume of water required for analysis exceeds 700 to 800 ml, the initial volumes should be proportionately increased (e.g., mix 400 ml of sediment and 1600 ml disposal site water). Alternately, several 1-litre dredged material/dredging site

water slurries may be prepared as outlined above and the filtrates combined to provide sufficient water for analysis.

f. (1) Cap the flask tightly with a noncontaminating stopper and shake vigorously on an automatic shaker at about 100 excursions per min for 30 min. A polyfilm-covered rubber stopper is acceptable for minimum contamination.

(2) During the mixing step given in paragraph 5f(1), the oxygen demand of the dredged material may cause the dissolved oxygen concentration in the elutriate to be reduced to zero. This change can alter the release of chemical contaminants from dredged material to the disposal site water and reduce the reproducibility of the elutriate test.⁵ If it is known that anoxic conditions (zero dissolved oxygen) will not occur at the disposal site or if reproducibility of the elutriate test is a potential problem, the mixing may be accomplished by using the compressed air mixing procedure instead of the mechanical mixing described in paragraph 5f(1). After preparation of the elutriate slurry, an air-diffuser tube is inserted almost to the bottom of the flask. Compressed air should be passed through a deionized water trap and then through the diffuser tube and the slurry. The flow rate should be adjusted to agitate the mixture vigorously for 30 min. In addition, the flasks should be stirred manually at 10-min intervals to ensure complete mixing.

g. After shaking or mixing with air, allow the suspension to settle for 1 hr.

h. After settling, carefully decant the supernatant into

appropriate centrifuge bottles and then centrifuge. The time and rpm's during centrifugation should be selected to reduce the suspended solids concentration substantially and therefore shorten the final filtration process. After centrifugation, vacuum or pressure filter approximately 100 ml of sample through a 0.45 μ membrane filter and discard the filtrate. Filter the remainder of the sample to give a clear final solution (the standard elutriate) and store at 4 $^{\circ}$ C in a clean noncontaminating container in the dark.

i. Analyze as soon as possible for major constituents using accepted procedures.^{1,2,3}

j. Prepare and test the elutriate in triplicate and report the average concentration of the three replicates as the concentration in the standard elutriate.

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APPENDIX B: MIXING ZONE PROCEDURES

Volume of Dilution Water

1. A mixing zone is that volume of water at a disposal site required to dilute contaminant concentrations associated with a discharge of dredged material to an acceptable level. In order to calculate the volume of disposal site water required for a specific proposed discharge, it is first necessary to perform the elutriate test described in Appendix A to determine the concentration of the critical constituents of greatest concern in the standard elutriate and in disposal site water.

2. The next step in determining the volume of the mixing zone is the derivation of an expression for the volume of disposal site water required to dilute to an acceptable level the concentration of a critical constituent in one unit volume of standard elutriate resulting in a dilution factor D. Since the mass of the constituent of interest in one volume of standard elutriate is (1) (C_e), the mass of the constituent in D volumes of disposal site water is (D)(C_a) and the total volume is (D+1), the resultant concentration can be determined. However, if rather than solving for the resultant concentration, one prescribes its value such that a desired water-quality standard is satisfied, then the expression below can be solved for the volume of disposal site water necessary to achieve such a dilution.

$$D = \frac{C_e - C_s}{C_s - C_a} \quad (B1)$$

where

C_s = numerical standard for constituent of interest, mg/l

C_a = concentration of constituent of interest in disposal site water, mg/l

C_e = concentration of constituent of interest in standard elutriate, mg/l

D = dilution factor required to dilute concentration of constituent of interest to a concentration equal to the numerical standard C_s , vol/vol

3. The total volume of water necessary to dilute a discharge of dredged material to acceptable levels is equal to the volume calculated in Equation B1 times the total volume of dredged material. This can be expressed as:

$$M = DV_d \quad (B2)$$

where

M = required volume of disposal site water, cu yd

D = dilution factor required to dilute concentration of constituent of interest to a concentration equal to the numerical standard C_s , vol/vol

Vd = volume of dredged material, cu yd

4. When using this approach to calculate the necessary volume of dilution water, the following recommendations and specifications should be considered:

a. Acute toxicity criteria rather than chronic toxicity criteria should be used in Equation B1 to calculate the mixing volume. The justification for this recommendation is that dredged material

disposal is an intermittent, short-term event and perturbations resulting from disposal activities would not be expected to persist for the lifetime of an organism. Thus, the use of chronic toxicity criteria, based on long-term exposure, would be technically inappropriate.

b. In using standards to calculate the volume of a mixing zone, consideration should be given to the basis of the standards. For example, the most stringent standards for iron and manganese are based on aesthetic considerations. Section 230.5(b)(1) of the Register gives consideration to discharging near municipal water intakes; therefore, iron and manganese standards that are used should reflect the toxicological and other properties of these metals rather than aesthetic properties if these metals are deemed critical constituents.

c. If the elutriate test concentration C_e is less than or equal to the numerical standard C_s , no calculation is necessary since no dilution is necessary.

d. If the elutriate test concentration C_e is greater than the numerical standard C_s and the proposed disposal site water concentration C_a is less than the numerical standard C_s , the required dilution volume can be calculated as described above.

e. If the elutriate test concentration C_e is greater than the proposed disposal site water concentration C_a and the proposed disposal site water concentration C_a is greater than or equal to the numerical standard C_s , the standard cannot be achieved by dilution. Some other procedure will have to be used to evaluate the proposed discharge activity. One possible method would be to use appropriate bioassays (Appendix C).

Shape of Mixing Zone

5. After calculating the required volume M of disposal site water that would be necessary for diluting the proposed discharge, the next step in implementing the mixing zone concept is to characterize the shape associated with the dilution volume. This can be accomplished by defining relatively simple three-dimensional geometric shapes for use with specified types of discharges and discharge conditions.

Discrete discharges

6. The general shape with greatest apparent applicability to discrete discharge operations is that of a conical frustum whose volume M is defined by:

$$M = \frac{d}{3} \left(A_b + \sqrt{A_b A_t} + A_t \right) \quad (B3)$$

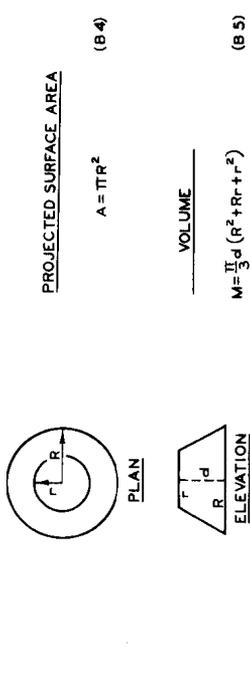
where

d = height of frustum

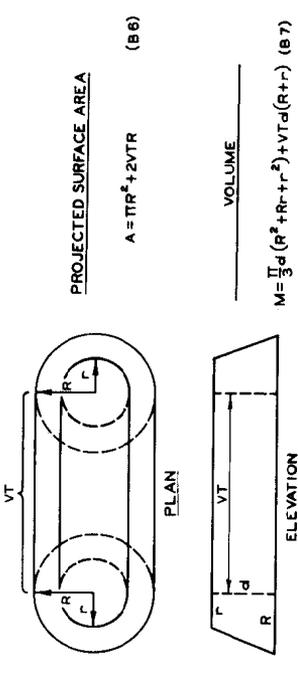
A_b = area of lower base of frustum

A_t = area of upper base of frustum

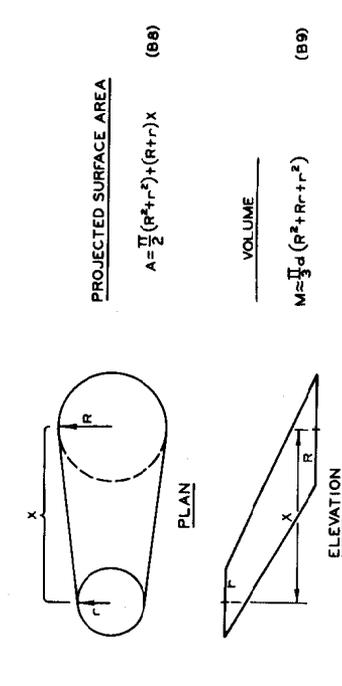
7. Five different combinations of disposal operations and ambient current conditions are considered for discrete discharge operations (Figure B1). Each combination can be described by a volumetric and a surface area equation that will define the mixing zone for a proposed discharge operation. The variables used in Equations B4-13 in Figure B1 are defined as follows:



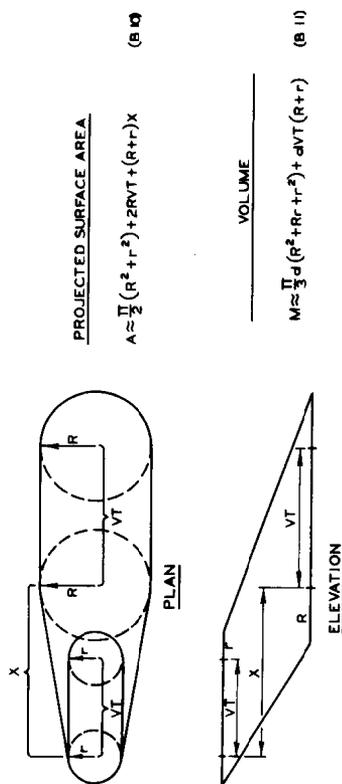
A. STATIONARY DISCHARGE WITH NEGLIGIBLE CURRENT



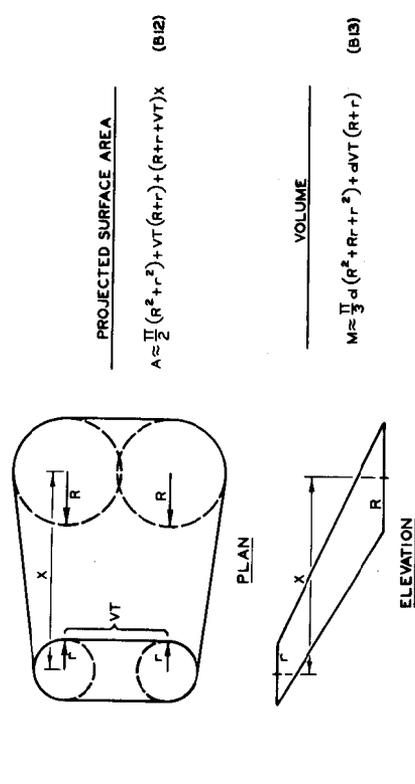
B. MOVING DISCHARGE WITH NEGLIGIBLE CURRENT



C. STATIONARY DISCHARGE WITH PREVAILING CURRENT



D. MOVING DISCHARGE WITH PREVAILING CURRENT



E. MOVING DISCHARGE ACROSS PREVAILING CURRENT

NOTE: THE VARIABLES USED IN THE EQUATIONS IN THIS FIGURE ARE DEFINED AS FOLLOWS:

- r = RADIUS OF INITIAL SURFACE MIXING
- d = DEPTH OF WATER AT PROPOSED DISPOSAL SITE
- R = BOTTOM RADIUS OF MIXING ZONE AREA
- V = VELOCITY OF DISCHARGE VESSEL
- VT = TIME REQUIRED TO EMPTY VESSEL DURING DISCHARGE
- W = WATER VELOCITY AT PROPOSED DISPOSAL SITE
- X = HORIZONTAL TRANSPORT DISTANCE OF DREGDED MATERIAL

Figure B1. Project surface area and volume equations for discrete discharge operations

r = radius of initial surface mixing

d = depth of water at proposed disposal site

R = bottom radius of mixing zone area

V = velocity of discharge vessel

T = time required to empty vessel during discharge

V_w = water velocity at proposed disposal site

X = horizontal transport distance of dredged material

8. The value r is intended to approximate the initial surface mixing that will occur at a disposal site. This value will be site specific and will vary with the type of disposal operation. In the absence of better information, an upper value for r can be estimated as 100 m as suggested by EPA in Reference 1 or one-half in length of the discharge vessel.

9. R is the radius of the bottom area of a conical frustum that defines a volume sufficient to dilute the proposed discharge to acceptable levels. R should be greater than or equal to the initial surface mixing radius r, since the discharge would be expected to expand horizontally as it settles through the water column.

10. X is the horizontal transport distance that dredged material will move away from the point of initial discharge as a result of water currents. A reasonable estimate of this value can be calculated as:

$$X = \left(\frac{\text{depth of water column}}{\text{appropriate settling velocity}} \right) \text{ water velocity} = \left(\frac{d}{V_s} \right) V_w \quad (\text{B14})$$

The most difficult parameter to define in Equation B14 will be the appropriate settling velocity V_s . The settling velocity that is used should represent the average settling velocity of the discharge and not the settling velocity of an average size particle in the discharge.

11. Each volumetric equation in Figure B1 can be solved for a single parameter R once the total volume M is specified, since other parameters should be constant for a proposed discharge operation and a given disposal site. The calculated R -value can then be substituted in the appropriate surface area projection equation to estimate the surface area that will be influenced by the proposed discharge.

12. The area calculation allows one to determine whether the projected surface area for a proposed discharge fits within the geographical limits of the authorized disposal site (where such limits are established) and to determine the most appropriate location for the initial dump to ensure that the projected surface area remains within the authorized disposal site. An estimate of the surface area to be influenced by a proposed discharge will also allow one to locate the disposal site in such a manner that possible adverse effects on other beneficial uses such as public water intakes or shell fisheries are avoided or minimized.

Continuous pipeline discharge

13. The approach to be taken in calculating the necessary mixing zone for a proposed pipeline disposal operation is similar to the discrete discharge approach except that the volume of water required for dilution is expressed as a rate of flow.

$$D = \frac{C_e - C_s}{C_s - C_a} \quad (B1)$$

with all terms as defined earlier in paragraph 2. However, since the discharge from a pipeline will occur at a specified rate V_p , the volume of ambient site water per unit time that would be required to dilute the discharge to acceptable levels can be defined as:

$$V_A = V_p D = V_p \left(\frac{C_e - C_s}{C_s - C_a} \right) \quad (B15)$$

where

V_A = volume of site water/unit time required for dilution, cfs

V_p = rate of disposal from pipeline, cfs

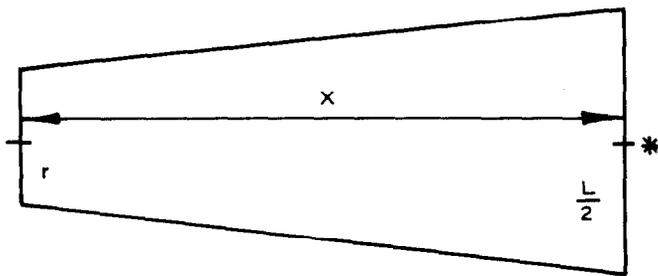
C_e = elutriate test concentration, mg/l

C_a = disposal site concentration, mg/l

C_s = acceptable level to be achieved by dilution, mg/l

14. It is assumed that the mixing zone associated with a pipeline discharge will resemble the shape in Figure B2. Therefore, once the required volume per unit time has been calculated, the next step is to determine the dimensions of the mixing zone. The required volume per unit time can also be expressed as:

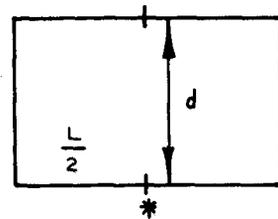
$$V_A = L d V_w \quad (B18)$$



PLAN

PROJECTED SURFACE AREA

$$A = \left(\frac{L}{2} + r \right) x \quad (B16)$$



FRONTAL ELEVATION

VOLUME PER UNIT TIME

$$V_A = LdV_w \quad (B17)$$

Figure B2. Projected surface area and volume equations for continuous pipeline discharge with prevailing current

where

V_A = required volume of water per unit time, cfs

L = width of mixing zone at time t , ft

d = depth, ft

V_w = velocity of water at disposal site, ft/sec

15. Since the depth and water velocity are known or can be measured, the width of the front edge of the mixing zone can be calculated as:

$$L = \frac{V_A}{d V_w} \quad (\text{B19})$$

16. Based on information presented by Brooks,² the time required for the front edge of the mixing zone to spread laterally to the required width L can be computed from:

$$t = \frac{1}{\lambda} \left(0.094 L^{2/3} - 0.149 r^{2/3} \right) \quad (\text{Reference 3}) \quad (\text{B20})$$

where

t = required time for lateral spreading, sec

L = necessary width of the front edge of mixing zone, ft

r = one-half initial width of the plume at point of discharge
(radius of initial surface mixing), ft

λ = turbulent dissipation parameter

Values for λ range from 0.00015 to 0.005 with a value of 0.005 being appropriate in a dynamic environment such as an estuary.⁴ As discussed earlier, values for r will be influenced by the method of disposal and will be site specific.

17. The calculated time can then be used to determine the longitudinal distance the discharge will travel as it is spreading to the required width. This distance can be computed from:

$$X = V_w t \quad (B21)$$

where

X = longitudinal movement of discharge, ft

V_w = velocity of water at disposal site, ft/sec

t = necessary time of travel, sec

18. The results of Equations B20 and B21 can then be combined to estimate the projected surface area of the proposed discharge. This area can be computed as:

$$A = \frac{L + 2r}{2} X \quad (B22)$$

where

A = surface area, ft²

L = width of front edge of mixing zone, ft

r = radius of initial surface mixing, ft

X = length of the mixing zone, ft

19. This approach will characterize a proposed discharge by defining the volume of dilution water per unit time that will be required to achieve some acceptable concentration at the edge of the mixing zone. Also, the length and width (and hence the surface area) of the necessary mixing zone will be approximated.

20. The approach used to calculate the required mixing zone for a continuous pipeline disposal operation may also be used to calculate the required mixing zone for a return flow from a confined disposal area. The calculations would be the same except that the volume of flow from a confined disposal area would be substituted for the volume of flow from a pipeline. The method should only be applied, however, where there is a discrete discharge source such as a conduit or a weir.

Sample Computations

21. The following computations are presented to illustrate the mixing zone concept as applied to two particular disposal operations: a moving, discrete discharge in the direction of a prevailing current (Figure B1, Case D) and a continuous discharge from a pipeline (Figure B2).

Discrete discharge

22. The following input values were used in the sample computations:

Volume of dredged material V_d	=	4000 yd ³
Water column depth d	=	50 ft
Vessel speed V	=	6 ft/sec
Ambient water velocity V_A	=	2 ft/sec
Time to end of discharge T	=	360 sec
Radius of initial surface mixing r	=	25 ft
Concentration of constituent of interest in standard elutriate C_e	=	30 mg/l

$$\begin{aligned}
\text{Ambient concentration } C_a &= 0.1 \text{ mg/l} \\
\text{Acceptable concentration } C_s &= 0.5 \text{ mg/l} \\
\text{Settling velocity } V_s &= 10 \text{ ft/sec}
\end{aligned}$$

23. The dilution factor required to dilute concentration of interest to a concentration of equal volume C_s , vol/vol, would be:

$$D = \frac{C_e - C_s}{C_s - C_a} = \frac{(30 - 0.5)}{(0.5 - 0.1)} = 73.75 \quad (\text{B1})$$

24. The volume of water to dilute the discharge to acceptable levels would be:

$$\begin{aligned}
M = D V_d &= (73.75)(4000 \text{ yd}^3) = 2.95 \times 10^5 \text{ yd}^3 \\
&= 7.96 \times 10^6 \text{ cu ft}
\end{aligned} \quad (\text{B2})$$

25. From Figure B1 (Case D), the equation for the volume of the mixing zone for a discrete discharge in the direction of a prevailing current is:

$$M = \frac{\pi}{3} d \left(R^2 + Rr + r^2 \right) + d V T (R + r) \quad (\text{B11})$$

By setting the volume equal to 7.96×10^6 cu ft, this equation can be solved for R, which equals 47 ft. This value can be used with the area equation in Figure B1 (Case D):

$$A = \frac{\pi}{2} \left(R^2 + r^2 \right) + 2 RVT + (R + r) X \quad (\text{B10})$$

where X is solved by Equation B14:

$$\begin{aligned}
X &= \frac{\text{depth of water column}}{\text{settling velocity}} \quad (\text{water velocity}) \\
&= \frac{50 \text{ ft}}{10 \text{ ft/sec}} \quad (2 \text{ ft/sec}) = 10 \text{ ft}
\end{aligned}$$

to arrive at the projected surface area = 208,212 sq ft.

26. Thus, the proposed mixing zone would have the following dimensions:

$$\text{Volume} = 7.96 \times 10^6 \text{ cu ft}$$

$$\text{Projected surface area} = 208,212 \text{ sq ft}$$

$$\text{Maximum dimensions} = 2242 \text{ ft by } 94 \text{ ft}$$

This information would be used in considering the compatibility of the size of the mixing zone required for the proposed discharge with the size of the proposed discharge site.

Continuous pipeline discharge

27. The following input values were used in the sample computations:

Volume of dredged material discharged	
per unit time V_p^*	= 44 cu ft/sec
Turbulent dissipation parameter λ	= 0.005
Water column depth d	= 10 ft
Water velocity V_w	= 0.5 ft/sec
Initial width of plume $2r$	= 30 ft
Ambient concentration C_a	= 0.1 mg/l
Elutriate test concentration C_e	= 30 mg/l
Acceptable concentration C_s	= 0.5 mg/l

28. The required volume per unit time will be:

$$V_A = V_p D = 44 \left(\frac{30 - 0.5}{0.5 - 0.1} \right) = 3245 \text{ cu ft/sec} \quad (\text{B15})$$

* Based on pipe radius of 12 in. and discharge velocity of 14 ft/sec.

29. The required width of the mixing zone will be:

$$L = \frac{V_A}{d V_w} = \frac{3245}{(10)(0.5)} = 649 \text{ ft} \quad (\text{B19})$$

30. The time required to achieve the lateral spread L will be:

$$t = \frac{1}{0.005} \left[(0.094)(649)^{2/3} - (0.149)(15)^{2/3} \right] \\ = 1228 \text{ sec} \quad (\text{B20})$$

31. The length of the mixing zone will be:

$$X = (0.5 \text{ ft/sec})(1228 \text{ sec}) = 614 \text{ ft} \quad (\text{B21})$$

32. Thus the proposed mixing zone would have dimensions of:

$$\text{Surface area} = \left(\frac{30 + 649}{2} \right) 614 = 208,453 \text{ sq ft}$$

$$\text{Maximum dimensions} = 614 \text{ ft by } 649 \text{ ft}$$

This information would be used in considering the compatibility of the size of the mixing zone required for the proposed discharge with the proposed discharge site.

Evaluation of calculations

33. The surface area and volumetric equations in Figures B1 and B2 were derived on the assumption that the dredged material would spread horizontally as it settles through the water column. Therefore, the calculated value for R should be greater than r. If the calculated value for R is less than r, this suggests that the input data is inappropriate. One possible reason for this discrepancy is that the selected value for r may have been too large. In this case, R can be recalculated using a smaller r value. (It also suggests that a cylinder

with radius r and depth d will provide sufficient water for dilution and that the surface area projection of the mixing zone can be estimated with r .)

34. Another possible reason for the calculated value of R being less than the selected value of r is the depth of the disposal site. If the depth d is large, the mixing zone will assume the shape of an inverted cone rather than a frustum. This also suggests that sufficient water is available for dilution under the surface area projection defined by r .

35. For the conditions where d is large, it may be more appropriate to specify a maximum portion of the water column (i.e., the upper 50 ft) that can be used for a mixing zone. Then the remaining dimensions of the mixing zone can be calculated using the specified value rather than the actual water column depth.

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APPENDIX C: GUIDANCE FOR PERFORMING BIOASSAYS

1. Two general types of potential problems associated with dredged material might be profitably evaluated by bioassays. The first is the potential for short-term effects of chemicals released to the water column during dredging and disposal operations. The organisms most likely to be affected by such a chemical release are the small, short-lived plants (phytoplankton) and animals (zooplankton) that spend their entire life in the water column or the larvae of fish or other animals that are in the water column during the critical early part of the life cycle. Techniques for conducting bioassays with such organisms are best established at present for phytoplankton or algae.

Algal Assay Implementation

2. Algal bioassays may be useful for evaluating the importance of dissolved chemical constituents released from the sediment during dredging and disposal operations. The algal assays consist of establishing a series of treatments and controls using the standard elutriate and filtered disposal site water. The experimental units are then inoculated with test organisms taken from a stock culture and held under a specified set of test conditions while a sampling program is conducted to determine response.

Species selection

3. A generally accepted species for algal bioassays in fresh water is Selenastrum capricornutum, while Skeletonema costatum or Thalassiosira pseudonana is recommended for marine assays. Stock cultures of these

species can be obtained from the EPA Environmental Research Center, Corvallis, Oregon.

Apparatus

4. The following items are required:
 - a. 500-ml Erlenmeyer flasks.
 - b. Polyurethane foam plugs for 500-ml Erlenmeyer flasks.
 - c. Facility for growing algae at constant temperature, illumination, and shaking rate. Psychrotherm incubators (New Brunswick Scientific, Inc.) are adequate for the growth conditions used in the algal bioassays. Alternatively, a walk-in chamber with shelves, fluorescent lighting, and proper temperature control may be used. When automatic shaking is not available, all flasks should be gently swirled at least twice daily at regular intervals. It is important that all test units receive approximately the same illumination and are maintained at the same temperature.
 - d. Equipment required for evaluating response. Requirements will depend on whether cell counts, C^{14} uptake, productivity, etc., are the responses to be measured.^{1,2,3,4}

Sample collection and preservation

5. Sediment and water samples are collected and the standard elutriate prepared as described in Appendix A, "Elutriate Test Procedure." Sediment should be collected from at least three sites within the area to be dredged. Eight litres of sediment from each site are sufficient. Twenty-four litres of water from each dredge site and 32 litres of disposal site water should be collected.

6. Dredge site water should be collected about 1 m above the sediment surface. Disposal site water should be collected from the surface.

Procedure

7. Procedures for the algal assay for freshwater and marine dredging and disposal sites are similar to those described in References 1 and 2, respectively. The references give details of procedure and rationale and must be used in conjunction with the guidance provided here.

8. Grow stock algal cultures in synthetic nutrient medium.^{1,2} Start new cultures each week by transferring 0.1 ml of a one-week-old culture to 100 ml of fresh medium using aseptic technique. Grow stock cultures at lab temperature (approximately 23°C) under continuous cool-white fluorescent lighting at an intensity of approximately 1500 $\mu\text{w}/\text{cm}^2$ and shake continuously at 110 rpm. If shaking tables are not available, swirl all flasks at regular intervals at least twice daily.

9. Use 500-ml pyrex Erlenmeyer flasks stoppered with polyurethane foam plugs for culture vessels. Wash all glassware with detergent, rinse with tap water, place in a clean 10-percent HCl acid bath for a minimum of 2 hr, rinse five times with tap water, and then rinse five times with distilled water.

10. Establish treatment levels using standard elutriate, disposal site water, and an inoculum of the test organism added to produce a total liquid volume of 100 ml in 500-ml Erlenmeyer flasks. A greater volume will be required for some of suggested techniques for measuring

response, such as C^{14} or productivity. Use the following treatment levels:

<u>Percent Elutriate</u>	<u>Percent Disposal Site Water</u>
0	100.0
0.1	99.9
1.0	99.0
10.0	90.0
100.0	0

11. Establish the following controls:

- a. 100 percent synthetic algal nutrient medium.
- b. 10 percent synthetic algal nutrient medium.
- c. 0 percent elutriate:100 percent disposal site water.

Addition of nutrients equal to 10 percent of stock culture concentration.

- d. 1 percent elutriate:99 percent disposal site water.

Addition of nutrients equal to 10 percent of stock culture concentration.

- e. 100 percent elutriate:0 percent disposal site water.

Addition of nutrients equal to 10 percent of stock culture concentration.

12. Adjust concentration of growth medium to be added to the controls so that when 1 ml is added, it produces a final concentration equivalent to 10 percent of the growth medium.

13. Prepare the inoculum by centrifuging and washing stock culture cells with sterile water containing 15 mg NaHCO_3 /litre for the freshwater algae or with sterile artificial seawater without the nutrients for the marine algae. Adjust the inoculum cell concentration by

dilution, then pipette the inoculum into the test water to give a starting concentration in the test waters of 1000 cells per ml.

Skeletonema costatum and T. pseudonana should be grown at the salinity of the proposed disposal site for at least two weeks prior to use in a bioassay. Procedures for adjusting the salinity of the growth medium are given in Reference 2.

14. Establish at least three replicates of each treatment level and control. Distribute the flasks randomly in two Psychrotherm incubators or appropriate chambers. Set temperature at 18°C for marine algal assays and 24°C for freshwater assays ($\pm 1^\circ\text{C}$), lighting intensity at approximately 1100 to 1500 $\mu\text{w}/\text{cm}^2$ using cool-white fluorescent bulbs, and the shaking rate at 110 rpm throughout the assays. Continue the assays until the maximum cell number occurs in each treatment. This does not necessarily occur on the same day for each treatment.

15. Determine the effect of the elutriate on the algae by comparing the response in the controls to that in the flasks containing elutriate. This may be done by comparing cell counts, C^{14} uptake, productivity, or chlorophyll values. Procedures for these standard methods for evaluating algal response may be found in References 1, 2, 3, and 4.

16. The statistical analysis of the data includes analysis of variance and mean contrast tests⁵ to determine if there are differences resulting from exposure to various elutriate concentrations and among individual sites within a particular location.

Evaluation

17. Algal bioassays using standard elutriate and disposal site

water will indicate the possible bioavailability of the dissolved constituents and their potential effect on phytoplankton primary productivity at the disposal site. When response of the test organisms is compared in the elutriate and disposal site water, stimulation, inhibition, or no effect may be observed. If response is equivalent in the elutriate and the disposal site water, it is an indication of no adverse effect on phytoplankton at the disposal site. One hundred percent elutriate used in a static bioassay represents an extreme worst-case situation since dilution by a factor of 10 or more occurs within seconds in the field.⁶ Therefore, if growth is stimulated or inhibited in the modified elutriate when compared to disposal site water, mixing and dilution at the disposal site must be considered. Dilution is simulated in the described bioassay procedure by mixing disposal site water and modified elutriate in various ratios. However, length of time at a particular concentration of elutriate is not considered and each dilution is the worst-case situation. It cannot be overemphasized that due to dilution, it is extremely unlikely 100 percent elutriate will ever be encountered in the field, except perhaps for very short periods.

18. Extreme care must be exercised in extrapolating from the results of a laboratory bioassay in attempting to predict field effects because existing procedures do not adequately address the changing conditions that can be expected at a disposal site. Existing procedures generally examine the effects of different concentrations of a test material for a constant but arbitrarily selected period of time.⁷ However, the effect of the test material is a function of the exposure

concentration and the exposure time, although the importance of time is not generally understood or recognized. Since the exposure concentration and the exposure time for a given concentration are both altered continually at a discharge site due to dilution, existing procedures would most likely overestimate potential effects at a disposal site. For this reason, mixing zone considerations (exposure times and concentrations) must always be incorporated into the final interpretation of water column bioassay results. It should be noted that stimulation of algal growth may be undesirable, since increased growth may indicate conditions that could lead to algal blooms.

Benthic Bioassay

General discussion

19. The other area of concern that might be addressed by bioassays is the potential for long-term impacts on bottom-dwelling (benthic) organisms on and around disposal sites. Bioassay techniques using these animals have been developed, but most have been designed to test only the soluble phase of a single substance or perhaps a mixture of two or three substances. Such designs are not suitable to dredged material, which may be a complex and poorly defined chemical mixture containing various substances in solution and/or particulate forms.

20. Techniques for long-term benthic bioassays appropriate to dredged material are still under development, and researchers are not in agreement on the approaches that might be most useful. Therefore, definitive interim guidance is not provided. However, should the need for benthic bioassays be sufficient to warrant an attempt at their use,

the following general suggestions should be considered.

21. The exposure procedure should simulate the conditions in the disposal area after the dredged material has settled to the bottom if the impact of long-term chemical uptake is the topic of concern. Conditions as the dredged material reaches the bottom should be duplicated if the concern is with the immediate physical impact of burying the animals. Benthic bioassays should use dredging site sediment as the test material. Controls should include disposal site sediment and either sediment from an undisturbed nearby reference area or an uncontaminated material such as kaolin or clean sand. Disposal site water should be used in both the test and control aquaria. Sublethal indicators of adverse effects should be measured rather than death, which may be viewed as the culmination of a series of sublethal changes and is the last response that an animal can exhibit.

22. All bioassays must include sufficient controls so that responses of the unstressed animals can be compared to the responses of similar animals exposed to the dredged material being studied. This means that control organisms must be exposed to exactly the same procedures of feeding, illumination, handling, etc., as the experimental organisms.⁴ In addition, adequate dissolved oxygen concentrations must be maintained in the experimental and the control containers during the bioassay.³ Although artificial aeration may be required, uncontrolled aeration with compressed air has been generally unsatisfactory due to the loss of volatile constituents. Water from the proposed disposal site should be used for the control aquaria.

23. After beginning the bioassay, both the control and experimental organisms should be periodically observed for several days to several weeks or more in order to determine their response to the dredged material. The techniques to be used to measure the organism response will depend on the organism being used, the type of response being measured, and the method of measurement. Specific details can be found in References 1, 2, 3, and 4.

24. The bioassay response may be expressed as the effective concentration for 50 percent of the test organisms (EC50), defined as the concentration of the test material at which 50 percent of the test organisms exhibit the response being measured after a specified period of exposure. A frequently calculated statistic is the EC50 for death, expressed as the LC50 or lethal concentration to 50 percent of the sample. The exposure period must always be stated (i.e., 96-hr LC50) to give these statistics meaning.

Relevant literature

25. Nearly all past bioassay research has considered only soluble toxicants in pure form, while dredged material is a complex chemical mixture of substances in soluble and particulate forms. Therefore, most presently available bioassay methods are not directly applicable to dredged material. Many of the same principles and theories are common to all bioassays, however, and a review of the literature may be helpful in this regard. Such a review will soon be published by the U. S. Army Engineer Waterways Experiment Station in a report entitled "Assessment of Equipment, Methodologies, and Institutional Capabilities for Conducting or Developing Bioassays." This report was prepared under

the Dredged Material Research Program Work Unit 1D02 (Contract
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APPENDIX D: TOTAL SEDIMENT ANALYSIS PROCEDURES

Sample Collection and Preservation

1. Approximately two to four litres of sediment should be taken from the proposed dredging site in such a manner as to ensure that the characteristics of the sample are representative of the site. The sample should be placed in plastic jars or containers and stored at 4°C until used. If trace organic constituents are to be determined, a separate sample of approximately the same size should be collected and stored in a glass container at 4°C. The length of time a sample may be stored depends on the analysis to be run and the method of preservation,* but it is recommended that samples be processed within one week of collection.¹

2. When an elutriate test is to be run on the same sample, care should be taken to minimize contact between the sample and oxygen during storage and sample preparation. If a total sediment analysis is the only evaluation procedure to be run on the dredged material sample, this precaution may be desirable, but not necessary.

Apparatus

3. The specific equipment necessary will vary depending on the chemical constituent(s) to be analyzed in the total sediment digest or the total sediment organic extract. Reference procedure manuals should

* Complete sample stability for every constituent can never be achieved. However, samples may be preserved to (a) retard biological action, (b) retard hydrolysis of chemical compounds and complexes, and (c) reduce volatility of constituents.

be consulted to determine specific needs, proper cleanup procedures for glassware and other apparatus, and possible interferences in the analysis.^{1,2}

Procedure

General

4. The stepwise procedure for total sediment analysis is given below. Referenced standard procedures for specific constituents are given in Table D1.

a. Transfer a well-mixed 1-litre sample of dredged or fill material to a 1-litre graduate, filling to the mark, and let settle overnight. If there is no separation of solid and liquid phases, the entire sample can be analyzed directly for chemical content as a settled phase.

b. Record the volume of supernatant and settled material for later calculations.

c. Decant the supernatant through a 10-cm conical funnel lined with a layer of glass wool. Retain the settled solids in the graduate as much as possible. If the dredged or fill material has been well drained, there may be no separation. In this case, the entire sample should be treated as the settled phase (i.e., no supernatant) as discussed below.

(1) Supernatant phase. The supernatant may be treated as any liquid sample and analyzed as described in the referenced methods.

(2) Settled phase. The settled solids may be analyzed as

either a wet or dry sample, depending on the instructions given in the special requirements in the next paragraph (paragraph 5). However, dry weight of the total solids (residue, total) must be determined prior to any analytical determinations because all concentrations are reported on a dry weight basis. This information will be used to report subsequent analyses on a milligram-per-kilogram basis. The material used for the determination may be used for subsequent analyses of dry settled material.

(a) Wet sample. Weigh a representative portion of the wet semisolid material in a container of the appropriate size and type specified in the reference method. If required, add ultra pure distilled water and agitate the sample to obtain a homogeneous mixture. Proceed with the analysis as described in the referenced method.

(b) Dry sample. Weigh a representative portion of the material from the settled phase, approximately 10 to 25 g, and dry to a constant weight at 105°C. Calculate the percent solids in the wet settled material. Grind* the dried sample used for the total solids measurements and weigh a representative aliquot, the size of which depends on the potential concentration levels. Proceed with analysis of this aliquot for the desired parameter by the method specified in Table D1. If volatile solids analyses are required, the determination must be made on a separate aliquot of material.

*The sample should be ground to pass a 100-mesh screen. A porcelain or agate mortar and pestle is sufficient for this purpose.

Special requirements

5. The following modifications are suggested for the analytical procedures listed in Table D1. The subparagraph designations in this section are the same as the superscript references in the first column of the table.

a. BOD. During the sample preparation, wet settled material should be used. Weigh a 1- to 10-g portion of sample and disperse with dilution water to a volume of 1 litre. Proceed with the referenced method under procedure.

b. COD. Nitrogen (all forms), phenol (general), and sulfide. During sample preparation, wet settled material should be used because the sediment drying procedure will reduce COD and sulfide by oxidation, alter the forms of nitrogen, and reduce phenol levels by volatilization. A sample size of 1 to 10 g is recommended.

c. Metals. For the determination of total metals, the digestion procedure given in the EPA Manual,¹ page 82 (4.1.3), is to be followed. Begin with "Transfer a representative aliquot of well-mixed sample, etc."

d. Selenium. Follow digestion for total metals as specified in the referenced method including digestion with the second portion of nitric acid. Then add 10 ml of 30-percent H_2O_2 and warm the beaker slightly. As soon as the reaction commences, remove the beaker from the hot plate. After the effervescence has subsided, return the covered beaker to the hot plate and reflux 15 min. Continue with the procedure for total metals as referenced, but eliminate the addition of (1:1) HCl.

e. Add 60 g of settled material (wet) to a 250-ml graduated Erlenmeyer flask and add sufficient 5-percent HCl to adjust volume to 200 ml. Stopper and shake mechanically or manually for 5 min. After settling, decant and filter water layer through Whatman No. 1 filter paper. Pipet 50 ml of filtrate into a 250-ml volumetric flask. Add 100 ml of distilled water. Carefully (while cooling), add sufficient 5-percent NaOH to adjust sample pH to 8.5 to 9.0. Adjust volume of cooled sample to 250 ml with distilled water.

f. Blend 100 g of settled material (wet) with 200 ml acetone for 30 sec using a mechanical high-frequency disperser. Filter through Whatman No. 1 filter paper. Wash disperser head and sample container with 25-ml portions of acetone and pour rinsings through filter. Rinse filter with two 20-ml portions of acetone. Concentrate the acetone solution to 100 to 150 ml on a hot water bath. Transfer the acetone to a separatory funnel containing 300 ml water and 25 ml saturated sodium sulfate solution. Extract the solution three times with 60-ml portions of the extracting solvent used in paragraph 9 of the reference method. Collect the separated solvent in another separatory funnel. Wash the combined solvent layers by shaking with two 200-ml portions of water. Pour the organic layer through a 3- to 4-in. column of sodium sulfate and collect it in a 500-ml Kuderna-Danish evaporator.

g. Air dry several hundred grams of settled material in a glass dish at room temperature for several days. Grind the sample with mortar and pestle to uniform size. Weigh 30 g of sample in a beaker. Add 3.0 ml of water. Mix well and transfer to a Soxhlet extractor.

Extract the sample for 16 hr with 300 ml of acetone-hexane in a 1-to-9 ratio. Pour the organic layer through a 3- to 4-in. column of sodium sulfate and collect it in a 500-ml Kuderna-Danish evaporator.

h. Place 50 g of settled material (wet) in a calibrated 250-ml Erlenmeyer flask and add sufficient 5-percent NaOH to adjust volume to 200 ml. Stopper and shake mechanically or manually for 5 min. After settling, decant and filter water layer through Whatman No. 1 filter paper. Pipet 50 ml of filtrate into a 250-ml volumetric flask. Add 100 ml of distilled water. Carefully (while cooling) add sufficient 5-percent HCl to adjust sample pH to three. Adjust volume of cooled sample to 250 ml.

i. When analyzing settled material for petroleum hydrocarbons, carbon tetrachloride is substituted for reagent 6.2; drying in paragraph 7.6 is done overnight at room temperature. After completing procedure in paragraph 7.7, transfer extract to a 100-ml volumetric flask and analyze by method for supernatant beginning with step 7.1. Reference material: 25 percent benzene, 37.5 percent isooctane, 37.5 percent hexadecane.

Calculations

6. The calculations of test results are performed as follows:

a. Supernatant. Report all concentrations as milligrams per litre.

$$\text{mg/l} = \frac{\left(\frac{\text{mg/l of constituent in}}{\text{prepared sample}} \right) \left(\frac{\text{volume of prepared}}{\text{sample, ml}} \right)}{\text{volume of sample aliquot, ml}}$$

(1) Percent volatile total solids v_{ts} :

$$v_{ts} = \frac{\text{volatile total solids, mg/l}}{\text{total solids, mg/l}} 100$$

(2) Percent volatile suspended solids v_{ss}

$$v_{ss} = \frac{\text{volatile suspended solids, mg/l}}{\text{suspended solids, mg/l}} 100$$

b. Settled material. Report all concentrations as milligrams per kilogram dry weight.

$$\text{Percent solids} = \frac{\text{wt of dry residue, g}}{\text{wt of wet sample, g}} 100$$

(1) Wet sample:

$$\text{Concentration, mg/kg} = \frac{\left(\frac{\text{mg/l of constituent}}{\text{in prepared sample}} \right) \left(\frac{\text{volume of prepared sample, litre}}{(\% \text{ solids}) (0.001)} \right)}{\text{(wt of wet sample, g)}}$$

(2) Dry sample:

$$\text{Concentration, mg/kg} = \frac{\left(\frac{\text{mg/l of constituent}}{\text{in prepared sample}} \right) \left(\frac{\text{volume of prepared sample, litre}}{(\text{wt of dry sample, g}) (0.001)} \right)}{}$$

c. Total weight of a single constituent Y in the original 1-litre sample:

$$Y = \left[\frac{(\text{volume of supernatant, ml})}{(1000 \text{ ml/l})} A \right] + \left[\frac{(\text{volume of settled material, ml}) (\text{density in g/ml})}{(1000 \text{ g/kg})} B \right]$$

where

Y = total weight of a single constituent in the original
1-litre sample

A = milligrams per litre of constituent in supernatant

B = milligrams per kilogram of constituent in settled material

REFERENCES

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2. American Public Health Association, Standard Methods for the Examination of Water and Wastewater, 13th Ed, American Water Works Association, Water Pollution Control Federation, APHA, New York, 1971.
3. American Society for Testing Material, 1974 Annual Book of ASTM Standards, Part 31, Water, 1974, Philadelphia.
4. Anonymous, "Direct Aqueous Injection for Quantification," Analytical Chemistry, Vol. 46, 1974, p 977. (*Column packing is available through Supelco, Inc., Bellefonte, Pa. Request Bulletin 738-Carbopack.*)
5. U. S. Environmental Protection Agency, "Method for Benzidine and Its Salts in Wastewater," 1973, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.
6. U. S. Environmental Protection Agency, "Methyl Mercury in Sediment," 1973, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.
7. U. S. Environmental Protection Agency, "Method for Polychlorinated Biphenyls (PCB's) in Industrial Effluents," 1973, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.
8. U. S. Environmental Protection Agency, "Method for N-Aryl Carbonate and Urea Pesticides in Industrial Effluents," 1973, Environmental Monitoring Support Laboratory, Cincinnati, Ohio.
9. U. S. Environmental Protection Agency, "Method for O-Aryl Carbamate Pesticides in Industrial Effluents," 1973, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.
10. U. S. Environmental Protection Agency, "Method for Organochlorine Pesticides in Industrial Effluents," 1973, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.
11. U. S. Environmental Protection Agency, "Method for Organophosphorus Pesticides in Industrial Effluents," 1973, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.

12. U. S. Environmental Protection Agency, "Method for Chlorinated Phenoxy Acid Herbicides in Industrial Effluents," 1973, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.
13. U. S. Geological Survey, "Methods for Analysis of Organic Substances in Water," Techniques of Water Resources Investigations, Book 5, Chap. A3, 1972, p. 39.
14. U. S. Environmental Protection Agency, "Method for Triazine Pesticides in Industrial Effluents," 1973, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.

Table D1
Procedure References for Total Sediment Analysis
Analytical Methods

Parameter*	Reference 1	Reference 2	Reference 3	Other References
<u>Physical Parameters</u>				
Solids				
Total Solids (Residue, Total)	p 270	Method 224A p 535	-	-
Suspended Solids (Nonfilterable)	p 268	-	-	-
Volatile Solids (Residue-Volatile)	p 272	Method 224B p 536	-	-
<u>Inorganic Constituents</u>				
BOD ^a	-	Method 214 p 489	-	-
COD ^b	p 20	Method 220 p 495	Method D1252 p 472	-
Cyanide (total)	p 40	Method 207 p 397	Method D2036 p 503	-
Fluoride (total)	p 59	Method 121A&C p 171	Method D1179 p 310	-
Metals (total) ^c	p 82(4.1.3)	-	-	-
Antimony	p 94	-	-	-
Arsenic	p 95	-	-	-
Beryllium	p 99	-	-	-
<u>Cadmium**</u>	p 101	p 210	p 351	-
Chromium	p 105	p 210	p 351	-
Cobalt	p 107	-	p 351	-
Copper	p 108	p 210	- 351	-
Iron	p 110	p 210	p 351	-
Lead	p 112	p 210	p 351	-
Manganese	p 116	p 210	p 351	-
<u>Mercury**</u>	p 118, 138	-	p 344	-
Nickel	p 141	-	p 351	-
Selenium ^d	p 145	-	-	-

*Superscript alphabetical notations refer to similarly lettered subparagraphs in text (paragraph 5) that include suggested modifications to methods described in the references.

**Listed in the proposed toxic pollutant effluent standards.

Table D1 (Continued)

Parameter*	Reference 1	Reference 2	Reference 3	Other References
Metals (continued)				
Vanadium	p 153	-	-	-
Zinc	p 155	p 210	p 351	-
Nitrogen^b				
Ammonia	p 159	-	-	-
Nitrate-Nitrite [†]	p 201	Method 213B p 458	-	-
Total Kjeldahl	p 175	Method 216 p 469	-	-
Phenol^b				
General	p 241	Method 222 p 501	Method D1783 p 542	-
Phosphorus				
Total	p 249	Method 223C III p 526	Method D515 p 387	-
Ortho	p 249	Method 223F p 532	Method D515 p 389	-
Sulfide^b				
	p 284	Method 228A	-	-
<u>Organic Constituents</u>				
Amines ^e	-	-	-	Reference 4
Benzidine ^e	-	-	-	Reference 5 step 8.2
Methyl mercury				
(elutriate/supernatant)	-	-	-	Reference 6
(settled material)	-	-	-	Reference 6
Oil and grease				
(elutriate/supernatant)	p 229, step 7.3	-	-	-
(settled material)	p 232, step 7.3	-	-	-
PCB's (polychlorinated biphenyls)				
	-	-	-	Reference 7
Pesticides				
N-Aryl Carbamates ^{f or g} barban	-	-	-	Reference 8 step 9.3

[†]If separate nitrate and nitrite values are required, these may be obtained by differences as described in the referenced method.

Table D1 (Concluded)

Parameter*	Reference 1	Reference 2	Reference 3	Other References
<u>Organic Constituents (Concluded)</u>				
Pesticides (continued)				
chloroprotham				
diuron				
linuron				
monuron				
O-Aryl Carbamates ^{f or g}	-	-	-	Reference 9 step 9.3
baygon				
carbaryl (Sevin)				
matacil				
mesural				
zectran				
Organochlorine ^{f or g}	-	-	-	Reference 10 step 9.3
<u>aldrin**</u>				
<u>DDT**</u>				
<u>dieldrin**</u>				
<u>endrin**</u>				
<u>toxaphene**</u>				
Organophosphorus ^{f or g}	-	-	-	Reference 11 step 9.3
malathion				
methyl parathion				
parathion				
guthion				
demeton				
diazinon				
disyston				
Phenoxy acids				
(elutriate/supernatant)	-	-	-	Reference 12
(settled material)	-	-	-	Reference 13
2, 4-D				
silvex				
2, 4, 5-T				
Triazines ^{f or g}	-	-	-	Reference 14 step 9.3
altrazine				
propazine				
Petroleum hydrocarbons				
(elutriate/supernatant)	step 6.3	-	-	-
(settled material) ⁱ	p 226	-	-	-
Phenols (specific) ^h	-	-	Method D2580 p 548 step 13.1	-
Phthalate esters ^{f or g}	-	step 9.3	-	-

APPENDIX E: COMMUNITY STRUCTURE DETERMINATION PROCEDURES

1. A community structure analysis may be required when the results will be of value in assessing the biological effects of the proposed discharge of dredged or fill material. The results of such analyses are usually expressed as a diversity index, which is a mathematical or graphical expression of the number of species and the number of individual organisms in a given sample.¹ Depending on the method of mathematical manipulation of the data, the index may be used to express the dominance, the species diversity, or the similarity of the community structure in two or more samples.²

2. Past use of community structure analysis has been generally restricted to determining the response of a natural population to a former condition; that is, to determining the change in a diversity index as a consequence of a discharge. There has been no attempt to use a diversity index to predict the effects of a proposed discharge. This is due to the fact that any relationships that exist between community structure and the physical and chemical characteristics of the sediments are exceedingly complex and not fully understood at this time. However, a community analysis may provide assistance in selecting appropriate organisms to use during bioassay testing procedures.

3. References 1 through 7 describe the sampling requirements, data manipulations, and assumptions that must be satisfied to calculate diversity indices.

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1. Wilhm, J., "Graphic and Mathematical Analyses of Biotic Communities In Polluted Streams," Annual Review of Entomology, Vol. 17, 1972, pp 223-252.
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3. Cairns, J., Jr. et al., "The Sequential Comparison Index - A Simplified Method for Nonbiologists to Estimate Relative Differences in Biological Diversity in Stream Pollution Studies," Journal of Water Pollution Control Federation, Vol. 40, 1968, pp 1607-1613.
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5. Peet, R. K., "The Measurement of Species Diversity," Annual Review of Ecology and Systematics, Vol. 5, 1974, pp 285-307.
6. Resh, V. H. and Unsicker, J. D., "Water Quality Monitoring and Aquatic Organism: The Importance of Species Identification," Journal of Water Pollution Control Federation, Vol. 47, 1975, pp 9-19.
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