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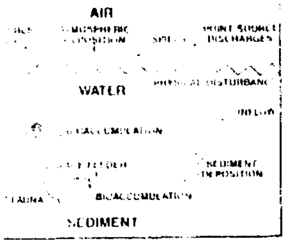

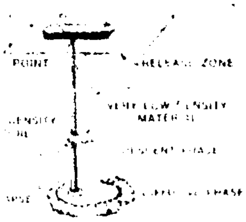

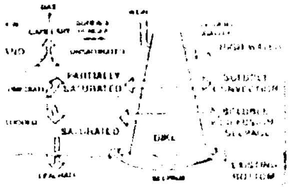

DREDGING OPERATIONS TECHNICAL
SUPPORT PROGRAM

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GENERAL DECISIONMAKING FRAMEWORK FOR MANAGEMENT OF DREDGED MATERIAL

EXAMPLE APPLICATION TO COMMENCEMENT BAY, WASHINGTON

by

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13. ABSTRACT *(Maximum 200 words)*

A general decisionmaking framework based on the results of technically sound test protocols is described. The decisionmaking framework includes consideration of sediment chemistry, physicochemical nature of disposal site environments, and biological effects of sediment contaminants, as well as comparison of test results from sediments to be dredged with test results from reference sediments and with established criteria.

The framework provides the basis for selection of the environmentally preferable disposal alternative and for identification of potentially appropriate control measures to minimize problems associated with the presence of contaminants. The decisionmaking process also leads to the identification and documentation of those sediments that require no special management considerations.

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The decisionmaking framework is illustrated in the form of case studies of the application of the framework process to specific sediments.

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Contaminants
Contaminated sediments
Decisionmaking framework
Dredged material management
Dredged material testing
Open water disposal
Upland disposal

SUMMARY

The State of Washington Department of Ecology (WDOE) has entered into a cooperative agreement with the US Environmental Protection Agency (EPA) to act as lead agency in the implementation of Phase I Remedial Investigations for the Commencement Bay Nearshore/Tideflats Superfund Site, Washington. Superfund remedial action may involve removing and handling contaminated sediments found in the bay. In addition, ongoing and proposed navigation activities in Commencement Bay require dredging and disposal of contaminated sediment located in the nearshore areas. As a result, Superfund site investigations and planning of navigation projects require identification and evaluation of alternative methods for dredging and disposal of contaminated sediments.

By agreement with WDOE, the Seattle District, US Army Corps of Engineers, requested the Environmental Laboratory, US Army Engineer Waterways Experiment Station (WES), to develop a decisionmaking framework for dredged material management that is based on the results of technically sound test protocols. This decisionmaking framework was developed and refined for the management of sediment dredged from Commencement Bay, which is located in southern Puget Sound. After this report was drafted, additional refinements and modifications (including regional administrative decisions (RADs) specific for the Puget Sound region) were made by the Evaluation Procedures Work Group (EPWG) and were published in a separate report (US Army Engineer District, Seattle 1986).

The decisionmaking framework considers sediment chemistry, physicochemical nature of disposal site environments, and biological effects of sediment contaminants and compares test results from sediments to be dredged with test results from reference sediments and with established criteria. Test protocols are discussed that consider the physicochemical conditions posed by aquatic (open-water) and confined nearshore (intertidal) and upland disposal environments. Descriptions of the physicochemical conditions at each disposal environment are provided as well as descriptions and citations of the test methods to be conducted. In addition, examples of test results obtained from recent test applications at other Corps dredging projects are discussed. Test results are used to formulate management strategies regarding placement of dredged material in specific physicochemical disposal environments and to

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determine what treatment and control methods are warranted to dispose of one or more contaminated sediments in an environmentally acceptable manner.

The decisionmaking framework is illustrated by applying it to specific sediments from Commencement Bay in the form of case studies at the end of this report. Since this is a continuous development of a decisionmaking framework, a certain amount of additional refinement will be required to more effectively streamline the approach and quantify the interpretation of test results.

PREFACE

This report presents a decisionmaking framework based on a management strategy for dredged material that incorporates results of a suite of test protocols to assess the effects of physicochemical changes on contaminant mobility from dredged material placed in aquatic, wetland, and upland disposal environments. The study was sponsored by the State of Washington Department of Ecology and the US Army Engineer District, Seattle, and was funded under Intra-Army Orders E86-84-3049 and E85-85-3220.

The original US Army Engineer Waterways Experiment Station (WES) decisionmaking framework was developed for Commencement Bay, Washington (Peddicord et al. 1986). The first revision of the WES decisionmaking framework was performed under the auspices of the Puget Sound Dredged Disposal Analysis (PSDDA) program. The purpose of this revision was to address some of the issues that required additional consideration before the strategy could be applied to the entire Puget Sound. The original WES decisionmaking framework and the first revision served as a foundation for the PSDDA program to build upon. The Evaluation Procedures Work Group (EPWG) has further modified the revised decisionmaking framework to accommodate additional specific regional needs. The EPWG modifications, including regional administrative decisions (RADs) made by EPWG for application to Puget Sound, are not part of this report, but they were published in a separate document (US Army Engineer District, Seattle 1986). It should be noted that the regulatory authorities in the Puget Sound region have used the term RAD in the same context as the term LAD (local authority decision) was used in the original WES decisionmaking framework (Peddicord et al. 1986). The authors have chosen to use the term RAD in this report, with the understanding that this term has the same meaning as the term LAD in the original WES decisionmaking framework.

Throughout the text, examples of decisions by regional authorities are presented. Regional authorities are defined as the State and Federal agencies having direct regulatory responsibilities. For the Commencement Bay area, the Washington Department of Ecology (WDOE) Superfund Project Manager, other WDOE staff, the Seattle District Corps of Engineers staff, and US Environmental Protection Agency Region X staff represent involved regional authorities. The examples of RADs are given only for the purpose of illustrating concepts that relate possible methods of quantifying the issues involved for ease of decisionmaking. These RADs are potential options that have been discussed for possible application to Commencement Bay. The workability and actual application of the RADs in the decisionmaking framework have not been tested as of the date of publication of this report. The intent of the sections involving tentative RADs, and of the document as a whole, is to provide a valuable first step in arriving at a decisionmaking framework with the full knowledge of the need for further refinement prior to actual implementation. Additional refinement and the actual RADs developed by the EPWG have been presented in the report by the US Army Engineer District, Seattle (1986) and are not included in this report.

The first revision was conducted at WES during the period October 1986 through March 1987 by Drs. R. K. Peddicord, C. R. Lee, S. H. Kay, and M. R. Palermo, and Mr. N. R. Francingues under the general supervision of Mr. D. L. Robey, Chief, Ecosystem Research and Simulation Division; Dr. R. L. Montgomery, Chief, Environmental Engineering Division; and Dr. John Harrison, Chief, Environmental Laboratory. The report was edited by Ms. Dorothy P. Booth, Environmental Information Analysis Center.

This second revision was conducted during the period August through September 1989 for the Dredging Operations Technical Support (DOTS) Program. Technical contributions in the form of examples of test protocol results and preparation of Appendix C tables were received from the following: Dr. B. L. Folsom, Jr. for the plant uptake/bioassay tests; Drs. J. W. Simmers and S. H. Kay and Mr. R. G. Rhett for the earthworm bioassay test; Dr. J. M. Brannon and Mr. N. R. Francingues for the leachate tests; Dr. M. R. Palermo for the effluent tests; Drs. T. M. Dillon and H. E. Tatem and Mr. V. A. McFarland for the aquatic and benthic bioassay tests; and Mr. J. G. Skogerboe for the surface runoff tests.

Review and constructive comments were received on 17 May 1984 from a working group that included Dr. R. Chaney, US Department of Agriculture--Agriculture Research Service; Dr. J. Anderson, Battelle Northwest Laboratories; Dr. W. Adams, Monsanto Co.; Mr. N. Rubinstein, EPA; Dr. J. O'Connor, New York University; Dr. W. Peltier, EPA; Dr. W. Pequegnat, Consultant, College Station, TX; Dr. J. Rogers, North Texas State University; Dr. J. Skelly, Pennsylvania State University; Mr. K. Phillips, US Army Engineer District, Seattle; and Mr. J. Krull, Washington Department of Ecology.

Additional comments were received on 6-10 August 1984 from members of the WES Plant and Animal Working Groups that included the following: Dr. W. Berry, University of California, Los Angeles; Dr. N. Beyer, US Fish and Wildlife Service; Dr. F. Bingham, University of California, Riverside; Dr. G. Bryan, Marine Biological Society, United Kingdom; Dr. R. Chaney, US Department of Agriculture (USDA); Drs. B. Davies and M. Ireland, and Ms. N. Houghton, University College of Wales, United Kingdom; Dr. C. Edwards, Rothamsted Experimental Station, United Kingdom; Dr. C. Foy, USDA; Drs. Ad H. L. Huiskes and R. H. D. Lambeck, and Mr. J. Nieuwenhuize, Delta Institute of Hydrobiological Research, The Netherlands; Dr. M. Johnson, University of Liverpool, United Kingdom; Dr. J. Marquenie, Technology for Society, TNO, The Netherlands; Dr. E. Neuhauser, Cornell University; Drs. W. Patrick, Jr. and W. Stickle, Louisiana State University (LSU); Dr. P. Peterson, University of London, United Kingdom; Dr. B. Pierce, Office, Chief of Engineers; Dr. F. Prosi, University of Heidelberg, FRG; Dr. W. van Driel, Institute of Soil Fertility, The Netherlands; Dr. B. Walton, Oak Ridge National Laboratory; Dr. G. Wilhelm, Morton Arboretum; Dr. N. Page, Clemson University; Mr. B. Hunter, University of Essex, United Kingdom; Mr. J. Mansky, US Army Engineer District, New York; Mr. A. Palazzo, Cold Regions Research and Engineering Laboratory, CE; Mr. N. Rubinstein, EPA; and Ms. A. Mudroch, National Water Research Institute, Canada.

Additional review and comments were received from: Mr. J. Bajek, New England Division, CE; Dr. T. O'Connor, US Department of Commerce, National Oceanic and Atmospheric Administration; Mr. A. Newell, New York State Department of Environmental Conservation; Mr. F. Calder, Florida Department of Environmental Regulation; Drs. L. Barnthouse and [illegible]. McCarthy, Oak Ridge National Laboratory; Mr. E. McGreer, Coastline Environmental Services, Ltd., Vancouver, B.C.; Mr. R. Medina, Galveston District, CE; Mr. R. Whiting, St. Paul District, CE; Messrs. D. Cowgill and D. Raven, North Central Division, CE; Dr. S. MacKnight, Ocean Chem group, Dartmouth, Nova Scotia; Mr. R. Parrish, EPA; Dr. J. Marquenie, Technology for Society, The Netherlands; Mr. R. Lazor, WES; Mr. J. Karau, Environment Canada; Mr. P. Bradley, Mobile District, CE; and Mr. J. Hilton, Jacksonville District, CE.

COL Allen F. Grum, USA, and COL Dwayne G. Lee, EN, were the previous Directors of WES. COL Larry B. Fulton, EN, is the present Commander and

Director of WES, and Dr. Robert W. Whalin is Technical Director. COL Roger F. Yankoupe, CE, was Commander and Director of the Seattle District.

This report should be cited as follows:

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

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
cubic feet	0.02831685	cubic metres
cubic feet per second	0.02831685	cubic metres per second
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square metres
square yards	0.8361274	square metres

GENERAL DECISIONMAKING FRAMEWORK FOR MANAGEMENT OF DREDGED MATERIAL
EXAMPLE APPLICATION TO COMMENCEMENT BAY, WASHINGTON

PART I: INTRODUCTION

Background

1. Navigable waterways of the United States have a vital and continuing role in the Nation's economic growth. The US Army Corps of Engineers (CE), in fulfilling its mission to maintain, improve, and extend these waterways, is responsible for the dredging and disposal of large volumes of sediment each year. Dredging is a process by which sediments are removed from the bottom of streams, rivers, lakes, and coastal waters, transported via ship, barge, or pipeline, and discharged to land or water. Annual quantities of dredged material average about 290 million cu m in maintenance dredging operations and about 78 million cu m in new-work dredging operations with the total annual cost now exceeding $250 million.

2. Over 90 percent of the total volume of material dredged is considered acceptable for disposal at a wide range of disposal alternatives. However, the presence of contamination in some locations has generated concern that dredged material disposal may adversely affect water quality and aquatic or terrestrial organisms. Since many of the waterways are located in industrial and urban areas, some sediments may be highly contaminated with wastes from these sources. In addition, sediments may be contaminated with chemicals from agricultural practices.

3. The chemistry of contaminants in sediments, and thus their mobility and potential to adversely impact the environment, is controlled primarily by the physicochemical conditions under which the sediment exists. Fine-grained sediments that are saturated with water typically are anoxic, reduced, and near neutral in pH. These conditions exist in typical open-water aquatic dredged material disposal sites and may exist in other disposal options such as marsh creation and disposal in shallow water along shorelines. In this document the term "aquatic disposal" is used in a general sense to refer to all disposal conditions in which fine-grained material remains water saturated, anoxic, reduced, and near neutral in pH. In contrast, when a

fine-grained sediment is taken out of the water and allowed to dry, it becomes oxidized or oxic and the pH may drop considerably. In this document all disposal options in which a fine-grained sediment has these characteristics are referred to generally as "upland disposal," even though such conditions can occur on the surface of dredged material islands, the above-tide portions of fills, etc. Nearshore confined disposal sites could have a combination of anoxic reduced conditions below tide elevation and oxic conditions in the dredged material placed above tidal elevation.

4. Potential concerns associated with aquatic disposal include contaminants released into the water during and following disposal and the subsequent toxicity and/or bioaccumulation of contaminants by aquatic organisms. Consequences of bioaccumulation may include a wide range of effects from organism toxicity to sublethal genetic abnormalities, food-web biomagnification, and possibly eventual consumption by man. Potential concerns associated with upland disposal include water-quality impacts from effluent discharged during disposal, surface runoff and leachate following disposal, and uptake of contaminants by plants and animals inhabiting the area following disposal operations, with contaminants possibly reaching man by direct or indirect routes. Each of these potential problems can be minimized by one or more management practices.

5. Since the nature and magnitude of contamination in dredged material may vary greatly on a project-to-project basis, the appropriate method of disposal may involve any of several available disposal alternatives. Further, control measures to manage specific problems associated with the presence or mobility of contaminants may be required as a part of any given disposal alternative. An overall management strategy for disposal of dredged material is therefore required. Such a strategy must provide a framework for decisionmaking to select the environmentally preferable disposal alternative and to identify potentially appropriate control measures to minimize problems associated with the presence of contaminants. The decisionmaking framework should also identify and document those sediments that require no special management considerations.

6. The lead responsibility for the development of specific ecological criteria and guideline procedures regulating the discharge of dredged and fill material at the national level was legislatively assigned to the US Environmental Protection Agency (EPA) in consultation or conjunction with the CE.

The enactment of Public Laws 92-532 (the Marine Protection, Research, and Sanctuaries Act of 1972) and 92-500 (the Federal Water Pollution Control Act Amendments of 1972), which are concerned with the discharge of dredged and fill material, required the CE to participate in developing guidelines and criteria for regulating dredged and fill material disposal. The focal point of research for these procedures is the CE Dredged Material Research Program (DMRP), which was completed in 1978; the ongoing CE Dredging Operations Technical Support (DOTS) Program and the Long-term Effects of Dredging Operations (LEDO) Program; and the CE/EPA Field Verification Program (FVP), which was completed in 1987. These research programs have provided the technical bases for this document.

7. One site in which there is a need to assess the potential environmental impacts of contaminants in sediments is Commencement Bay in southern Puget Sound near the city of Tacoma, WA. The State of Washington Department of Ecology (WDOE) has entered into a cooperative agreement with the EPA to act as lead agency in the implementation of Phase I Remedial Investigations for the Commencement Bay Nearshore/Tideflats Superfund Site, Washington. Superfund remedial action may involve removal and handling of contaminated sediments found in the bay. In addition, ongoing and proposed navigation activities in Commencement Bay require dredging and disposal of sediments located in the nearshore areas. As a result, Superfund site investigations and planning of navigation projects require identification and evaluation of alternative methods for dredging and disposal of contaminated sediments.

8. Several studies of the nearshore waters of Commencement Bay have indicated sediment contamination by potentially toxic materials, accumulation of some of those contaminants by estuarine biota, and even possible pollution-related abnormalities in indigenous biota (Tetra Tech 1984). Considerable effort was conducted to determine the extent of the contamination and the potential threat to public health under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This effort was necessary to determine what remedial actions are required to clean up and protect the estuarine environment of Commencement Bay.

Purpose and Scope

9. By agreement with WDOE, the Seattle District has funded the Environmental Laboratory, US Army Engineer Waterways Experiment Station (WES), to develop and refine a decisionmaking framework for environmental assessment of dredged material based on technically appropriate tests and scientifically sound interpretation of test results. Its major focus is on the question of how dredged material should be tested and test results interpreted to evaluate the degree of potential contaminant impact and the disposal conditions in which the dredged material would have minimal adverse impact on the overall environment. Part II of this document outlines the appropriate types of tests and the environmental interpretation of the results. This part is written so as to be generally applicable to all dredged material evaluations. Part III is an example application of the guidance of Part II to specific Commencement Bay sediments and illustrates the integration of various test results and the role of regional regulatory goals and objectives in decisionmaking on the basis of test results. This report describes a framework that provides a means of obtaining a sound technical basis for decisionmaking regarding the disposal of contaminated dredged material. The framework indicates which type of disposal should be considered for a given dredged material and when restrictions on disposal are warranted. Appendixes A and B present details of the decisionmaking framework for aquatic and upland disposal options, respectively, and Appendix C contains related information and data tables. Appendix D gives procedures for and examples of mixing-zone calculations.

10. The report describes testing protocols as they are related to the physicochemical conditions posed by aquatic and upland disposal and, in the example of Commencement Bay in Part III, to conditions in a "nearshore" site that will result in some of the material retaining characteristics of aquatic disposal and some of it becoming similar to typical upland conditions. Under each of these alternatives, a discussion is presented of what each test is intended to accomplish and why the information is important. The tests discussed have been proposed in a recent report (Francingues et al. 1985). The present report discusses test procedures, the rationale for when a test should be applied, and the interpretation of test results. A decisionmaking

framework incorporating the interpretation of test results is discussed and applied to specific sediments from Commencement Bay in case studies.

11. The framework indicates when disposal site controls and treatment options are required and the availability of technology to achieve the required control or treatment. The framework is fully comprehensive as to the present state of the art in technical knowledge, but does not address economics/cost feasibility of the recommended criteria or public acceptance/sociopolitical factors. In addition, discussion of testing required to address design of a disposal site or selection of necessary control or treatment options is beyond the scope of this report and is addressed elsewhere (Cullinane et al. 1986).

PART II: EVALUATION AND MANAGEMENT OF DREDGED MATERIAL DISPOSAL

12. The following discussion presents the general approach to the management of dredged material disposal in reference to a recent document on the subject (Francingues et al. 1985). Later, the discussion becomes more detailed in describing the suite of tests used in the management strategy. The final portion of Part II discusses a general decisionmaking framework that incorporates test results and gives guidance on the interpretation of test results for making decisions. The actual application of the framework to specific sediments of Commencement Bay is discussed in Part III of this report.

Management Strategy

13. The discussion in this section is cited directly from Francingues et al. (1985) and serves as a focus point for this report. The selection of a disposal management strategy must consider the nature of the sediment to be dredged, potential environmental impacts of the disposal of the dredged material, nature and degree of contamination, dredging equipment, project size, site-specific conditions, technical feasibility, economics, and other socioeconomic factors. This discussion presents an approach to consider the nature and degree of contamination, potential environmental impacts, and related technical factors. The approach, shown in the flowchart in Figure 1, consists of the following:

a. Initial evaluation to assess contamination potential.
b. Selecting a potential disposal alternative.
c. Identifying potential problems associated with that alternative.
d. Testing to evaluate the problems.
e. Assessing need for disposal restrictions.
f. Selecting an implementation strategy.
g. Identifying available control options.
h. Examining design considerations to evaluate technical and economic feasibility.
i. Choosing appropriate control measures and technologies.

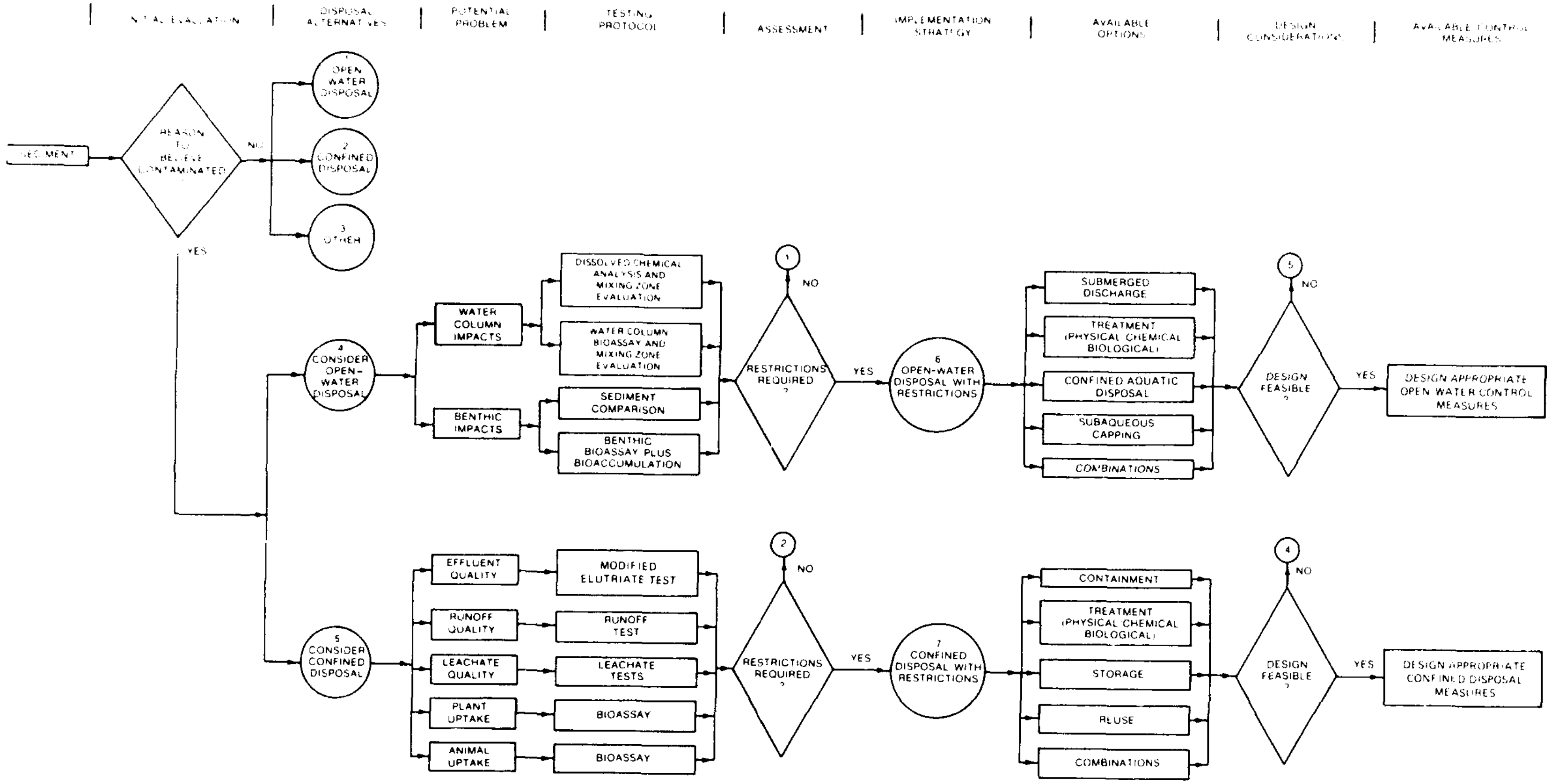

Figure 1. Management strategy flowchart

Initial evaluation

14. The initial screening for contamination is the initial evaluation outlined in the proposed testing requirements for Section 404 of the Clean Water Act (USEPA 1980a). The evaluation is designed to determine if there is reason to believe the sediment contains any contaminants "in forms and amounts that are likely to degrade the aquatic environment, including potential availability to organisms in toxic amounts." This evaluation also allows identification of specific contaminants of concern in the particular sediment in question, so that testing and analyses may be focused on the most pertinent contaminants. The initial evaluation section is quoted as follows from EPA (1980a), Section 230.61, page 85362:

> §230.61 Initial evaluation of dredged or filled material.
>
> (a) An initial evaluation shall be conducted and documented to determine if there is reason to believe that any dredged or fill material to be discharged into waters of the United States contains any contaminant above background level. This initial evaluation will be used in assigning the proposed discharge to a category for testing. This evaluation should be accomplished with existing data on file with or readily available to the permitting authority; Regional Administrator, EPA; and other public and private sources, as appropriate. Factors which may be considered for the extraction site and, if appropriate, the disposal site, include, but are not limited to, the following:
>
> (1) Potential routes of introduction of specific contaminants. These may be identified by examining maps, aerial photographs, and other graphic materials that show watercourses, surface relief, proximity to tidal movement, private and public roads, location of buildings, agricultural land, municipal and industrial sewage and storm outfalls, etc., or by making field inspections.
>
> (2) Previous tests on the material at the extraction site or on samples from other similar projects in the vicinity, when there are similarities of sources and types of contaminants, water circulation and stratification, accumulation of sediments, general sediment characteristics, and potential impact on the aquatic environment, as long as no known changes have occurred to render the comparisons inappropriate.
>
> (3) The probability of past substantial introduction of contaminants from land runoff (e.g., pesticides).
>
> (4) Spills of toxic substances or substances designated as hazardous under Section 311 of the Clean Water Act (see 40 CFR Part 116).

(5) Substantial introduction of pollutants from industries.

(6) Source and previous use of materials proposed for discharge as fill.

(7) Substantial natural deposits of minerals and other natural substances.

(b) Before the permitting authority concludes that there is no reason to believe that contaminants are present in the discharge material above background levels, he should consider all relevant, reasonably available information which might indicate its presence. However, if there is no information indicating the likelihood of such contamination, the permitting authority may conclude that contaminants are not present above background levels. Examples of documents and records in which data on contaminants may be obtained are:

(1) Report of Pollution Caused Fish Kills (U.S. EPA)

(2) Selected Chemical Spill Listing (U.S. EPA)

(3) Pollution Incident Reporting System (U.S. CG)

(4) Surface Impoundment Assessment (U.S. EPA)

(5) Identification of In-Place Pollutants and Priorities for Removal (U.S. EPA)

(6) Revised Status Report--Hazardous Waste Sites (U.S. EPA)

(7) Hazardous Waste Management Facilities in the United States--1977 (U.S. EPA)

(8) Corps of Engineers studies of sediment pollution

(9) Sediment tests for previously permitted activities (U.S. CE/District Engineers)

(10) Pesticide Spill Reporting System (U.S. EPA)

(11) STORET (U.S. EPA)

(12) Past 404(b)(1) evaluations

(13) USGS water and sediment data on major tributaries

(14) Pertinent and applicable research reports

(15) NPDES permit records

15. Contaminant concentrations in the sediment to be dredged can be compared to those concentrations of a reference and/or background sediment to assist in evaluating a sufficient cause for concern. The determination of a critical level of contamination above the reference and/or background should

be made on a site-by-site basis and will depend on the administrative goal established for the disposal site such as maintaining nondegradation, achieving clearer conditions, or returning to background conditions. Under some circumstances, contamination factors of 1.5 above reference have been proposed as an acceptable approach. The acceptability of elevation factors must be established through deliberations with appropriate concerned parties and will be a regional administrative decision (RAD).*

16. If there is available information indicating contaminants are not present above background levels, restrictions are not required. In this case any disposal alternative may be selected, though the possibility of other environmental impacts such as effects of salinity, substrate alteration, and low dissolved oxygen concentrations must be considered in the final selection. Three disposal alternatives are shown in the flowchart (Figure 1) for uncontaminated or so-called "clean" sediments: [1]** aquatic, [2] upland, and [3] others, which include marsh or wetland development and other beneficial uses. The final selection is based on environmental considerations, available dredging alternatives, site-specific conditions, technical feasibility, economics, and other socioeconomic considerations.

17. If there is reason to believe that contaminants are present, the sediment must be evaluated in relation to the conditions that would be present at the disposal site to examine the potential for environmental impacts. Either aquatic [4] or upland disposal [5] could be considered initially and appropriately evaluated, or both alternatives could be evaluated concurrently. The selection of the disposal alternative to be considered is dependent on the potential problems posed by contaminants, available dredging equipment, site-specific conditions, technical feasibility, economics, and socioeconomic considerations. The evaluation of aquatic or upland disposal of contaminated sediment may not necessarily require that additional tests be conducted. As USEPA (1980a) Section 23^.60 points out, "Where the results of prior evaluations, chemical and biological tests, scientific research, and experience can

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* The regulatory authorities in the Puget Sound region use the term regional administrative decision (RAD), which for the purpose of this report, is considered by the authors to have the same meaning as local authority decision (LAD) as used by Peddicord et al. (1985).

** Numbers in brackets refer to the respective disposal alternative as numbered in Figure 1.

provide information helpful in making a determination, these should be used. Such prior results may make new testing unnecessary."

Consideration of aquatic disposal [4]

18. Consideration of aquatic disposal [4] for a contaminated sediment requires an evaluation of the potential impacts on the water column and the benthic environment. Other special disposal problems such as effects on health of disposal personnel would be a rare occurrence but should also be considered. Water-column impacts can be evaluated by chemical analysis of dissolved contaminants for which water-quality criteria exist. Bioassays are used when no water-quality criteria exist or when there is concern about possible interactive effects of multiple contaminants. The effects of mixing and dilution should be considered during assessment of the test results.

19. Potential benthic impacts of deposited sediment are first evaluated by comparing both contaminant concentrations and toxicity of the sediments in the dredging and disposal sites. If contaminant concentrations and toxicity in the dredging site sediment are less than or equal to the concentrations in the disposal site sediment, it can be concluded that disposal will not have further unacceptable adverse impacts on the benthic environment. If contaminant concentrations or toxicity are greater in the dredging site sediment, a bioaccumulation test should be performed. If the initial evaluation for contaminants and initial sediment characterization indicate a potential for special dredging problems (e.g., noxious emissions), appropriate tests must be performed.

20. If the impacts are acceptable, the dredged material can be disposed in aquatic sites without restrictions [1]. If unacceptable, options for aquatic disposal with restrictions [6] must be evaluated.

Aquatic disposal with restrictions [6]

21. Four options are available for implementing aquatic disposal with restrictions [6]. These options include bottom discharge; treating the material by physical, chemical, or biological methods; confining the dredged material subaqueously; and capping the dredged material subaqueously. Each option may be used separately or in combination with other options. The design considerations for these options must be examined to evaluate the technical feasibility of the disposal alternative based on effectiveness, availability,

compatibility, cost, and scheduling. If the design is feasible, the appropriate aquatic control measures and technologies can be chosen and implemented. If the design is not feasible, upland disposal [5] should then be considered.

Consideration of upland disposal [5]

22. Consideration of upland disposal [5] for a contaminated sediment requires evaluation of the following potential problems: effluent quality, surface runoff quality, leachate production and quality, and contaminant uptake by plants and animals. Impacts of effluent, runoff, and leachate quality can be evaluated by chemical analysis of contaminants released in modified elutriate, runoff, and leachate tests, respectively. If the contaminant levels exceed applicable criteria after considering mixing and dilution effects, bioassays are performed to determine the potential toxicity. Potential contaminant mobility in the upland/wetland ecosystem can be evaluated by appropriate plant and animal bioassay and bioaccumulation tests. If the initial evaluation and sediment characterization indicate a potential for special dredging or disposal problems (e.g., noxious emissions), appropriate tests must be performed. If the impacts are acceptable, the dredged material can be disposed in upland areas without restrictions [2]. If unacceptable, options for upland disposal with restrictions [7] must be evaluated.

Upland disposal with restrictions [7]

23. Four basic options are available for implementing upland disposal with restrictions. These options include containment, physical/chemical/biological treatment, reuse, and storage and rehandling. Combinations of the options exist for this strategy. The selection of the appropriate option is dependent mainly on the nature and level of contamination, site-specific conditions, economics, and socioeconomic considerations. The design considerations for these options must be examined to evaluate the technical feasibility of the disposal alternative based on effectiveness, availability, compatibility, cost, and scheduling. If the design is feasible, the appropriate upland disposal control measures and technologies can be chosen and implemented. If the design is not feasible, aquatic disposal [4] should be considered.

Description of Test Procedures for Aquatic Disposal

Physicochemical conditions

24. When sediments are dredged from a waterway and placed in stable deposits in a low-energy aquatic environment, very little change occurs in the physicochemical nature of the dredged material. In other words, when a reduced anaerobic sediment with a pH value near neutral is disturbed, removed, and placed in a similar aquatic environment, it will remain anaerobic with a pH near neutral. Consequently, contaminant mobility at the aquatic disposal site will be very similar to that occurring at the original dredging site in the waterway. There will be a minor tendency for limited oxidation to occur as the dredged material is mixed with oxygenated water during the dredging operation. However, the oxygen demand of the reduced sediment is usually so great that any oxygen added via the dredging water will be consumed immediately and will not have any important effect on the physicochemical nature of the sediment. The sediment will therefore remain reduced and maintain a near-neutral pH similar to that originally found at the dredging site.

Evaluation of aquatic impacts

25. When highly contaminated dredged material is placed in an aquatic environment, there is a conceptual potential for impacts due to release of contaminants into the water column during disposal, although this potential has rarely been realized in practice. In addition, there is potential for physical effects on benthic organisms and for long-term toxicity and/or bioaccumulation of contaminants from the dredged material. These biological effects are best determined at present by site-specific bioassays. Other special disposal concerns such as potential impacts on health of operating crews would be a rare occurrence and beyond the scope of this document, but should be evaluated when considered appropriate.

Aquatic bioassay and bioaccumulation

26. It must be recognized that aquatic bioassays of dredged material cannot be considered precise predictors of environmental effects in the field. They must be regarded as providing qualitative estimations of those effects, making interpretation of the potential for environmentally adverse effects in the field somewhat subjective. This interpretative uncertainty increases when a parameter whose ecological meaning is uncertain is used as the bioassay end point. In view of the interpretative difficulties, most of the animal

bioassays in this document specify death, or occasionally the ecologically important parameters of growth or reproduction, as the response to be measured. The term "toxicity" is defined by the American Public Health Association (1980) as "adverse effect to a test organism caused by pollutants" and is used in this document in a more restricted sense to refer to ecologically important bioassay end points such as those directly related to survival, growth, and reproduction.

27. The environmental interpretation of bioaccumulation data is difficult because in many cases it is impossible to quantify either the ecological consequences of a given tissue concentration of a constituent that is bioaccumulated or even the consequences of that body burden to the animal whose tissues contain it. Almost without exception there is little technical basis for establishing, for example, the tissue concentration of zinc in an organism that would be detrimental to that individual, not to mention the uncertainty of estimating the effect of that organism's body burden on a predator. Research is under way at WES, the EPA Environmental Research Laboratory at Narragansett, and other laboratories in the United States and abroad to determine the relationship, if any, between body burden of contaminants and important biological functions. Dillon (1984) provides an initial step in this process, but the data base is still inadequate to allow evaluation of the potential ecological consequences of a particular body burden of a specific contaminant(s). Therefore, at present, bioaccumulation data can be interpreted only by comparison to levels in organisms exposed to reference sediment and to levels determined to be safe for human consumption. Such levels have been established by the US Food and Drug Administration (FDA) and the Australian National Health and Medical Research Council for some contaminants in seafood and are presented in Appendix C, Table C1. There are no such levels for aquatic organisms not commonly eaten in these countries. However, there is a potential for contaminants in nonfood organisms to reach some seafood organisms through predation. Although trophic transfer of contaminants from aquatic prey to aquatic predator is known to occur, food-web biomagnification of contaminants to higher concentrations in the predator than in the prey has been established in aquatic systems for only a few contaminants, including polychlorinated biphenyls (PCBs), DDT, and mercury (and possibly selenium, zinc, kepone, mirex, benzo(a)pyrene, and naphthalenes) (Biddinger and Gloss 1984, Kay 1984). The above considerations lead to the recommendation that

levels in predatory organisms considered safe for human consumption should be applied to aquatic species that are seldom directly consumed by man. The interpretive guidance assumes that any statistically significant bioaccumulation relative to animals not in dredged material, but living in reference material of similar sedimentological character, is potentially undesirable. The evaluation of experimental results using this approach requires the user to recognize the fact that a statistically significant difference cannot be presumed to predict the occurrence of an important impact in the field.

28. Interpretive guidance for environmental tests of dredged material was the subject of a working group convened by WES on 15-17 May 1984. The participants were all recognized scientific experts in a wide variety of relevant disciplines who also have experience in the practical application of environmental science to regulatory decisionmaking. They included Dr. R. Chaney, US Department of Agriculture--Agriculture Research Service; Dr. J. Anderson, Battelle Northwest Laboratories; Dr. W. Adams, Monsanto Co.; Mr. N. Rubenstein, EPA; Dr. J. O'Connor, New York University; Dr. W. Peltier, EPA; Dr. W. Pequegnat, Consultant, College Station, Texas; Dr. J. Rogers, North Texas State University; Dr. J. Skelly, Pennsylvania State University; Mr. K. Phillips, CE, Seattle District;and Mr. J. Krull, WDOE. After three days of discussion, consensus was reached on the following two major points related to regulatory interpretation of properly conducted aquatic bioassay and bioaccumulation testing of dredged material under Section 404 of the Clean Water Act:

a. There is a cause for concern about unacceptable adverse toxicity impacts in the field when laboratory tests result in greater than 50-percent toxicity* attributable to the dredged material.

b. Bioaccumulation data can be interpreted in relation to human health, but evaluation of ecological impacts of bioaccumulation is much less certain at present. Tentative assessment of the potential for such impacts must consider concentrations in tissues of reference animals and other effects of the sediment, such as degree of toxicity.

The recommendation of 50-percent toxicity was made since toxicological data and criteria have been developed over the years in relationship to LC 50

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* This level of toxicity may be considered too liberal by the regional regulatory authorities. Consequently, regional authorities may wish to establish a lower, hence more conservative, percent toxicity as the maximum acceptable. *For Section 103 evaluations, 10-percent toxicity should be used.*

values (that concentration of toxic substance that results in 50-percent mortality upon exposure).

Impact to water column

29. The standard elutriate test (USEPA/CE 1977) is appropriate for evaluating the potential for dredged material disposal to impact the water column. Since this test includes contaminants in both the interstitial water and the loosely bound (easily exchangeable) fraction in the sediment, it approximates the fractions of chemical constituents that are potentially available for release to the water column when sediments are dredged and disposed through the water column. The standard elutriate is prepared by mixing the sediment and either disposal site water or dredging site water, as appropriate, in a volumetric sediment-to-water ratio of 1:4. Mixed with agitation and vigorous aeration for 30 min, it is then allowed to settle for 1 hr. The supernatant is then centrifuged and/or filtered to remove particulates prior to chemical analysis. This procedure is followed because the water-quality criteria apply only to dissolved contaminants, and chemical analyses of an unfiltered water sample cannot identify the bioavailable fraction of sediment-sorbed contaminants. A detailed description of the procedure, including sample preparation, is provided in USEPA/CE (1977, 1990).

30. Chemical evaluation. Water-column impacts of dredged material may be evaluated either as described in this paragraph or as specified in paragraph 31, depending on the situation. Where the initial evaluation (paragraph 14) identifies concern about the presence of specific contaminants that may be released in soluble form, the standard elutriate may be analyzed chemically and the results evaluated by comparison to water-quality criteria for those contaminants after allowance for mixing (paragraphs 32-36) at the disposal site. This provides an indirect evaluation of potential biological impacts of the dissolved contaminants since the water-quality criteria were derived from bioassays of solutions of the various contaminants. Chemical analyses of the standard elutriate are quantitatively interpretable in terms of potential impact only for those contaminants for which specific water-quality criteria have been established.

31. Biological evaluation. If the water-quality criteria approach is not taken, the potential for water-column impacts must be evaluated by bioassays, with consideration given to mixing (paragraphs 32-36). An aquatic bioassay should also be used to determine the potential interactions among

multiple contaminants. In this way elutriate bioassays can aid in evaluating the importance of dissolved chemical constituents released from the sediment during disposal operations. The standard elutriate is prepared just as for chemical use, but the filtrate is used as a bioassay test solution rather than for chemical analysis. A series of experimental treatments and controls are established using graded dilutions of the elutriate. The test organisms are added to the test chambers and exposed under standard conditions for a prescribed period of time. The surviving organisms are examined at appropriate intervals to determine if the test solution is producing an effect. Any bioassay protocol designed for use with solutions can be used by substituting the standard elutriate for the original solution. A useful general protocol is presented in USEPA/CE (1977, 1990).

32. Mixing. All data from chemical analyses and bioassays of the standard elutriate must be interpreted in light of mixing. This is necessary since biological effects (which are the basis for water-quality criteria) are a function of biologically available contaminant concentration and exposure time of the organism. In the field both concentration and time of exposure to a particular concentration change continuously. Since both factors will influence the degree of biological impact, it is necessary to incorporate the mixing expected at the disposal site in the interpretation of both chemical and biological data. *An extremely conservative approach to management of dredged material disposal would be to disregard mixing zone considerations.** This ignores the assimilative capacity of the receiving water. It would frequently result in the application of restrictions on the operation, when, in fact, important impacts would not occur from an unrestricted discharge operation. Disregarding mixing will result in increased cost with little concomitant reduction in potential adverse impacts for most discharge operations.

33. Precise prediction of the shape and areal configuration of the plume within which the required dilution will be achieved is a very difficult problem involving hydrodynamic and sediment transport considerations. Numerical models are available that provide this capability. For small projects with little anticipated impact a simplified approach for calculating the projected surface area of the mixing zone may be used. The approach is based on assuming particular geometrical shapes for the disposal plume depending upon

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* Important sentences are italicized for emphasis.

the mode of discharge and the disposal site environment. Procedures for using the simplified approaches are given in Appendix D and are used for the examples in this report. In practice it is not necessary to calculate the mixing zone for every contaminant in the discharge, but only the one requiring the greatest dilution. All others will be encompassed within that mixing zone.

34. Use of the simplified approach will indicate the maximum portion (volume) of the total aquatic environment and the surface area projection 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. Included in the discussion in Appendix D 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.

35. At this time, there is no fully satisfactory simple and rapid technique that can be used to determine the size and configuration or the acceptability of the mixing zone required to accommodate a discharge into an aquatic system. However, there are several important concepts that should be considered in determining the acceptability of 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. In other words, a decision should be based on a case-by-case evaluation at each proposed disposal site and the beneficial use(s) to be protected. In addition to the considerations listed below, a relatively larger mixing zone can be tolerated for intermittent discharges (compared to continuous discharges) without having an important adverse impact on the receiving waters. Concern over acceptability of the calculated mixing zone increases in proportion to:

<u>a</u>. Size.

<u>b</u>. Configuration.

<u>c</u>. Proportion of volume of receiving water body occupied.

<u>d</u>. Proportion of cross-sectional area of receiving water body occupied.

<u>e</u>. Time required to achieve desired dilution for each discrete discharge event.

<u>f</u>. Frequency of discharges during the dredging and disposal operation.

g. Duration of the dredging and disposal operation.

h. Proximity to municipal water intakes.

i. Proximity to sources of recharge for drinking water aquifers.

j. Proximity to areas of high human water-contact activities at the time of major use.

k. Proximity to shellfish beds with commercial or recreational importance.

l. Proximity to major sport or commercial fishery areas at the time of major use.

m. Proximity to unique or concentrated fish or shellfish spawning areas at the time of major use.

n. Proximity to unique or concentrated fish or shellfish nursery areas at the time of major use.

o. Proximity to major fish or shellfish migration routes at the time of major use.

p. Proximity to other major disposal sites or discharges at the time of their use.

An example of how these factors can be evaluated is: a finding of *high concern* in any five or more factors leads to a DECISION OF AN UNACCEPTABLE MIXING ZONE. A finding of *high concern* in four or less factors leads to a DECISION OF AN ACCEPTABLE MIXING ZONE. The number of factors should be determined by the RAD on a case-by-case basis.

36. Several authors have defined mixing zones in terms of biological effects. However, the mixing zone calculated by the method described 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 criteria or bioassay results are used to define the volume of water in which acceptable concentrations may be equaled 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 where discharge concentrations will exceed a particular value during the actual discharge.

Impact on benthic environment

37. It is generally felt that if a dredged material is going to have an environmental impact, the greater potential for direct impact lies with the deposited sediment at the disposal site. This is because it is not mixed and

dispersed as rapidly or as greatly as the dissolved material; most contaminants remain associated with the particulates; and bottom-dwelling animals live and feed in and on the deposited material for extended periods. Therefore, the major evaluative efforts should be placed on the deposited material. No chemical procedures exist that will determine the environmental activity of any contaminants or combination of contaminants present in the solid phase of dredged material. Therefore, animals are used in a bioassay to provide a measurement of environmental activity of the chemicals found in the material.

38. Scientific studies conclusively indicate that most subaqueous disposal of dredged material in low-energy aquatic environments where stable mounding will occur will generally minimize changes in mobility of most contaminants (Brannon 1978; Gambrell, Khalid, and Patrick 1978; Neff, Foster, and Slowey 1978; Wright 1977). The potential for accumulation of a contaminant in the tissues of an organism (bioaccumulation) may be affected by exposure concentration and factors such as duration of exposure, salinity, water hardness, temperature, chemical form of the contaminant, sediment characteristics such as organic carbon content, and the particular organism under study. The relative importance of these factors varies. Elevated concentrations of contaminants in the ambient medium or associated sediments are not always indicative of high levels of contaminants in tissues of benthic invertebrates or of biological effects. Chemical analyses alone are insufficient to assess impact on aquatic biota since they convey no information, in themselves, regarding bioavailability. Chemical analyses can, however, serve to identify contaminants of potential concern present in the sediment and their presence in high or low concentration.

39. In the case of neutral organic chemicals that are persistent and common contaminants of sediments, chemical analyses can provide the information necessary for an estimation of the equilibrium levels that could be reached in the tissues of exposed organisms for which the sediments provide the only source of contamination (McFarland 1984; McFarland and Clarke 1986; McFarland and Clarke 1987). This application of sediment chemical analysis data involves a thermodynamically defined bioaccumulation potential (TBP) calculated by applying a preference factor (pf) to the concentration of the neutral organic chemical of concern (e.g., PCBs or polynuclear aromatic hydrocarbons (PAHs) in the sediment), normalized to the organic carbon content of

the sediment. TBP is calculated using pf = 1.72 (McFarland and Clarke 1986) as:

$$TBP = 1.72\ (Cs/OC)$$

where

Cs = concentration of chemical in sediment
OC = organic carbon content of sediment (percent or decimal fraction)
TBP = equivalent concentration in organism lipid, same units as Cs

A pf corrects for the difference in equilibrium phase activity between the lipid phase (in the organism) and organic carbon phase (in the sediment) and expresses concentration of the chemical in the sediment in lipid equivalents. *To express TBP on a fresh-weight basis, multiply by the percent or decimal fraction of that organism's lipid content.* Implicit in these calculations are two important idealizations: (a) the assumption of no metabolic degradation or biotransformation of the chemical and (b) total bioavailability of sediment-associated chemical to the organism. Estimations involving TBP, then, are inherently conservative.

40. *The potential maximum amount of contaminant bioavailable to an aquatic organism is calculated by multiplying TBP by the decimal fraction of the lipid content of that organism.* For neutral organic chemicals, the organic carbon fraction is the dominant phase of activity in sediment, and TBP can be used to determine whether the concentration of chemical in the sediment is great enough to warrant concern. If TBP calculations using chemical analytical results indicate an acceptably low value for the potential equilibrium concentration of a neutral organic chemical that is bioavailable, no further biological testing may be required. If the calculated *equilibrium potential* is not acceptable, then tests to assess *achievable bioaccumulation* (true bioavailability) could follow in which the steady-state chemical residue in exposed organisms could be determined empirically or could be projected from exposures of a sufficient duration.

41. Benthic or deposited sediment bioassays are derived from more traditional techniques for testing contaminants in solution. While there are many variations, those most useful for this document all involve exposure of

aquatic test organisms to deposits of whole sediment for a specified period, followed by quantification of the responses.

42. For reasons of regulatory interpretation and implementation, the response of choice here is mortality (and occasionally growth or reproduction), as discussed in paragraph 26. A technique widely used and suitable for a wide variety of aquatic macroorganisms is given in USEPA/CE (1977). This technique should be utilized to test effects on a finfish, a crustacean, a mollusk, and an annelid acceptable to all regional interests as sufficiently sensitive and adequately representative of the regional aquatic environment. Many other exposure designs, species, and life stages can also provide useful information and may be utilized in addition to, or instead of, those described in USEPA/CE (1977).

43. All widely recognized sediment bioassay techniques of regulatory utility involve toxic effects of exposure of a few days to a few weeks. Tissues of surviving organisms that exceed about 1 g in weight can be analyzed for contaminants at the end of the exposure period to indicate the potential for bioaccumulation from the sediments. The contaminants to be analyzed should be those for which there is a sufficient cause for concern as identified in paragraph 14.

44. Potential benthic impacts are best evaluated by a combined consideration of total or bulk chemical analyses of sediment and toxicity/bioaccumulation test(s) to determine their bioavailability. If results of these tests do not provide sufficient information for decisionmaking as discussed later in this document, a test of *bioaccumulation to steady state* should be performed to determine the *extent* of bioavailability and the probable levels of chemicals that could accumulate in the tissues of organisms after prolonged exposure to the dredged material.

45. In order to best interpret bioaccumulation data, it is necessary to know concentrations in tissues at steady state rather than only at an indeterminant point on the uptake curve. For relatively soluble chemicals, this can be achieved by extending the exposure period until steady state is reached. However, many of the most bioaccumulating chemicals equilibrate slowly and may take weeks or even months to reach steady-state levels. For example, the highly chlorinated PCB congeners reach steady-state concentrations, if at all, only after several months of exposure. In practical terms, the time required to reach steady state can be estimated at about 3.32 biological half-lives

($t_{1/2}$). This represents 90 percent of actual steady state and is considered sufficiently accurate given the variability encountered in environmental exposures. The $t_{1/2}$'s of many chemicals are reported in the literature or can be calculated from reported values for elimination rate constants (k_2) as: $t_{1/2} = 0.693/k_2$. Estimation of the time required to reach steady state by this relationship can be used to estimate the maximum length of time required to conduct a bioaccumulation exposure.

46. An alternative to using impracticably long laboratory exposures in order to empirically reach steady-state concentrations (Css) is estimation of Css based on residues in surviving organisms at the end of the standard sediment bioassay (McFarland, Gibson, and Meade 1984). This single-time-point estimation requires knowledge of elimination rate constants for the chemicals of concern, or their estimation from other chemical properties such as water solubility or octanol/water partition coefficients (Kows). Lacking empirically determined rate constants *under conditions of exposure identical to those of the sediment bioassay*, the method is limited in utility to chemicals having log Kows ranging from about 2 to 5 and is inappropriate for super-lipophilic compounds, e.g., PCBs having three or more chlorine substitutions per molecule. The method is also inaccurate for chemicals that are appreciably metabolized. Within these constraints, single-time-point estimations may have only occasional practical application.

47. Methods that currently provide the best projections of Css are variations on the first-order pharmacokinetic model for simultaneous uptake and elimination of chemicals by an organism. The one-compartment model described by Blau, Neely, and Branson (1975) and Branson et al. (1975) is still widely and easily used. This simple model can be run on virtually any computer having an iterative nonlinear equation-solving algorithm. The essential data inputs are a series of organism tissue residues measured sequentially during a short period (1 week to 1 month) of unvarying exposure. Advanced versions of this model have recently been published that consider the effects on Css of growth dilution (Branson et al. 1985) or of metabolic degradation of chemicals (Karara and Hayton 1984). A third approach, probably the best under the circumstances where it is possible, is the use of field data as discussed in USEPA/CE (1977).

48. Applications involving assessments of bioavailability, using TBP where it is possible to do so, and bioaccumulation testing as discussed above,

are discussed under DECISIONS FROM BIOACCUMULATION EVALUATIONS* in paragraphs A16 and A17.

Description of Test Procedures for Upland Disposal

Physicochemical conditions

49. When dredged material is placed in an upland environment in which it does not remain water saturated, drastic physicochemical changes occur. As soon as the dredged material is placed in a confinement area and allowed to be exposed to the atmosphere, oxidation processes begin. As influent slurry water is discharged into a confinement area from a hydraulic dredge, initially it is dark in color, reduced, and contains little oxygen. Sediment dredged mechanically, such as with a clamshell, has sediment pore water that is initially dark in color and reduced. As the slurry water passes across the confined disposal site and approaches the discharge weir, the water becomes oxygenated and usually becomes light gray or light yellowish brown. The color change indicates further oxidation of iron complexes in the suspended particulates as they move across the confinement area.

50. Once disposal operations are completed, dredged material consolidation forces pore water up and out of the dredged material, and it drains toward the discharge weir. The drainage water continues to become oxidized and lighter in color. When the surfaced pore water has drained or evaporated from the confinement area, the surface of the dredged material becomes oxidized and lighter in color, such as changing from black to light gray. The dredged material may crack as it dries out or it may vegetate immediately. Salts may accumulate on the surface of dredged material, especially on the edge of the cracks caused by drying. Rainfall may dissolve and remove these salt accumulations in surface runoff.

51. Recent research on contaminant mobility from dredged material placed in an upland disposal site indicates that certain metal contaminants can dissolve in surface runoff as dredged material dries out (Skogerboe et al. 1987). During the drying process, organic complexes oxidize and decompose. Sulfide compounds also oxidize to sulfate salts. These chemical

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* All decisions reached on the basis of test results and interpretations are indicated in UNDERLINED CAPITAL LETTERS.

transformations could release complexed contaminants to surface runoff, soil pore water, and leachate through the material. In addition, plants and animals that colonize the upland site could bioaccumulate these released contaminants. Contaminant mobility will be significantly controlled by the physicochemical changes that occur during drying and oxidation of the dredged material.

Contaminant mobility determination

52. Upland disposal of contaminated dredged material must be planned to contain the dredged material within the site and restrict contaminant mobility out of the site in order to control or minimize potential environmental impacts. There are five possible mechanisms for transport of contaminants from upland disposal sites:

- a. Release of contaminants in the effluent during disposal operations in either dissolved or suspended particulate form.
- b. Surface runoff of contaminants in either dissolved or suspended particulate form following disposal.
- c. Leaching into ground water and surface waters.
- d. Plant uptake directly from sediments, followed by indirect animal uptake from feeding on vegetation.
- e. Animal uptake directly from sediments.

The environmental impact of upland disposal of contaminated dredged material may be more severe than aquatic discharge (Gambrell, Khalid, and Patrick 1978; Jones and Lee 1978).

53. Any test protocol used to predict contaminant mobility should account for the physicochemical changes occurring in the dredged material when placed in the specific disposal environment. The following discussion of test protocols will address each of the above aspects in detail.

54. Effluent quality. Water-quality effects of upland disposal effluents (water discharged during active disposal operations) have been identified as one of the greatest deficiencies in knowledge of the environmental impact of dredged material disposal (Jones and Lee 1978). Dredged material placed in an upland disposal area undergoes sedimentation, while clarified supernatant waters are discharged from the site as effluent during active dredging operations. The effluent may contain levels of both dissolved and particulate-associated contaminants. A large portion of the total contaminant level is particulate associated.

55. The standard elutriate test is sometimes used to evaluate effluent water quality, but this test does not reflect the conditions existing in confined disposal sites that influence contaminant release. A modified elutriate test procedure, developed under the CE Long-term Effects of Dredging Operations (LEDO) Research Program (Palermo 1984), can be used to predict both the dissolved and particulate-associated concentrations of contaminants in upland disposal area effluents (water discharged during active disposal operations). The laboratory test simulates contaminant release under upland disposal conditions and reflects sedimentation behavior of dredged material, retention time of the containment, and chemical environment in ponded water during active disposal.

56. The modified elutriate test procedure is illustrated in Figure 2. Sediment and dredging-site water are mixed to a slurry concentration equal to the expected influent concentration under field conditions. The mixed slurry is aerated in a 4-ℓ cylinder for 1 hr to ensure that oxidizing conditions will be present in the supernatant water. Following aeration, the slurry is allowed to settle under quiescent conditions for a period equal to the expected mean field retention time, up to a maximum of 24 hr. A sample is then extracted from the supernatant water and analyzed for total suspended solids and dissolved and total concentrations of contaminants of concern as described in paragraph 14. The contaminant fractions of the total suspended solids may then be calculated. Column settling tests, similar to those used for design of disposal areas for effective settling (Palermo, Montgomery, and Poindexter 1978; Palermo 1984), are used to define the concentration of suspended solids in the effluent for a given operational condition, i.e., ponded area, depth, and inflow rate. Using results from both of these analyses, a prediction of the total concentration of contaminants can be made. The predictive technique is illustrated in Figure 3. Detailed procedures are given in Palermo (1984).

57. The acceptability of the proposed upland disposal operation can be evaluated by comparing the predicted dissolved contaminant concentrations with applicable water-quality standards while considering an appropriate mixing zone and the quality of the receiving water body. Where the primary administrative goal is maximum containment of contaminants, appropriate controls and restrictions may be required to first meet water-quality criteria without a mixing zone or, secondarily, to ensure that an acceptable mixing zone is maintained.

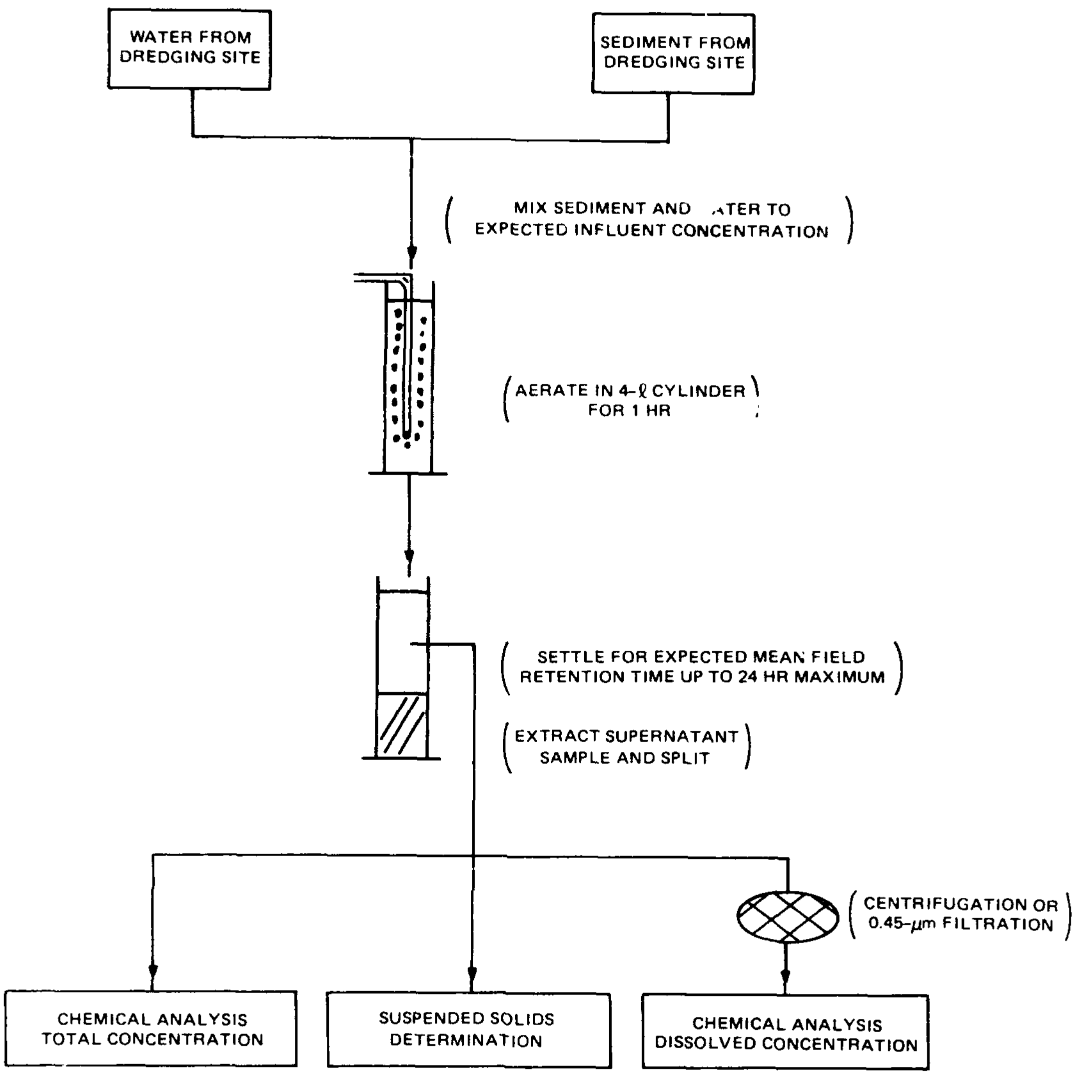

Figure 2. Modified elutriate test procedure

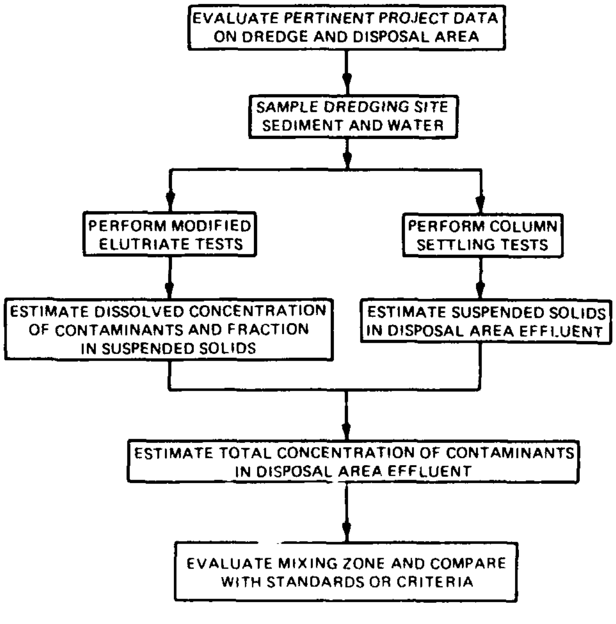

Figure 3. Effluent quality predictive technique

58. Surface runoff quality. After dredged material has been placed in an upland disposal site and the dewatering process has been initiated, contaminant mobility in rainfall-induced runoff is considered in the overall environmental impact of the dredged material being placed in a confined disposal site. The quality of the runoff water varies depending on the physicochemical process and the contaminants present in the dredged material. Drying and oxidation promote aerobic microbiological activity, which more completely breaks down the organic component of the dredged material and oxidizes sulfide compounds to more soluble sulfate compounds. Concurrently, reduced iron compounds become oxidized and iron oxides are formed that can act as metal scavengers to adsorb soluble metals and render them less soluble. The pH of the dredged material is affected by the amount of acid-forming compounds present as well as the amount of basic compounds that can buffer acid formation. Generally, large amounts of sulfur, organic matter, and/or pyrite material generate acid conditions. Basic components of dredged material such as calcium carbonate tend to neutralize acidity produced. The resulting pH of the dredged material depends on the relative amounts of acid-formed and basic compounds present.

59. Runoff water quality depends on the results of physicochemical processes that occur as the dredged material dries out. For example, should there be more acid formation than the amount of bases present to neutralize the acid, then the dredged material will become acidic in pH. Excessive amounts of pyrite when oxidized can reduce pH values from an initial pH 7 down to pH 3. Under these conditions surface runoff water quality can be acid and could contain elevated concentrations of trace metals.

60. An appropriate test for evaluating surface runoff water quality must consider the effects of the drying process to adequately estimate and predict runoff water quality. At present there is no single simplified laboratory test to predict runoff water quality. Research was initiated in November 1984 to develop such a test. A laboratory test using a rainfall simulator has been developed (Figure 4) and was used to predict surface runoff water quality from dredged material as part of the CE/EPA FVP (Westerdahl and Skogerboe 1981; Lee and Skogerboe 1983a, 1983b; Skogerboe et al. 1987). This test protocol involves taking a sediment sample from a waterway and placing it in a soil-bed lysimeter in its original wet reduced state. The sediment is allowed to dry out. At intervals during the drying process, rainfall events

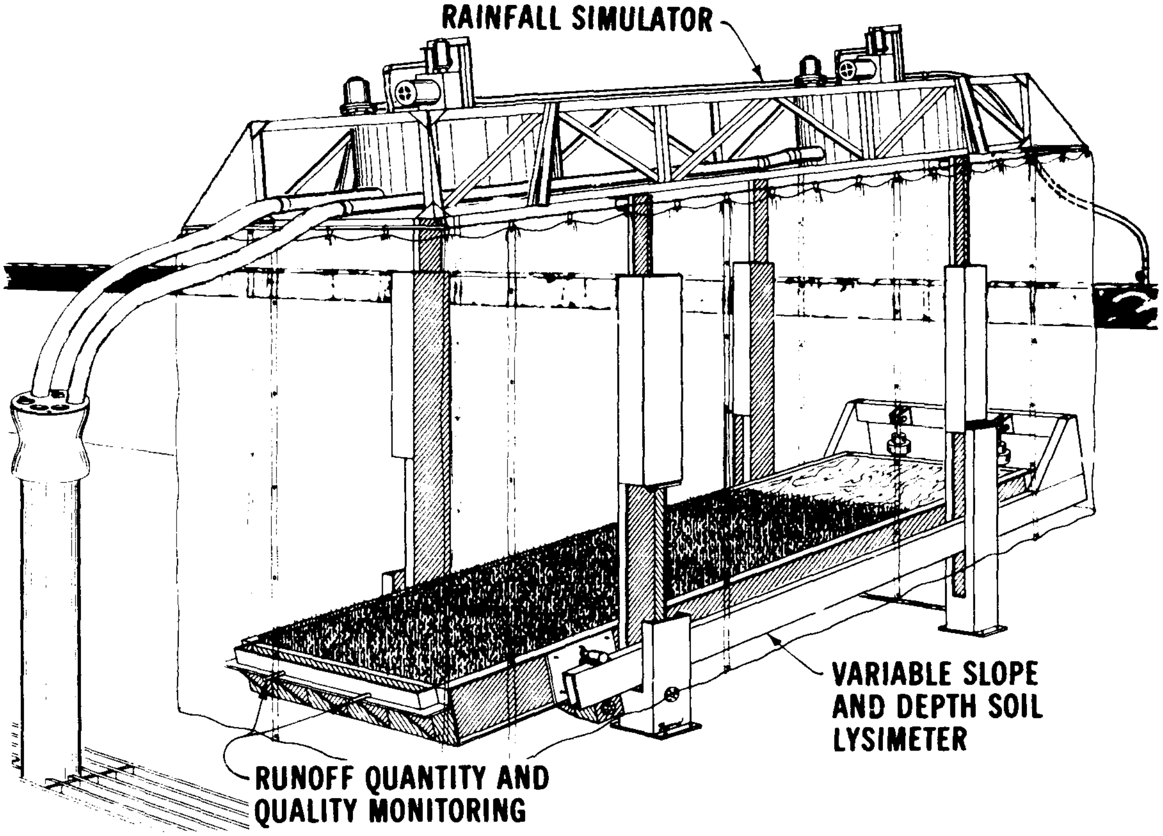

Figure 4. Surface runoff evaluation system

are applied to the lysimeter, and surface runoff water samples are collected and analyzed for selected water-quality parameters. Rainfall simulations are repeated on the soil-bed lysimeter until the sediment has completely dried out. Results of the tests can be used to predict the surface runoff water quality that can be expected in a confined disposal site when the dredged material dries out. From these results control measures can be formulated to treat surface runoff water if required to minimize the environmental impact to surrounding areas.

61. An example of the use of this test protocol can be cited (Lee and Skogerboe 1983b; Skogerboe et al. 1987). An estuarine dredged material highly contaminated with the metals zinc, copper, cadmium, nickel, and chromium was evaluated using this test procedure. An acid rainfall simulating typical rainfall quality at the upland disposal site was used. Test results indicated significant solubilization of these metals in surface runoff water after the dredged material dried out. (The pH of the dredged material became acid because of limited base neutralizing compounds present and the acid rainfall

applied.) The oxidation of sulfide compounds and organic complexes apparently released metals into more soluble and mobile forms. Based on these test results, control measures were designed to neutralize acidity and remove these metals in surface runoff water. These lab test results were verified at a field disposal site. After drying and oxidation the pH of the dredged material dropped to pH 4.7 and large amounts of soluble metals were measured in surface runoff water. The lab test accurately predicted the quality of surface runoff water from the upland disposal site. This procedure has been used on a number of dredged materials from Indiana Harbor, Indiana and New Bedford Harbor, Massachusetts, to Oakland Harbor, California.

62. Leachate quality. Subsurface drainage from disposal sites in an upland environment may reach adjacent aquifers or may enter surface waters. Fine-grained dredged material tends to form its own disposal area liner as particles settle with percolation of drainage water, but the consolidation may require some time for self-sealing to develop. In addition, diffusion of contaminants through fine-grained materials will continue even after self-sealing has stopped much of the water convection. It is surmised, but not demonstrated, that hydrophobic organic contaminants associate with naturally occurring dissolved organic carbon and thus can diffuse into ground water beneath a site. Further work is needed to substantiate this theory. Since most contaminants potentially present in dredged material are closely adsorbed to particles, primarily the dissolved fraction will be present in leachates. A potential for leachate impacts exists when a dredged material from a saltwater environment is placed in an upland site adjacent to freshwater aquifers or to surface waters. The site-specific nature of subsurface conditions is the major factor in determining possible impact (Chen et al. 1978).

63. An appropriate leachate quality testing protocol must predict which contaminants may be released in leachate and the relative degree of release. There is presently no routinely applied testing protocol to predict leachate quality from dredged material disposal sites. An evaluation of available leaching procedures is needed before a leaching test protocol for confined dredged material can be recommended. Although a wide variety of leaching or extraction tests have been proposed for hazardous waste (Lowenbach, King, and Cheromisinoff 1977; Houle and Long 1980; Goerlitz 1984), none has been field verified for use to evaluate leaching of dredged material placed in upland disposal sites.

64. A framework for predicting leachate quality from dredged material disposal sites has been developed using mass transport theory (Hill, Myers, and Brannon 1988). By applying the principles of mass transport theory, the physical-chemical processes governing leaching were identified and described mathematically. The mechanisms and factors that can influence and control contaminant transfer from the dredged material solids to the aqueous phase were also considered in detail. These factors include equilibrium, dissolution kinetics, intraparticle diffusion, and film effects.

65. Hill, Myers, and Brannon (1988) reviewed state-of-the-art leaching procedures for potential application to dredged material. Various topics, including bulk transport of contaminants by seepage, contaminant leachability under various environmental conditions, and long-term geochemical consequences that alter contaminant leachability were also reviewed. A sequential batch leaching procedure, in conjunction with a column leaching test, was recommended for obtaining the coefficients needed in the mass transport equation (Hill, Myers, and Brannon 1988).

66. The recommended experimental procedures for predicting leachate quality have been used to evaluate the potential impacts of confined disposal of dredged material from Indiana Harbor, Indiana; Everett Harbor, Washington; and New Bedford Harbor, Massachusetts (US Army Engineer Waterways Experiment Station 1987; Palermo et al. 1989; Myers and Brannon 1988a). Results are briefly summarized in Technical Note EEDP-02-7 (Myers and Brannon 1988b) as are a review of test procedures conducted at a research needs workshop held by Louisiana State University in 1988. Workshop panelists were of the opinion that research conducted to date was good and generally validated the basic technical approaches contained in Hill, Myers, and Brannon (1988). However, the consensus was that much research remains to be done before a leach test(s) will be available for routine use. The EP Toxicity Test (40 CFR 261) is not appropriate for application to dredged material, and consequently, is not being investigated.

67. Workshop participants identified the following eight directions for future research. These are being actively pursued under the LEDO Program at WES.

a. Redesign the column leach test to include thin-layer columns and improved leachate collection systems.

b. Reevaluate the aerobic column test.

c. Investigate the impact of colloidal organic matter on interactions between solid and liquid phases.

d. Determine the role of key parameters such as ionic strength, pH, and contaminant-sediment association on leachate results.

e. Investigate desorption kinetics.

f. Investigate techniques for accelerating sediment oxidation.

g. Develop a more comprehensive mathematical model and verify the model for comparing batch and column test results.

h. Verify test protocols in a field situation, preferably at a multiagency national research site.

68. Plant uptake. After dredged material has been placed in either an intertidal, wetland, or upland environment, plants can invade and colonize the site. In most cases, fine-grained dredged material contains large amounts of nitrogen and phosphorus, which promote vigorous plant growth. Elevations in confined disposal sites can range from wetland to upland terrestrial environments. In many cases, the dredged material was placed in upland disposal sites because contaminants were present in the dredged material. Consequently, there is potential for movement of contaminants from the dredged material into the environment through plants and then eventually into the food chain.

69. An appropriate test for evaluating plant uptake of contaminants from dredged material must consider the ultimate environment in which the dredged material is placed. The physicochemical processes become extremely important in determining the availability of contaminants for plant uptake.

70. There is a plant bioassay test protocol that was developed under the LEDO Program based on the results of the DMRP. This procedure has been applied to a number of contaminated dredged materials (both freshwater and estuarine sediments). Results obtained from these plant bioassays have provided sufficient information to confirm the usefulness of the technique for predicting the potential for plant uptake of contaminants from dredged material (Folsom and Lee 1981, 1983; Folsom, Lee, and Preston 1981; Lee, Folsom, and Engler 1982). The estuarine procedure was field verified under the CE/EPA FVP. The freshwater bioassay procedure was applied to a wide variety of contaminated sediments and materials such as sewage sludge-amended soils in the United States, and metal-mining waste-contaminated soils in Wales, U. K. The results were used to construct a plant bioassay prediction model. The model will be available shortly.

71. The plant bioassay procedure requires taking a sample of sediment from a waterway and placing it either in a flooded wetland environment or an upland terrestrial environment in the laboratory. An index plant, *Spartina alterniflora* for estuarine flooded sediments, *Sporobolus virginicus* for upland estuarine sediments, and *Cyperus esculentus* for freshwater sediments, is then grown in the sediment under conditions of both wetland and upland disposal environments. Plant growth, phytotoxicity (i.e., growth reduction), and bioaccumulation of contaminants are monitored during the growth period (Figure 5). Plants are harvested and analyzed for contaminants. The test results indicate the potential for plants to become contaminated when grown on the dredged material in either a wetland or an upland terrestrial environment. From the test results, appropriate management strategies can be formulated as to where to place a dredged material to minimize plant uptake or how to control and manage plant species on the site so that desirable plant species that do not take up and accumulate contaminants are allowed to colonize the site, while undesirable plant species are removed or eliminated.

72. Data required for the plant prediction model include total sediment concentrations, diethylenetriamine-pentaacetic acid (DTPA) extraction, percent organic matter, and sediment pH of the sediment or material in the condition of disposal (i.e., flooded or upland). Plant uptake of metals such as zinc, cadmium, nickel, chromium, lead, and copper can be predicted using the above-mentioned prediction model. The DTPA test procedure requires a sample of dredged material in the flooded reduced wetland condition and another sample that has been air-dried for an upland condition. The samples are extracted for 24 hr in a modified DTPA extraction solution according to Lee, Folsom, and Bates (1983). This solution is then filtered through a millipore filter and the filtrate is analyzed for soluble contaminants. The DTPA data can then be used in the plant prediction model. This procedure has been successful in predicting plant leaf tissue contents of certain metals more so than others. There is no existing extraction procedure that predicts plant availability of organic contaminants.

73. Animal uptake. Many animal species invade and colonize upland dredged material disposal sites. In some cases, prolific wildlife habitats have become established on these sites. These habitats are usually rich in waterfowl and often become the focus of public interest through regional ornithologists, sportsmen, and the environmentally aware public. Concern has

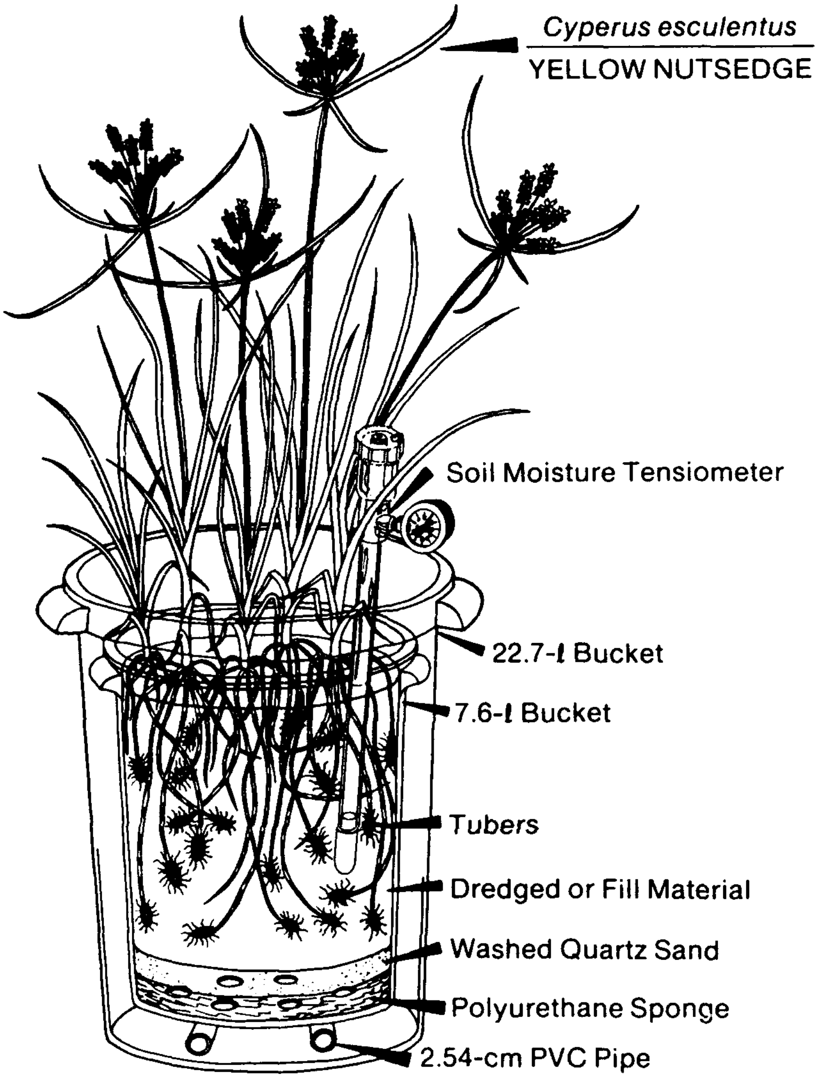

Figure 5. Plant bioassay procedure

developed recently over the potential for invertebrate animals inhabiting upland disposal sites to become contaminated and contribute to the contamination of food webs associated with the site.

74. An appropriate test for evaluating animal uptake of contaminants from dredged material must consider the ultimate environment in which the dredged material is placed, the anticipated ecosystem developed, and the physicochemical processes governing the biological availability of contaminants for animal uptake.

75. A recommended test protocol was tested under the CE/EPA FVP that utilizes an earthworm as an index species to indicate toxicity and

bioaccumulation of contaminants from dredged material. In this procedure, earthworms are placed in sediment maintained in moist and semi-moist air-dried environments (Figure 6). The toxicity and bioaccumulation of contaminants are monitored over a 28-day period (Marquenie and Simmers 1984; Simmers, Rhett, and Lee 1983; Marquenie, Simmers, and Kay 1987). This procedure is a modification of a procedure developed for the European Economic Commission for determining the hazardous nature of manufactured chemicals prior to approval for sale in the European Common Market. Test results to date indicate the terrestrial earthworm test procedure can indicate potential environmental effects of dredged material disposal in upland environments. The evaluative portion of the test is mainly tissue analysis rather than strictly mortality. While the test is being established, those treatments necessary to ensure survival for the test period (such as washing or dilution) can indicate potential field-site management strategies. The earthworm contaminant levels can also be related to the food web that could exist on the site after disposal. This test can identify bioavailable metals and organic contaminants in the material to be dredged.

Cost of Conducting Test Protocols

General

76. An example of the cost and time required to conduct each test protocol is estimated in Table 1. Dollar amounts are considered as 1990 dollars. General assumptions made to calculate costs were that the equipment and facilities to conduct the test were available. Therefore, equipment costs are not included. In addition, each sediment sample was considered to be tested in four replicates to ensure some degree of precision. Cost to conduct the test will vary from one part of the nation to another. Chemical analysis costs will also vary across the nation. Cost varies with the number of samples and the number of parameters determined. Sediment core samples can be split so that one half of each core can be archived and the other half can be used for compositing. In most cases, fewer composited sediment samples can be evaluated to give an indication of potential contaminant mobility from sediment to be dredged. In addition, if fewer contaminants are determined, especially organic compounds, the cost of chemical analysis will be reduced. Table 1 clearly illustrates the enormous cost that can be developed from the chemical

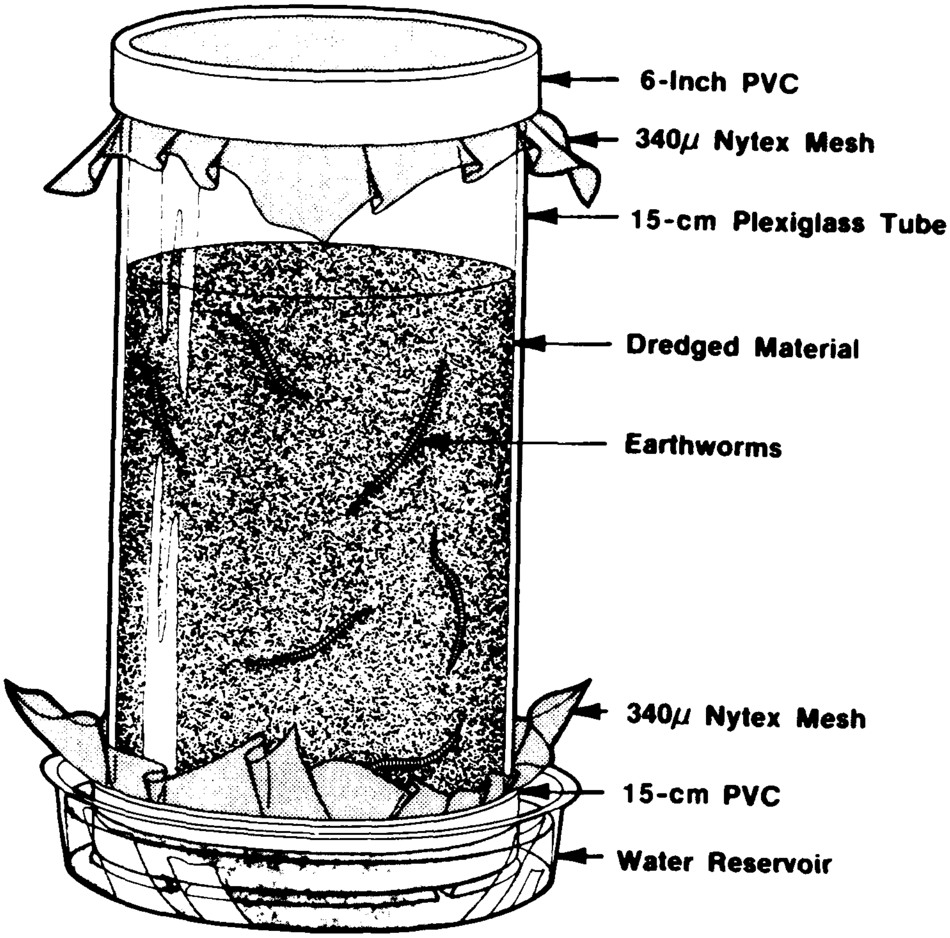

Figure 6. Earthworm bioassay procedure

analysis of samples. While it may cost approximately $50,000 to obtain samples from the suite of tests, chemical analysis costs for the sample generated could mount to between $178,000 and $270,000. Leachate test costs are high because the leachate test is under development and an accurate cost estimate is extremely difficult to project. Leachate test cost should be lowered when a routine test is available. Costs in Table 1 can be generated from the testing of only one sediment sample. Additional sediment samples will increase these costs proportionally, rapidly escalating the chemical analysis costs.

77. While Table 1 lists all of the test protocols that could be applied to a contaminated sediment, the decisionmaking framework to be discussed in the next section of this report will indicate when one or more of the test protocols should actually be conducted. From those test results, the

framework will indicate additional test protocols that should then be conducted, if warranted.

Small projects

78. The problem of cost and the need for cost reduction are best exemplified by the so-called "small project." A small project may be defined as any dredging and disposal project that involves less than 25,000 cu yd* of sediment. This volume may change somewhat from location to location: large harbors may not have projects as small as 25,000 cu yd, but rather more in the vicinity of 50,000 cu yd; and small harbors may have projects smaller than 10,000 cu yd. The cost of running a full-scale set of tests could easily exceed the actual cost of the dredging/disposal operation by an order of magnitude. Consequently, the evaluation of small projects must be somewhat different than that of large projects.

79. Bulk chemical analyses should be conducted on a minimum of sediment samples. The number of samples will vary from project to project. However, one approach to determining numbers of samples is collecting a minimum of one core per dredging management unit load (about 4,000 cu yd for one barge load). This approach would allow for the appropriate disposal of each barge load of dredged material. The size of a dredging management unit load will vary with the size of the barges available for the project. If a small project with high contamination is to be dredged about the same time as a large project nearby, one may wish to consider open-water disposal without further testing and covering (i.e., capping) with the dredged material from the large project, provided the material dredged from the large project is clean enough to be used as a cap. If the small project contains highly contaminated material and no large project is available to provide capping material, further testing may be required.

80. Another approach may be to compare the bulk chemical analysis of a composite sample from the small project to existing data from other projects that have undergone extensive biological and chemical testing to assess potential problems. For this approach to be valid, the physicochemical characteristics (as well as the type of contaminants of concern) of both sediments

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 12.

should be similar. In some cases, existing harborwide sediment characterization possibly may be useful in lieu of some testing for the small project if the small project does not come from an area of unusually high contamination, but is from an area that is representative of the harbor as a whole.

81. The question of how to deal with small projects requires further investigation. Thus, the approaches described in paragraphs 79 and 80 must not be construed as specific recommendations. Further evaluations of other approaches to evaluate small projects are required before a recommendation can be made. At the present, the final decision on how to handle small projects must be a RAD.

Contaminant Detection Limits

82. Table 2 presents the detection limits for contaminants identified by Tetra Tech (1984) as being of potential concern in Commencement Bay that generally could be used in the chemical analyses of samples from the test protocols. Not all of these will be identified as contaminants of real concern in any specific sediment. All of the detection limits for water samples listed in Table 2 are for procedures approved by EPA for compliance with requirements of the National Pollutant Discharge Elimination System and the National Interim Primary Drinking Water Regulations and described in 40 CFR Part 136. These detection limits are based on relatively clean samples with few interferences.

83. In general, detection limits are determined primarily by sensitivity of the analytical instrument (which is fixed), the degree of contamination, and the mass of sample available for extraction or digestion. Most of the detection limits for metals may be achieved using an atomic absorption spectrometer equipped with a heated graphite furnace or an inductively coupled plasma emission spectrometer. Detection limits for mercury are obtained using a cold vapor technique with the atomic absorption spectrometer. The detection limits for the organics (except pesticides and PCBs) are for gas chromatography/mass spectrometry (GC/MS) procedures using 1 ℓ of water or 50 g of solid material. The lower detection limits cited for pesticides and PCBs are based on GC/electron capture detection (GC/ECD) procedures. Although all of these procedures have been in use for a number of years at laboratories analyzing environmental samples, most require analysts who are experienced in

the methodology and who are acquainted with the interferences that can alter results. Levels of detection can be lowered by up to a factor of 10 in many cases by further concentration and cleanup of samples. Further lowering of detection levels will require the use of more recently developed techniques and experienced analysts.

Decisionmaking Framework

84. A decisionmaking framework is presented in detail in Appendixes A and B. This framework utilizes the management strategy illustrated in Figure 1 and incorporates the results from the suite of test protocols described in paragraphs 24-75 into 10 flowcharts. The appendixes discuss in detail the steps to be followed in using the flowcharts. Relevant information and data have been compiled in a number of tables in Appendix C. The information and data are used to make the decisions called for in the framework. Appropriate cross-referencing of paragraphs and appendix tables has been incorporated into the flowcharts to assist the user in stepping through the framework and in and out of associated tabular information. Terms that will be used in the framework include:

a. *Reference site--location from which biological and sediment or water chemistry data are used for comparison to test results from contaminated dredged material. This may vary from an existing disposal site to an existing background site and will be determined by a regional administrative decision.*

b. *Regional administrative decision (RAD)--a decision made by regional regulatory authorities having jurisdiction over the project in question. The term regional administrative decision (RAD) is equivalent to the term local authority decision (LAD) used in the original version of the decisionmaking framework (Peddicord et al. 1985).*

Responsibility for regional administrative decisions

85. There are certain decisions that must be made initially and then periodically within the decisionmaking framework that are the sole responsibility of the regional authorities. These regional administrative decisions (RADs) are required to initially set specific goals to be achieved. For example, a RAD must establish the environmental quality ultimately desired at the site and the rate at which this goal is to be achieved. A RAD must determine the appropriate reference site(s) for test result comparisons in the

decisionmaking framework in order to achieve the ultimate and intermediate goals. As described previously, the selection of reference sites can vary from the actual disposal site to a pristine background site. This selection is dependent on the goal established for the area such as a goal of non-degradation (reference site is disposal site) or cleaner than present condition (reference site is pristine background site) or some other goal. *The clear identification of the ultimate and intermediate goals and selection of appropriate references to achieve them is a crucial responsibility of the regional authorities and will influence the outcome of all test result interpretations.*

86. In addition, RADs must be made whenever technical knowledge and understanding are inadequate to support a scientific decision. In such cases a regulatory decision must be made by regional authorities on the basis of a combination of scientific judgment and administrative considerations. For example, a RAD must determine whether or not to consider mixing zones when test results exceed reference site values or water-quality criteria. Should the RAD be to consider mixing zones and an acceptable mixing zone is available, a decision for no restrictions on that particular aspect of the disposal might be made. In contrast, should the RAD be not to consider mixing zones, then a decision for restrictions might be made, which will generally be more conservative but may prove to be more costly upon implementation of the restrictions. Many of these RADs are shown in the flowcharts as diamonds ◊ . Scientific guidance for making each RAD is provided at the appropriate points in the text. This general guidance is appropriate for nationwide use, but the actual implementation of the general guidance must vary in different areas to meet different regional goals, objectives, and concerns.

Initial evaluation of contaminants

87. The initial evaluation determines if the sediment to be dredged is likely to be contaminated (Figure 7). This decision is based on consideration of available information as described in paragraph 14. The information considered in the initial evaluation also allows identification of the specific contaminants of concern in each sediment being considered.

88. It is recommended that all potential dredging projects analyze at least one composited sediment sample from the project. This sample should be representative of the entire depth of dredging as well as the reach of waterway to be dredged. The number of samples collected for a project will depend

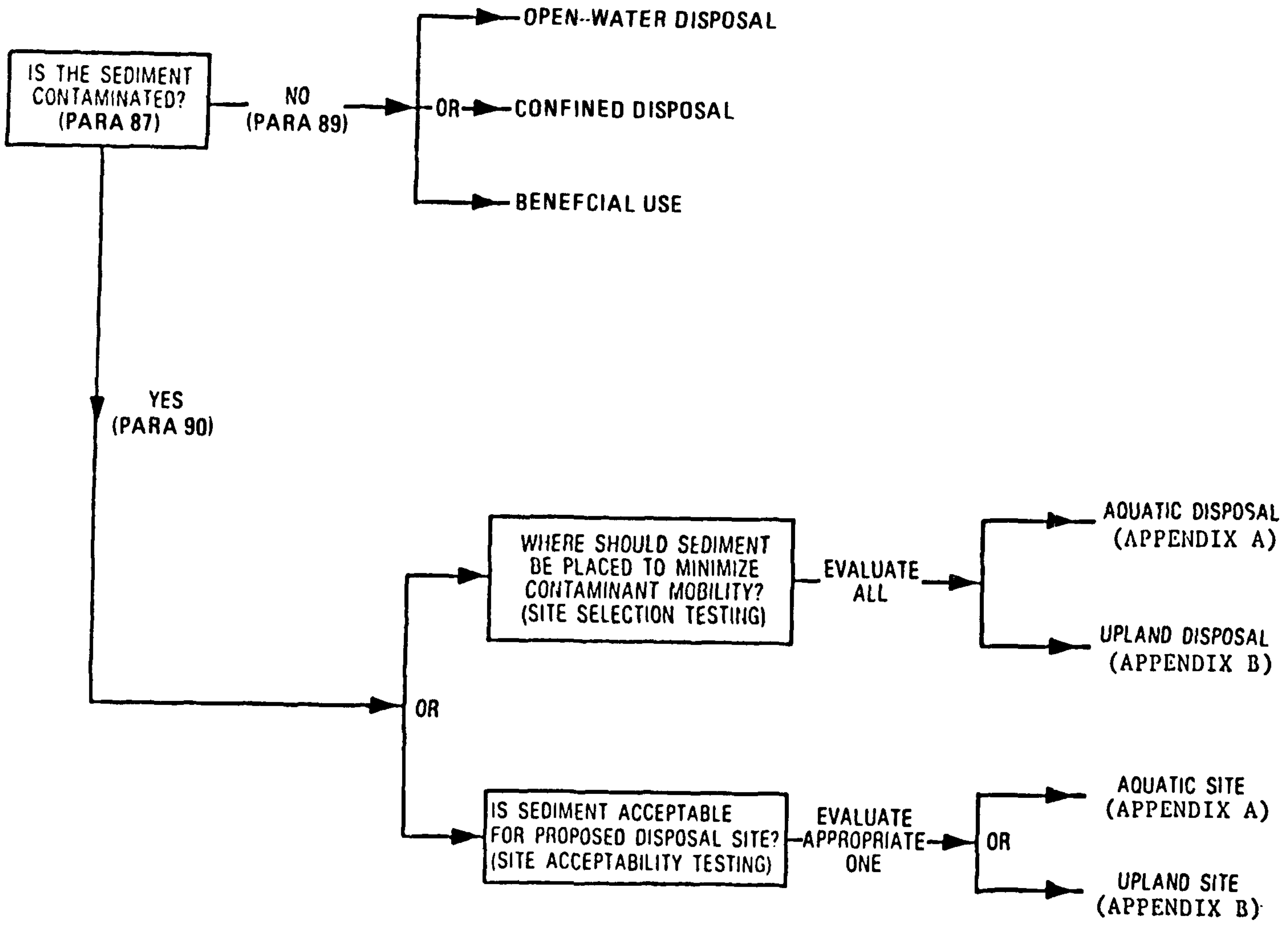

Figure 7. Flowchart for initial decisions for using framework

on suspected contamination, potential pollution sources, sediment type, basin configuration, etc. A possible example of a composited sample might be the collection of one sediment core for each management unit (4,000 cu yd) of sediment along the waterway. This would be the equivalent of one 4,000-cu-yd barge load of dredged material. The size of the management unit should be a RAD. These cores are then divided in half lengthwise. One half of each of the cores is kept separate while the other halves of all cores are mixed to get a homogeneous composited sample. This sample is then analyzed for the entire list of EPA priority pollutants to inventory the contaminants present. If the composite sample indicates elevation of one or more contaminants, then each separate remaining half core can be analyzed to determine which sample or samples along the waterway contain contaminants. Likewise, a composited sediment sample should be obtained from an appropriate RAD reference site and analyzed for the entire list of EPA priority pollutants. Further details on sediment sampling and processing procedures are reported by Plumb (1981).*

89. DECISION OF NO CONTAMINATION. *If sufficient information is available and provides no substantive reason to believe contaminants are present based on the chemical analysis of a composite sediment sample*, a DECISION FOR NO FURTHER TESTING is made. The sediment can be dredged and disposed in an aquatic site, in an upland site, or used productively such as for marsh creation or enhancement of agricultural land with *no restrictions and no contaminant impacts on the environment*. In such cases, the selection of a disposal site is based on considerations other than potential contaminant impacts on the environment.

90. DECISION OF SEDIMENT CONTAMINATION. *If the available information is inadequate or provides a substantive reason to believe contaminants are present*, then a DECISION FOR FURTHER TESTING is made. The testing of the sediment depends on which of the two questions in Figure 7 is being addressed. The question *"In what type of disposal environment should the sediment in question be placed to minimize contaminant mobility?"* is *SITE SELECTION TESTING* and represents the situation where aquatic and upland (and nearshore) disposal sites are available. The emphasis is on selecting the disposal

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* The above is only an example and should not be construed to be the only approach to compositing samples. There are other approaches to compositing samples that could be selected and implemented by a decision of the regional authorities.

environment minimizing the potential for adverse contaminant impacts from the dredged material. The second question, *"Is this sediment suitable from a contaminant perspective for placement in a particular disposal environment?"*, could be considered as *SITE ACCEPTABILITY TESTING* and addresses the situation that there are limitations on available disposal sites. Therefore, the sediment is tested to determine the acceptability of a given disposal environment for the disposal of the sediment. For example, if the only disposal sites available are upland sites, then testing should focus on upland disposal and not on aquatic disposal. Ultimately, the testing should be tailored to the available disposal site. Once the appropriate question is identified, a decision to consider AQUATIC DISPOSAL (Appendix A) or UPLAND DISPOSAL (Appendix B) can be made.

Application of restrictions to disposal

91. In Appendixes A and B, test results are compared to established numerical values where these are available and appropriate for test interpretation. When such values do not exist, these appendixes provide guidance on interpreting test results in comparison to results of the same test performed on a reference sediment selected in accordance with paragraph 86. For each test, guidance is provided on these bases for determining whether or not restrictions on the discharge are required to protect against contaminant impacts or whether further evaluation is required to determine the need for restrictions. In some cases, there is inadequate scientific knowledge to reach a decision solely on the basis of test results, and RADs that incorporate both scientific and administrative judgments are required to reach a decision. In such cases, guidance is given on evaluating the scientific considerations involved. In this manner, guidance is provided for systematically interpreting the results of each test required to evaluate potential impacts of aquatic disposal (Appendix A) and upland disposal (Appendix B). Applying the systematic detailed guidance of Appendixes A and/or B will lead to a decision that restrictions are or are not required for aquatic disposal and/or upland disposal. Possible restrictions to minimize the potential impact of aquatic disposal are discussed in paragraphs 92-97 and by Cullinane et al. (1986). Cross-references in Appendix A refer to specific paragraphs where appropriate. Possible restrictions to minimize the potential impacts of upland disposal are discussed in paragraphs 98-114. These paragraphs are referenced specifically in Appendix B wherever appropriate.

Aquatic disposal with restrictions

92. In cases where testing protocols indicate that water-column or benthic effects will be unacceptable when conventional aquatic disposal techniques are used, aquatic disposal with restrictions may be considered. This alternative involves the use of dredging or disposal techniques that will reduce water-column and benthic effects. Such techniques are discussed in detail in a report by the US Army Engineer District, Seattle (1984) and include use of submerged discharge points and diffusers, subaqueous confinement of material, or capping of contaminated material with clean material, and treatment techniques. Guidelines for selecting control and treatment options for contaminated dredged material requiring restrictions are given in Cullinane et al. (1986). The same basic considerations for conventional aquatic disposal site designation, site capacity, and dispersion and mixing also apply to aquatic disposal with restrictions.

93. Submerged discharge. The use of a submerged point of discharge reduces the area of exposure in the water column and the amount of material suspended in the water column and susceptible to dispersion. The use of submerged diffusers also reduces the exit velocities for hydraulic placement, allowing more precise placement and reducing both resuspension and spread of the discharged material. Considerations in evaluating feasibility of a submerged discharge and/or use of a diffuser include water depth, bottom topography, currents, type of dredge, and site capacity. The DMRP (Barnard 1978) developed a conceptual design for a submerged diffuser that has been successfully demonstrated by European dredging interests and has been studied in the United States at Calumet Harbor, Chicago, IL, under the CE DOTS Program. This recent study showed that the total suspended solids were reduced significantly in the zones above and surrounding the diffuser.*

94. Subaqueous confinement. The use of subaqueous depressions or borrow pits or the construction of subaqueous dikes can provide confinement of material reaching the bottom during aquatic disposal. Such techniques reduce the areal extent of a given disposal operation, thereby reducing both physical benthic effects and the potential for release of contaminants. Considerations in evaluating feasibility of subaqueous confinement include type of dredge,

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* Personal Communication, April 1986, C. L. Truitt, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

water depth, bottom topography, bottom sediment type, and site capacity. Subaqueous confinement has been utilized in Europe and to a limited extent by the New York District. Precise placement of material and use of submerged points of discharge increase the effectiveness of subaqueous confinement.

95. Capping. Capping is the placement of a clean material over material considered contaminated. Considerations in evaluating the feasibility of capping include water depth, bottom topography, currents, dredged material and capping material characteristics, and site capacity (Montgomery 1989). Both the Europeans and the Japanese have successfully used capping techniques to isolate contaminated material in the aquatic disposal environment. Capping is also currently used by the New York District and New England Division as a means of offsetting the potential harm of aquatic disposal of contaminated or otherwise unacceptable sediments. The London Dumping Convention has accepted capping, subject to careful monitoring and research, as a physical means of rapidly rendering harmless contaminated material disposed in the ocean. The physical means are essentially to seal or sequester the unacceptable material from the aquatic environment by a covering of acceptable material.

96. Testing procedures have been developed to assess the efficiency of capping and the thickness of cap material needed to isolate contaminated sediment. Testing procedures using small-scale (22.6-ℓ) units have been developed for predicting the cap thickness required to chemically isolate contaminated sediment from the overlying water. Release rates of several mobile sediment constituents, including ammonium-N have been evaluated and found to be useful as tracers in the small-scale predictive test. Guidance for use of the small-scale predictive tests is presented in Gunnison et al. (1987). Testing procedures for large-scale units with a volume of 250 ℓ have been used to assess the medium- (Brannon et al. 1985; Brannon et al. 1986b) and long-term (Brannon et al. 1986a) effectiveness of capping for chemically and biologically isolating contaminated dredged material from the overlying water. Medium- and long-term capping effectiveness in the large-scale units was assessed by following the movement of chemical contaminants from contaminated dredged material into the overlying water column and by monitoring biological uptake by organisms such as clams and polychaetes. The capping technique for disposal of dredged material has potential for relieving some pressure on acquiring sites for confined disposal areas in localities where land is rapidly becoming unavailable.

97. Chemical/physical/biological treatment. Treatment of discharges into open water may be considered to reduce certain impacts. For example, the Japanese have used an effective in-line dredged material treatment scheme for highly contaminated harbor sediments (Barnard and Hand 1978). However, this strategy has not been widely applied and its effectiveness has not been demonstrated for solution of the problem of contaminant release during aquatic disposal.

Upland disposal with restrictions

98. Conventional confined upland disposal methods can be modified to accommodate disposal of contaminated sediments in new, existing, and reusable disposal areas. The design or modification of these areas must consider the problems associated with contaminants and their effects on conventional design. Many of the following design considerations apply to all of the implementation options. Guidelines for selecting control and treatment options for contaminated dredged material requiring restrictions are given in Cullinane et al. (1986).

99. Site selection and design. Site location is an important consideration since it can mitigate many contaminant mobilization problems. Proper site selection may reduce surface run-on and, therefore, contaminated runoff and contaminant release by flooding. Ground-water contamination problems can be minimized through selection of a site with natural clay foundation instead of a sandy area and through avoidance of aquifer recharge areas (Gambrell, Khalid, and Patrick 1978).

100. Careful attention to basic site design as discussed previously will aid in implementing many of the controls outlined. Retention time can be increased to improve suspended solids removal and, therefore, contaminant removal. Additional ponding depth can also improve sedimentation. Decreasing the weir loading rate and improving the weir design to reduce leakage and control the discharge rate can also reduce the suspended solids and contaminant concentrations of the effluent.

101. Dewatering should be examined carefully before selecting a method since dewatering promotes oxidation of the material and thereby increases the mobility of certain contaminants (Gambrell, Khalid, and Patrick 1978). Care must also be taken to reduce loss of contaminated sediment by erosion during drainage and storm events.

102. Available options. Depending on the particular dredging operation, one or more types of restrictions may be required. The particular restriction or combination of restrictions may eliminate certain disposal options. For the purposes of developing a management strategy, four options are considered available for upland disposal with restrictions. These options include:

- a. Containment--dredged material and associated contaminants are contained within the disposal site.
- b. Treatment--dredged material is modified physically, chemically, or biologically to reduce toxicity, mobility, etc.
- c. Storage and rehandling--dredged material is held for a temporary period at the site and later removed to another site for ultimate disposal.
- d. Reuse--dredged material is classified and beneficial uses are made of reclaimed materials.

Obviously, combinations of the above options are available for a particular dredging operation.

103. Containment of contaminated dredged material can be in either an existing or a new facility. These facilities can be designated or modified to handle a wide variety of contaminants. Most contaminated sediments can be disposed of in an existing site where special controls have been incorporated in consideration of the restrictions discussed in paragraphs 109-115. In the case of highly contaminated sediments, a more secure disposal facility would be required, and, in all probability, disposal restrictions would dictate the design of a new facility.

104. The treatment option can be associated with either existing or new facilities. Some form of physical, chemical, or biological treatment would probably be associated with the disposal of highly contaminated dredged material. Treatment may also be combined with other options for disposal of slightly to moderately contaminated dredged material in confined disposal sites.

105. Of the four available options, storage and rehandling can serve two beneficial functions: (a) continued use of upland sites located close to dredging areas, and (b) use as a rehandling facility for contaminated dredged material prior to later disposal offsite.

106. Finally, the concept of a reuse option would incorporate beneficial uses of materials reclaimed by the classification/separation process.

Such materials could include sand and gravel or slightly contaminated construction fill to be used for raising dikes or acceptable offsite uses.

107. Design considerations. Contaminated dredged material management includes methods for dewatering, transporting, storing, treating, and disposing of contaminated material. The most technically and economically effective strategy to handle contaminated dredged material will depend on many site-specific variables, which include the following:

a. Method of dredging used--hydraulic versus mechanical.

b. Method of dredged material transport--pipeline versus truck or hopper or barge.

c. Physical nature of removed material--consistency (solids/water content) and grain-size distribution.

d. Volume of removed material.

e. Nature and degree of contamination; physical and chemical characteristics of contaminants.

f. Proximity of acceptable treatment, storage, containment, or reuse facilities.

g. Available land area for construction of new facilities or expansion of existing facilities.

108. Restrictions. Conventional confined upland disposal methods may be modified to accommodate disposal of slightly to highly contaminated sediments. Many of the restrictions on upland disposal that may be required are common to the available options. Among these restrictions are:

a. Effluent-quality controls during dredging operations.

b. Runoff water-quality controls after dredging operations.

c. Leachate controls during and after dredging operations.

d. Control of contaminant uptake by plants and animals during and after dredging operations.

e. Control of atmospheric contaminants after dredging operations.

109. Many of the contaminant controls described in the following paragraphs are directly applicable to the control of highly contaminated sediments. These controls will be extremely site specific. Special considerations that are based on the physical nature and chemical composition of the dredged material will be required to effectively design a confined disposal facility. For example, some contaminated dredged material may require in-pipeline treatment prior to discharging the material into the containment facility. Similarly, if the facility requires a bottom-liner system, the liner materials (synthetic membrane or clay) must be chemically compatible

(resistant) with the dredged material to be placed on them. Special compatibility testing will be needed for selection of appropriate liner materials. Other requirements such as leachate detection and monitoring are likely due to the potentially adverse environmental effects of the liner leaking.

110. Effluent controls. Effluent controls at conventional upland disposal areas are generally limited to chemical clarification. The clarification system is designed to provide additional removal of suspended solids and associated adsorbed contaminants as described in Schroeder (1983). Additional controls can be used to remove fine particulates that will not settle or to remove soluble contaminants from the effluent. Examples of these technologies are filtration, adsorption, selection ion exchange, chemical oxidation, and biological treatment processes. Beyond chemical clarification, only limited data exist for treatment of dredged material (Gambrell, Khalid, and Patrick 1978).

111. Runoff controls. Runoff controls at conventional sites consist of measures to prevent the erosion of contaminated dredged material and the dissolution and discharge of oxidized contaminants from the surface. Control options include maintaining ponded conditions, planting vegetation to stabilize the surface, liming the surface to prevent acidification and to reduce dissolution, covering the surface with synthetic geomembranes, and/or placing a lift of clean material to cover the contaminated dredged material (Gambrell, Khalid, and Patrick 1978).

112. Leachate controls. Leachate controls consist of measures to minimize ground-water pollution by preventing mobilization of soluble contaminants. Control measures include proper site selection, dewatering to minimize leachate production, chemical admixing to prevent or retard leaching, lining the bottom to prevent leakage and seepage, capping the surface to minimize infiltration and thereby leachate production, using vegetation to stabilize contaminants and to increase drying, and leachate collection, treatment, or recycling (Gambrell, Khalid, and Patrick 1978).

113. Control of contaminant uptake. Plant and animal contaminant uptake controls are measures to prevent mobilization of contaminants into food webs. Control measures include selective vegetation to minimize contaminant uptake, liming or chemical treatment to minimize or prevent release of contaminants from the material to the plants, and capping with clean sediment or excavated material (Gambrell, Khalid, and Patrick 1978).

114. Control of atmospheric contaminants. The control of gaseous emissions or dust that might present human health hazards can consist of physical measures such as covers or vertical barriers. Control of contaminated surface materials is another type of management or operating control to minimize transport of contaminants offsite. Techniques for limiting wind erosion are generally similar to those employed in dust control and include physical, chemical, or vegetative stabilization of surface soils (US Army Engineer Waterways Experiment Station 1983; Lee et al. 1984).

PART III: EXAMPLE APPLICATION OF FRAMEWORK AND INTERPRETATION OF TEST RESULTS

Disposal Environment Descriptions

115. In order to apply the decisionmaking framework and to illustrate the integration of test results to evaluate proposed disposal options or to select among alternatives, it is necessary to have results for the tests described in Part II for several sediments and disposal environments. This example utilizes a hypothetical scenario involving sediments and disposal environments under consideration in Commencement Bay, Washington. The disposal sites being considered are described below.

Aquatic environment

116. An aquatic site is located midway between the mouth of a major waterway and the northern part of the bay about 3/4 of a mile from the nearest shoreline. Depths range between 100 and 200 ft at mean lower low water (MLLW). The site is a natural horseshoe-shaped depression; closing the fourth side with an underwater dike would provide capacity for disposing and capping of over 2.5 million cu yd of dredged material. Ownership of the site is with the State of Washington, but there is little practical control over potential long-term use of the site. The site is within 2 miles of major dredging areas. No other major discharge sites are nearby that could result in cumulative impacts. Water-column temperatures of 9° to 12° C are usual at the site. Surface salinity varies from a winter/spring low of 14 ppt to a summer high of 27 to 30 ppt. Bottom salinity remains close to 30 ppt year-round.

117. Regional fishermen indicate that the area is popular for bottom fishing though success is unknown. While the depths are outside the normal feeding range of salmonids migrating over the site, the regional Native American tribe indicates that the upper water column is seasonally used by drift netters. Human activity directly affecting the site bottom has not been recorded. However, past and present use of the water surface for extensive log booming may have influenced bottom sediment composition. Moderate to high recreational shellfishing occurs along the nearest shoreline to the site; however, there is no other human water-contact activity. The site is not regarded as a major spawning or nursery area.

Upland environment

118. A 60-acre upland disposal site is bounded by roads on the northeast and northwest and by a railroad switchyard on the southeast. The site was formerly a dredged material disposal area and has been filled to approximately +16 ft MLLW. The top 10 to 15 ft of the site is composed of loose fill containing coarse sand, gravel, and debris. Under the fill is found a 10-ft-thick layer of silt; below that is found dense sand. Filling of the site to industrial grade found in adjacent lands would provide capacity of 100,000 cu yd; fill to +35 ft MLLW (a likely maximum) would provide capacity for an additional 1,450,000 cu yd. The site is centrally located and is within 1 mile from major dredging areas. Ownership is by the regional Port Authority, and the area is zoned for port industrial area development. A relatively new warehouse and office facility exists on an elevated corner of the site. However, there is little firm regulatory control over future site use.

119. Effluent discharge from hydraulic disposal in this site would be directed through an existing drainage canal to the nearby navigation waterway, which also receives other major discharges. Due to recent use of this site as a disposal area, the area contains a sparse mixture of upland grasses and exposed sandy dredged material, but it does not serve as wildlife habitat. The area is suspected of being a recharge area for a shallow aquifer, but there are no wells in this aquifer at present.

Nearshore environment

120. In addition to the aquatic and upland sites described above, consideration is also being given to closing off and filling Milwaukee Waterway, a dead-end channel excavated into the shoreline of Commencement Bay. The Milwaukee Waterway nearshore disposal area is a 30-acre navigation waterway separated from the major river entering the bay on the south and another actively used waterway on the north by finger fills overlying tide flats. The top 15 to 20 ft of the finger fills along the sides of the waterway are composed of loose coarse fill. Below the fill is found a layer of softer silt, varying in thickness from 10 to 30 ft. Dense sand is further below. The bottom of the waterway is mostly covered with approximately 5 ft of soft organic mud. Consolidated silt (20 ft thickness) underlies the surface silt, with sand further below. Salinity of the nearby water is similar to that of the aquatic site. Average site elevation is -26 ft MLLW. Elevation of adjacent

fill surfaces is +18 ft MLLW. Wet capacity (area that would remain tidally influenced and saturated) is 1,870,000 cu yd; dry capacity is 290,000 cu yd to industrial grade. Owned by the regional Port Authority, the site is intended to be filled to accommodate a container terminal facility, but there is no control over site use. The site is within 1 mile of major dredging areas.

121. There is little probability of wildlife use of the site. Little aquifer recharge is expected here. The site is near seasonal fish migration routes, but it is not used as a spawning or nursery area. There is no human water-contact activity, but some recreational shellfishing occurs near the site. There are no wells in the area.

122. If the Milwaukee Waterway is filled with dredged material, the physicochemical conditions controlling contaminant mobility will be a combination of those occurring under aquatic and upland disposal. Three distinct physicochemical environments will develop after the filling operation and can be described as:

a. Upland--dry unsaturated layer.

b. Intermediate--partially or intermittently saturated layer.

c. Flooded--totally saturated layer.

123. Initially, all of the dredged material will be saturated, anaerobic, and reduced when placed in Milwaukee Waterway. After the filling operation is completed, the upper surface layer of dredged material above the high tide elevation will become upland. The layer of dredged material between the high tide and low tide elevations will become an intermediate layer with a moisture content varying between saturated and unsaturated. The degree of moisture will depend on the rate of water movement in, through, and out of this layer. The layer of dredged material at and below the low-tide elevation will remain saturated. Potential pathways of contaminant mobility are illustrated in Figure 8. The three physicochemical environments that will develop at this disposal site are also indicated.

124. The test protocols for predicting contaminant mobility at the Milwaukee Waterway disposal site should address the pathways illustrated in Figure 8. Test protocols similar to those described under upland disposal (paragraphs 49-75) should be applied to dredged material placed at the Milwaukee Waterway disposal site. The following tabulation lists the specific test protocol and the pathway of contaminant mobility from Figure 8:

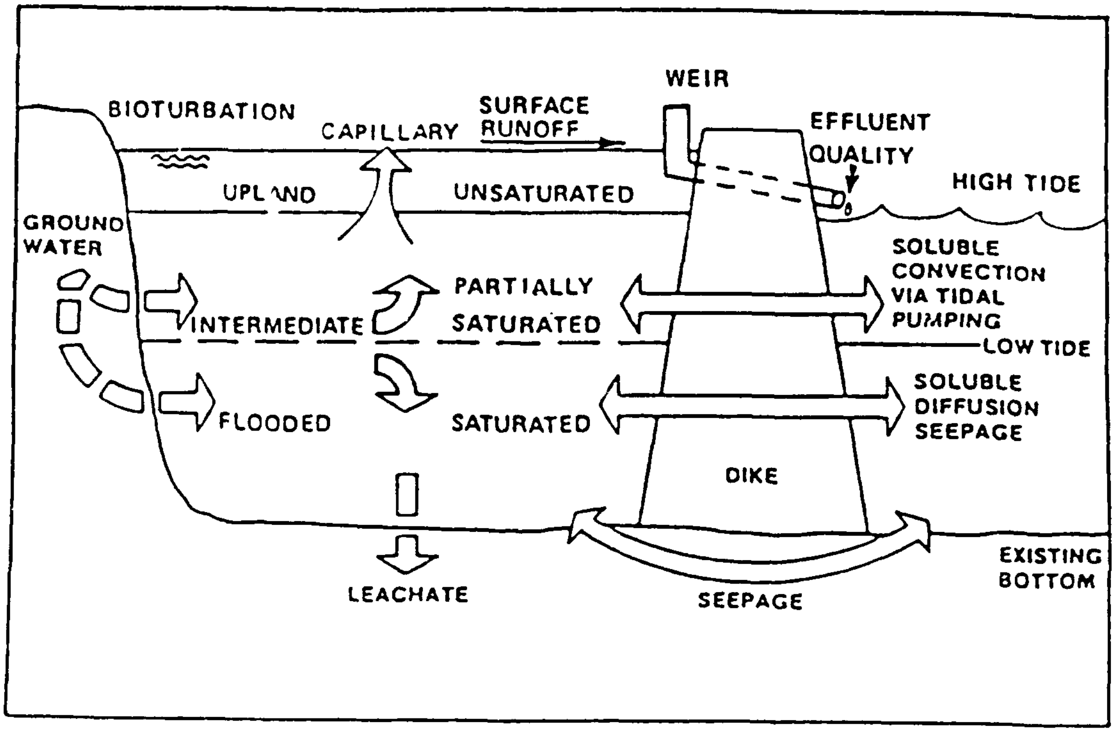

Figure 8. Nearshore disposal: filling of Milwaukee Waterway

Test Protocol	Pathway of Contaminant Mobility
Effluent quality	Effluent discharge
Surface runoff quality	Runoff
Leachate quality	Leachate
	Seepage
	Soluble diffusion, seepage
	Soluble convection via tidal pumping
	Capillary
	Mobility between layers
Plant uptake	Bioturbation
Animal uptake	Bioturbation

Test results for sediments scheduled to be dredged in Commencement Bay will provide appropriate information to indicate which sediments should be placed in the flooded, intermediate, and upland layers at the Milwaukee Waterway disposal site in order to minimize contaminant mobility according to the pathways illustrated in Figure 8.

Sediment Description

125. In addition to descriptions of disposal environments, example application of the decisionmaking framework also requires test results for several sediments. While all the tests of Part II have been performed on various sediments, no single sediment has been analyzed by more than a few of the tests. Therefore, Puget Sound sediments were reviewed on the basis of existing bulk chemistry data. On the basis of these data, one sediment was selected as a hypothetical reference sediment and three sediments with different concentrations of various types of contaminants were selected as hypothetical test sediments.

126. On the basis of the considerations discussed in paragraph 14, 16 contaminants were chosen for illustrative purposes as contaminants of concern. These contaminants are potentially environmentally important and include a spectrum of metals and hydrocarbons, encompassing the acid extractable, pesticide, and base-neutral fractions, including one- through five-ring compounds. When data were not available for some of the contaminants selected, hypothetical values were substituted that appeared reasonable on the basis of other sediments similarly contaminated with the compounds for which data were available.

127. The complete hypothetical bulk chemistry obtained in this manner for the four sediments was presented to scientists familiar with the various tests of Part II. Recognizing that the results of other tests cannot accurately be predicted on the basis of bulk chemistry alone, these scientists were asked to provide hypothetical examples of possible test results that would not seem unreasonable if the tests had actually been performed on sediments with the hypothetical chemical concentrations. This provided the hypothetical example values in Tables 3-21. *These tables are used here only for hypothetical illustration of the procedures for interpreting test results and cannot be used for any other purpose.*

Example Interpretation of Hypothetical Test Results

Approach

128. The interpretation of hypothetical test values presented for example test sediments A, B, and C is purely for purposes of illustrating the

decisionmaking framework. The hypothetical test results presented in Tables 3-21 for sediments A, B, and C were interpreted according to the guidance in Appendixes A and B in order to arrive at the illustrative results that follow. *For this illustration the authors have assumed the role of the regional authority for all RADs and have made those decisions according to the initial approach discussed with regional authorities for the Commencement Bay area. This approach is discussed conceptually in paragraph 85 and described quantitatively at the appropriate points throughout the document. However, these illustrative RAD decisions should not be construed as implied guidance or precedents for actual RADs.*

Possible Commencement Bay area RAD

129. *Regional authorities for the Commencement Bay area have discussed a variety of potential goals for the environmental quality of Commencement Bay. One of the alternatives discussed was the goal of returning the bay to a cleaner environment as represented by relatively untouched areas of Puget Sound. For purposes of discussion and illustration in this report, the following interpretation of test results was based on this cleaner environment goal. Accordingly, regional authorities were assumed to have selected an example reference site from among the more pristine areas of Puget Sound. With this example goal, more dredged material will be found to exceed reference values by wider margins, and thus restrictions will be required in more cases than if a less pristine reference site were chosen. This may often result in increased costs to implement the restrictions, but will not necessarily provide increased environmental protection. This is due to the fact that a relatively pristine area may be able to accept a considerable increase in contaminants before adverse effects result, and small elevations above reference may not be environmentally important. On the other hand, a less pristine reference area may already be sufficiently contaminated to produce adverse results.*

Example Interpretation of Results-Aquatic Disposal of Sediment A

130. In the initial evaluation, the available information discussed in paragraph 14 is assembled and reviewed to decide whether it is adequate to conclude that there is no reason to believe the test material is contaminated.

Bulk chemical data would be specifically required in order to assist in this evaluation. If there is insufficient information to reach this conclusion or if there is information indicating there is reason to believe contaminants are present, then specific testing following the decisionmaking framework should be initiated.

131. Sediment A was hypothetically much more highly contaminated with metals than any other of the test sediments (Table 14). It was also considerably higher in sand-sized particles and lower in clay than the reference sediment. This is probably at the outer limits of similarity in grain sizes required for valid comparisons between test and reference sediments. These must be roughly similar in grain size for bulk chemical comparisons since contaminants are naturally higher and more tightly associated with clay than with sand. Therefore, a given contaminant concentration in clay is of less environmental concern than the same concentration would be in sand.

Water-column evaluation

132. Regional authorities proposed to place emphasis on effects as well as mass movement of contaminants. The implementation of this is illustrated in Figure 9. Hypothetically, the RAD might be that site- and sediment-specific water-column testing is warranted (paragraph A3) due to the unusually high concentrations of metals in sediment A.

133. Chemical evaluations. Hypothetically, the RAD might be to conduct a chemistry-based evaluation of the potential for water-column impacts paragraph A4) since water-quality criteria exist for most of the metals, which are the primary contaminants of concern in sediment A.

134. Chemical evaluation of contaminants for which acute water-quality criteria exist. Hypothetical elutriate test values (Table 3) for cadmium, copper, mercury, and zinc do not require restrictions (paragraph A6b). The hypothetical elutriate value for PCB requires a RAD (paragraph A6e). Hypothetically, the RAD for PCB might be for FURTHER EVALUATION by considering mixing, since there could be cause for high concern in relation to subparagraphs A7a and A7e. The mixing zone required to dilute the PCB in the discharge to the acute criterion at the aquatic disposal site (paragraphs 116 and 117) has the following characteristics (calculations on page D16):

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* Alphanumeric identification refers to similarly identified items in the appendixes.

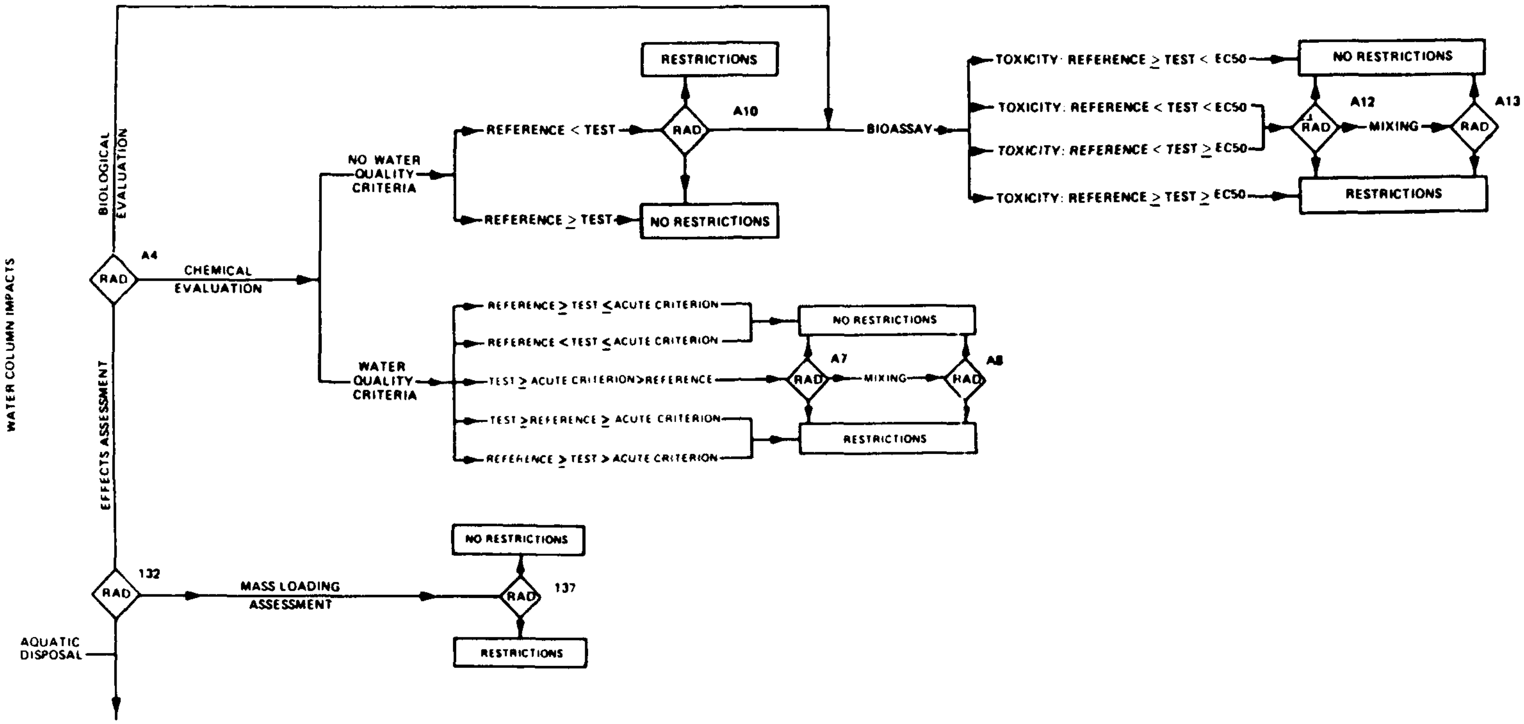

Figure 9. Flowchart for decisionmaking for aquatic disposal (number near RAD is paragraph discussing RAD)

a. Volume of 29,160 cu ft and surface area projection of 103,023 sq ft.

b. Plume 583 ft long by 190 ft wide parallel to shore.

c. Time to achieve dilution of 3.25 min.

d. One barge discharge every 3 hr around the clock.

e. Three-month dredging and disposal operation.

f. No municipal water intakes in Commencement Bay.

g. No potential drinking water aquifers recharge from Commencement Bay.

h. Low human water-contact activities in Commencement Bay.

i. Moderate to high recreational shellfishing along shore 1 mile away.

j. Year-round recreational bottom fishing at the site, seasonal drift netting of salmonids overlaps dredging by approximately 2 weeks.

k. Nearest major fish or shellfish spawning or nursery areas used during the operation are 6 miles away.

l. Salmonids migrate over site; migration overlaps dredging by approximately 2 weeks.

m. Nearest major discharge is sewage outfall 3 miles distant.

Hypothetically, the RAD might be that such a mixing zone is acceptable (paragraph A9a) in view of the considerations of paragraph 35. Therefore, the regional authorities might decide that there are NO RESTRICTIONS REQUIRED to protect against potential water column impacts of contaminants of concern for which water-quality criteria have been established.

135. Chemical evaluation of contaminants for which acute water-quality criteria do not exist. Hypothetical elutriate values (Table 3) for pyrene, benzo(a)pyrene, hexachlorobutadiene, hexachlorobenzene, and pentachlorophenol do not require restrictions (paragraph A11a). Hypothetical elutriate values for arsenic, lead, naphthalene, fluorene, phenanthrene, and fluoranthene require a RAD (paragraph A11b). Hypothetically, the RAD might be for FURTHER EVALUATION by conducting bioassays, since there was moderate concern in relation to subparagraphs A7a and e.

136. Biological evaluation. Hypothetical elutriate toxicity values (Tables 4 and 5) require a RAD for *Cymatogaster* (paragraph A14c), *Neomysis*, *Cancer*, and *Crassostrea* larvae (paragraph A14d). Hypothetically, the RAD might be that there are RESTRICTIONS REQUIRED by the bioassay results due to high concern in relation to subparagraphs A15a, b, and c.

137. Mass loading assessment (Figure 9). Mass loading for each contaminant in the water column can be calculated from the water-column chemical evaluation using chemical data for both filtered and unfiltered elutriate water samples. These calculations estimate the total amount of suspended solids and contaminants associated with them remaining in the water column during aquatic disposal operations. The percentage of total containment of sediment and associated contaminants at the aquatic disposal site can then be calculated. In addition, dispersion models might be used to predict the spread of suspended solids and associated contaminants into the aquatic environment surrounding the disposal site. After these calculations are made and the factors discussed under mixing zone in paragraph 35 are considered, the RAD might be that there are NO RESTRICTIONS REQUIRED. This may be appropriate in light of the considerations given in paragraph 134. The RAD, however, might be that there are RESTRICTIONS REQUIRED after consideration of paragraph 134 or from a purely administrative point of view. Some potentially appropriate restrictions are discussed in paragraphs 92 and 93.

138. The conclusion of the hypothetical water column assessment of paragraphs 134-137 is that there are RESTRICTIONS REQUIRED to prevent unacceptable adverse water-column impacts from discharging sediment A into the aquatic environment under the conditions evaluated. Some potentially appropriate restrictions are described in paragraphs 92 and 93.

Benthic evaluation

139. Chemistry and toxicity evaluations. Hypothetical sediment chemistry values for all contaminants of concern except hexachlorobutadiene (Table 14) and hypothetical *Grandifoxus* toxicity values (Table 6) indicate RESTRICTIONS REQUIRED (paragraph A20f) to prevent unacceptable adverse benthic impacts from discharging sediment A into the aquatic environment under the conditions evaluated. Some potentially appropriate restrictions are discussed in paragraphs 94-97. Since restrictions were required by this species, it was unnecessary to evaluate results for other species, nor was it necessary to evaluate bioaccumulation potential.

140. Mass loading assessment (Figure 10). Mass loading to the benthic environment for each contaminant can be calculated from the sediment chemistry data. These calculations might be useful as input into an inventory on the location and amount of contaminants in Commencement Bay for future reference. The implementation of mass loading assessment is illustrated in Figure 10.

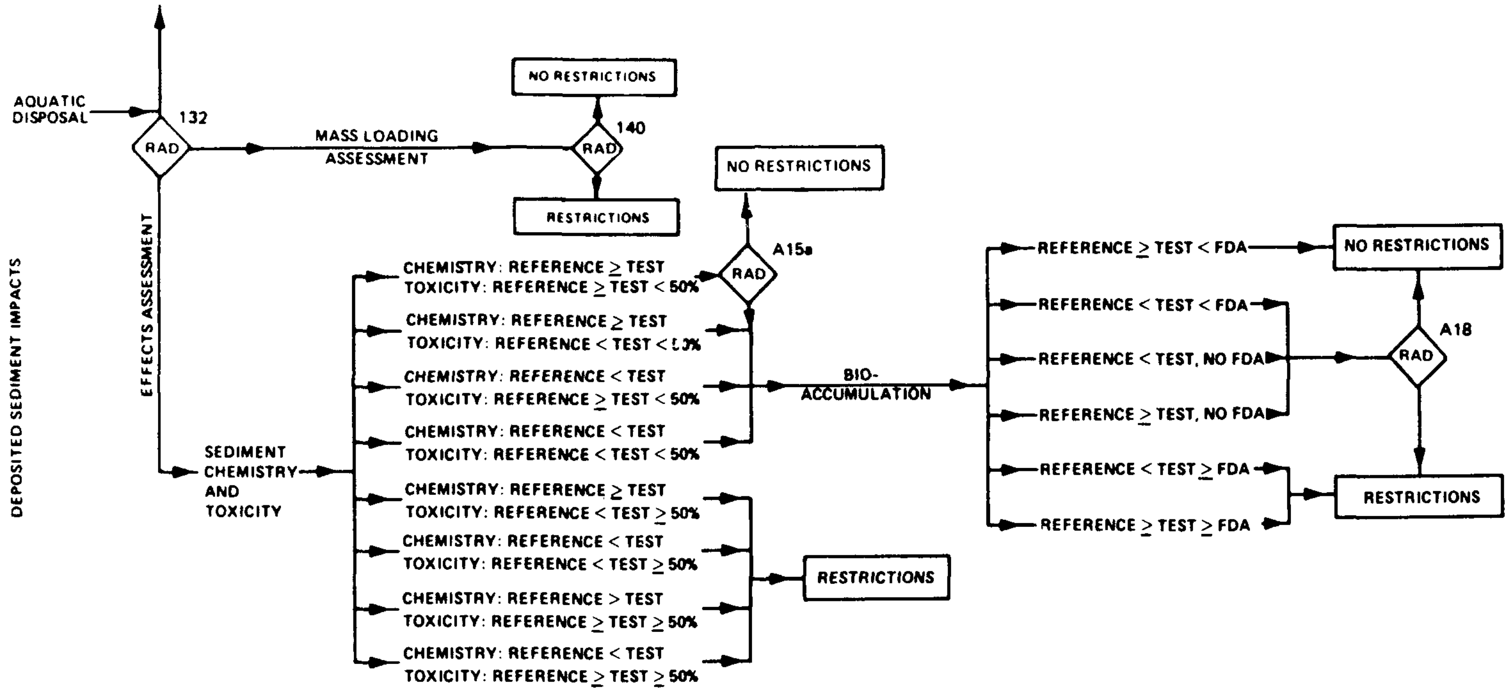

Figure 10. Flowchart for decisionmaking for Section 404 aquatic disposal benthic impacts with a mass loading assessment (number near RAD is paragraph discussing RAD). For Section 103 evaluations, 10-percent toxicity should be used.

The regional authorities will have to decide whether or not restrictions are required from a purely administrative point of view.

Overall conclusion

141. The conclusion of the hypothetical assessment of aquatic disposal in paragraphs 132-140 is that there are RESTRICTIONS REQUIRED to prevent unacceptable adverse water-column impacts, and there are RESTRICTIONS REQUIRED to prevent unacceptable adverse benthic impacts from discharging sediment A into the aquatic environment under the conditions evaluated.

Example Interpretation of Results-Upland Disposal of Sediment A

Effluent evaluation

142. Chemical evaluations. Hypothetically, the RAD might be to conduct a chemistry-based evaluation of the potential for effluent impacts (paragraph B4) since water-quality criteria exist for all but two of the metals, which are the primary contaminants of concern in sediment A.

143. Chemical evaluation of contaminants for which acute water-quality criteria exist. Hypothetical effluent test values (Table 12) for mercury do not require restrictions (paragraph B6b). Hypothetical results for cadmium, copper, zinc, and PCB require a RAD (paragraph B6e). Hypothetically, the RAD might be that there are RESTRICTIONS REQUIRED to prevent possible contaminant impacts of the effluent on the receiving water, since there could be cause for concern in relation to subparagraphs B7a, b, c, d, and e. Some potentially appropriate restrictions are discussed in paragraphs 98-110. Since restrictions were required by these test results, it is unnecessary to complete other effluent evaluations.

144. A potential RAD discussed was to also evaluate unfiltered effluent water quality (Figure 11). Since there are no water-quality criteria for unfiltered water, two evaluations are possible: a suspended solids bioassay and comparison to unfiltered reference water. A suspended solids bioassay might indicate potential contaminant impacts of effluent and surface runoff discharge from the upland disposal site. Comparison of test results with a suspended solids bioassay of the reference sediment should be made according to Figure 9. Discussion of the RADs for this figure is similar to that in paragraphs B12-B18.

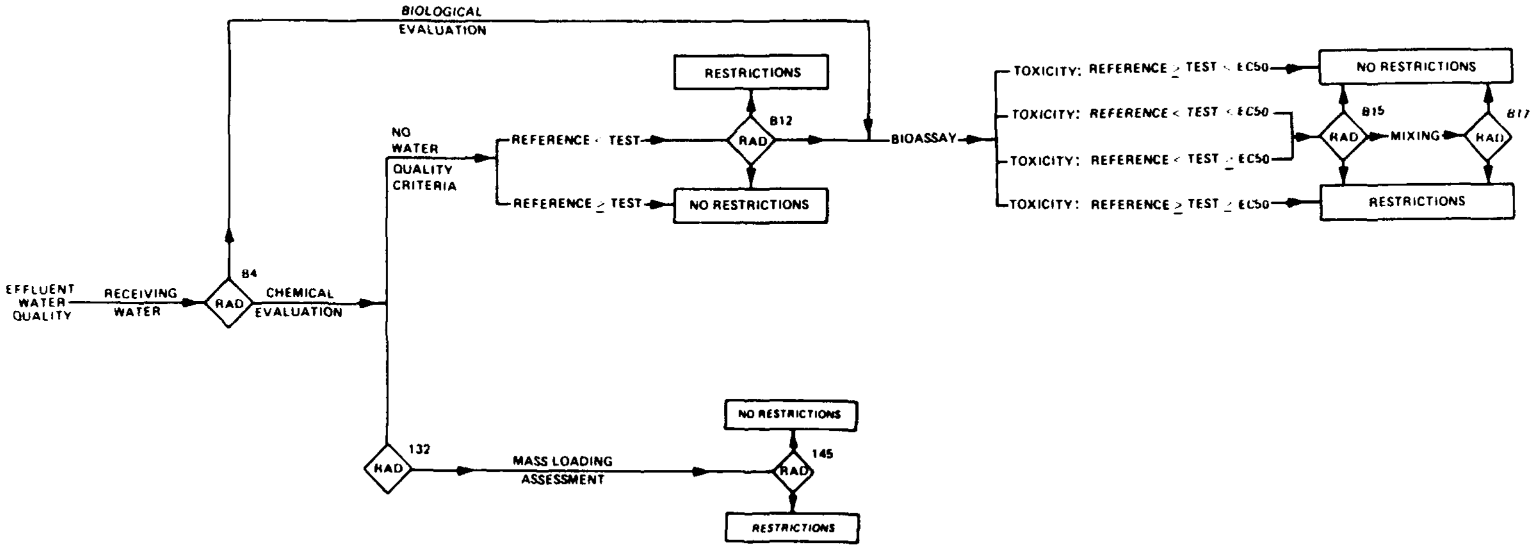

Figure 11. Flowchart for decisionmaking for unfiltered effluent water quality with mass loading assessment (number near RAD is paragraph discussing RAD)

145. Mass loading assessment (Figure 11). Mass loading for each contaminant in effluent discharge can be calculated from the modified elutriate test evaluation by using chemical data from an unfiltered modified elutriate water sample. These calculations estimate the total amount of suspended solids and associated contaminants discharged into the receiving water during upland disposal operations. The percentage of total containment of dredged material and associated contaminants in the upland disposal site can then be calculated. In addition, dispersion models might be used to predict the potential spread of suspended solids and associated contaminants into the aquatic environment receiving the effluent discharge. After these calculations are made and the factors discussed under mixing zone in paragraphs 35 and 36 are considered, the RAD might be that there are NO RESTRICTIONS REQUIRED. This may be appropriate in light of the considerations given in paragraph 35. The RAD, however, might be that there are RESTRICTIONS REQUIRED after consideration of paragraphs 35 and 36 or from a purely administrative point of view. This assessment was not necessary since restrictions were required in paragraph 143.

Surface runoff evaluation

146. Chemical evaluations. Hypothetically, the RAD might be to conduct a chemistry-based evaluation of the potential for surface runoff impacts (paragraph B19) since water-quality criteria exist for all but two of the metals that are the primary contaminants of concern in sediment A.

147. Chemical evaluation of contaminants for which acute water-quality criteria exist. Hypothetical surface runoff test values (Table 13) for cadmium, copper, mercury, zinc, and PCB require a RAD (paragraph B22e). Hypothetically, the RAD might be that there are RESTRICTIONS REQUIRED to prevent possible contaminant impacts of the surface runoff on the receiving water, since there would be cause for concern in relation to subparagraphs B22a, b, c, d, and e. Some potentially appropriate restrictions are discussed in paragraphs 98-109 and 111. Since restrictions were required by these test results, it is unnecessary to complete other surface runoff evaluations.

148. Mass loading assessment (Figure 12). Mass loading for each contaminant in surface runoff discharges can be calculated from the surface runoff test evaluation by using chemical data from an unfiltered runoff water sample. These calculations estimate the total amount of suspended solids and associated contaminants discharged into the receiving water during a storm

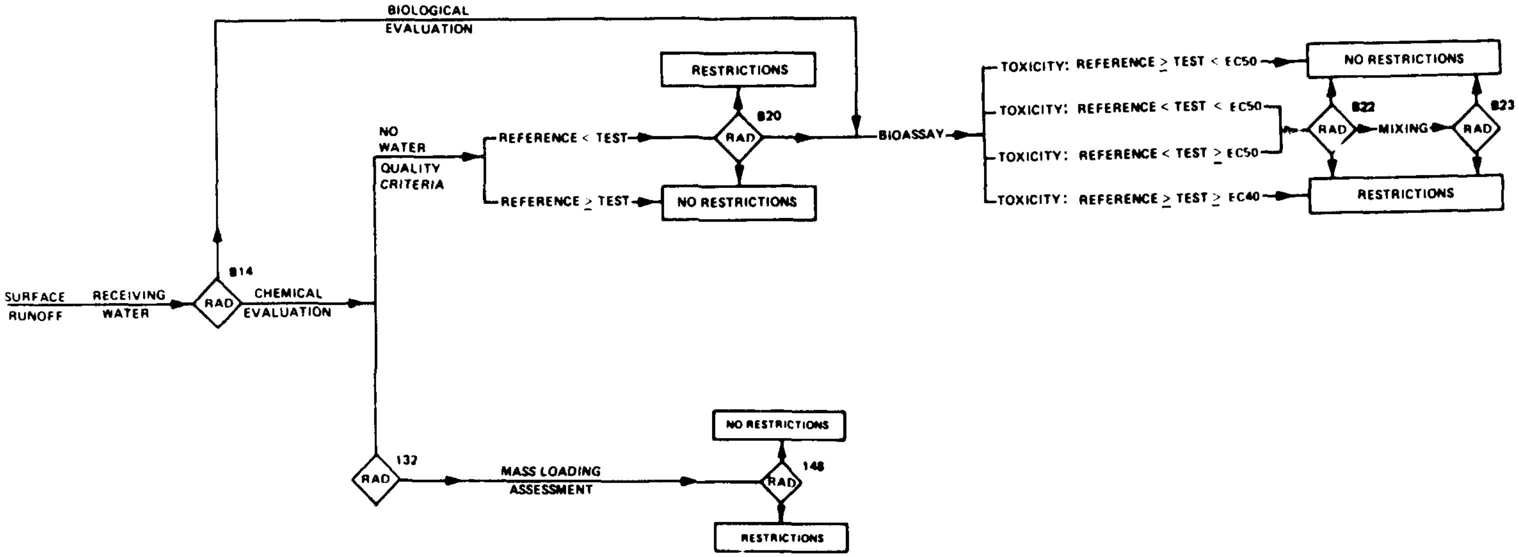

Figure 12. Flowchart for decisionmaking for unfiltered surface runoff water quality with mass loading assessment (number near RAD is paragraph discussing RAD)

event at the upland disposal site. The percentage of total containment of dredged material and associated contaminants in the upland disposal site can then be calculated. In addition, dispersion models might be used to predict the potential spread of suspended solids and associated contaminants into the aquatic environment receiving the surface runoff discharge. After these calculations are made and the factors discussed under mixing zone in paragraph 35 are considered, the RAD might be that there are NO RESTRICTIONS REQUIRED. This may be appropriate in light of the considerations given in paragraphs 35 and 36. The RAD, however, might be that there are RESTRICTIONS REQUIRED after consideration of paragraphs 35 and 36 or from a purely administrative point of view. This assessment was not necessary since restrictions were required in paragraph 147.

Leachate quality evaluation

149. The regional authority may choose to consider leachate quality in relation to drinking water since the area is suspected of being a recharge area for a shallow aquifer (paragraph 119). The RAD might be to conduct a leachate test due to the unusually higher concentration of metals in sediment A than in the reference sediment. Hypothetical test results (Table 15) indicate leachate concentrations of arsenic, cadmium, copper, lead, and mercury from sediment A that exceed the reference water and drinking water standards and therefore lead to a DECISION FOR RESTRICTIONS (paragraph B51c). In the case of a nonpotable ground water, the regional authority might consider potential water-column impacts (Figure B5) by following the approach discussed in paragraphs B55-60.

Plant uptake evaluation

150. Hypothetically, the RAD might be that a DTPA extraction test (paragraph 73) is warranted due to the unusually high concentrations of metals in sediment A. Hypothetical test results (Table 16) indicate a potential for plant uptake of cadmium, copper, lead, mercury, and zinc and lead to a DECISION FOR FURTHER EVALUATION (paragraph B66d) by conducting a plant growth bioassay (paragraphs 70 and 71).

151. Hypothetically, results of plant-growth (yield) bioassays (Table 17) lead to a REGIONAL AUTHORITY DECISION (paragraph B50b). The RAD might be a DECISION FOR FURTHER EVALUATION by evaluating a bioaccumulation on plant tissues from the growth bioassay (paragraph 71). Bioaccumulation results (Table 17) indicate plant uptake of cadmium and zinc above

demonstrated effect levels (Table C7) and cadmium above FDA-type levels (Table C10), which would lead to a DECISION FOR RESTRICTIONS (paragraph B52d). The RAD could have been to require restrictions rather than conduct a plant bioaccumulation evaluation.

Animal uptake evaluation

152. Hypothetically, the RAD might be that an animal uptake/bioassay test (paragraph 75) is warranted due to the unusually high concentrations of metals in sediment A. Hypothetical toxicity test results (Table 18) and bioaccumulation (Table 19) lead to a DECISION FOR RESTRICTIONS (paragraph B56a) and no further testing is required.

Human exposure evaluation

153. Hypothetically, concentrations of lead and mercury in sediment A (Table 14) exceed tabulated values for soil ingestion of lead and mercury (Tables C11 and C12) and therefore lead to a DECISION FOR RESTRICTIONS (paragraph B59b).

Example Interpretation of Results-Nearshore Disposal of Sediment A

154. The foregoing test results and decisions for upland disposal will apply equally well to the nearshore disposal site. An additional aspect that needs to be considered is the leachate quality of dredged material placed in the saturated zone of the nearshore site (Table 20). Sediment A will be discussed in relationship to the previous paragraphs.

155. Restrictions would be required for effluent discharge (paragraphs 142-145). Restrictions will also be required for surface runoff (paragraphs 146-148). Leachates from the upland portions of the site will require restrictions (paragraph 149). Hypothetical test results of sediment A leachate from the saturated zone (Table 20) indicate arsenic concentrations substantially greater than reference sediment concentrations and lead to a REGIONAL ADMINISTRATIVE DECISION (paragraph B30b). The regional authorities might choose to reach a DECISION FOR RESTRICTIONS due to sediment A leachate containing arsenic at a substantial margin above reference concentrations (paragraph B31). Restrictions would be required for sediment A for plant uptake concerns (paragraphs 150 and 151), animal uptake (paragraph 152), and human exposure (paragraph 153).

Example Interpretation of Results-Aquatic Disposal of Sediment B

Water-column evaluation

156. Hypothetically, the RAD might be that site- and sediment-specific water-column testing is warranted (paragraph A3).

157. Chemical evaluations. Hypothetically, the RAD might be that chemistry-based evaluations of the potential for water-column impacts are inappropriate (paragraph A4), due to concern over possible interactive effects of the multiple contaminants of concern (particularly several organics) hypothetically present in sediment B (Table 14). Therefore, a biological evaluation would be appropriate.

158. Biological evaluations. Hypothetical elutriate toxicity values (Tables 4 and 5) require a RAD for *Cymatogaster, Neomysis, Cancer,* and *Crassostrea* larvae (paragraph A11c). Hypothetically, the RAD might be that there are RESTRICTIONS REQUIRED by the bioassay results, since there could be cause for concern in relation to subparagraphs A12a, b, and c.

159. The conclusion of the hypothetical water-column assessment of paragraphs 156-158 is that there are RESTRICTIONS REQUIRED to prevent adverse water-column impacts from discharging sediment B into the aquatic environment under the conditions evaluated. Some potentially appropriate restrictions are described in paragraphs 92 and 93.

Benthic evaluation

160. Chemistry and toxicity evaluation. Hypothetical sediment chemistry values for all contaminants of concern (Table 14) and hypothetical *Pandalus, Macoma, Neanthes,* and *Parophrys* toxicity values (Table 7) and hypothetical *Grandifoxus* (Table 6) toxicity values require FURTHER EVALUATION by assessing the potential for bioaccumulation (paragraph A15c or d).

161. Bioaccumulation evaluation. Hypothetical contaminant concentration of arsenic, cadmium, and mercury in *Macoma* (Table 8), arsenic in *Pandalus* (Table 9), cadmium in *Neanthes* (Table 10), and arsenic, cadmium, and lead in *Parophrys* (Table 11) exceed FDA-type limits and indicate RESTRICTIONS REQUIRED (paragraph A17b) to prevent unacceptable adverse benthic impacts from discharging sediment B into the aquatic environment under the conditions evaluated. Some potentially appropriate restrictions are discussed in paragraphs 92 and 94-96. In practice, the bioaccumulation assessment can be halted as soon as one contaminant-species combination gives results requiring

restrictions; all were identified above for the sake of completeness for illustrative purposes.

Overall conclusion

162. The conclusion of the hypothetical assessment of aquatic disposal in paragraphs 156-161 is that there are RESTRICTIONS REQUIRED to prevent unacceptable adverse water-column impacts, and there are RESTRICTIONS REQUIRED to prevent unacceptable adverse benthic impacts from discharging sediment B into the aquatic environment under the conditions evaluated.

Example Interpretation of Results-Upland Disposal of Sediment B

Effluent evaluation

163. Chemical evaluation. Hypothetically, the RAD might be that chemistry-based evaluations of the potential for effluent impacts are inappropriate (paragraph B4) due to concern over possible interactive effects of multiple contaminants of concern (particularly several organic compounds) hypothetically present in sediment B (Table 14). Therefore, a biological evaluation would be appropriate.

164. Biological evaluation. Hypothetical effluent (modified elutriate) toxicity values (Table 21) require a RAD for *Cymatogaster, Neomysis, Cancer* larvae (paragraph B11c), and *Crassastrea* larvae (paragraph B11d). Hypothetically, the RAD might be for FURTHER EVALUATION by considering mixing, since there would be a cause for concern in relation to subparagraphs B12a, b, and c. When the mixing zone required to bring the discharge to less than the EC50 for *Crassostrea* (the species requiring the greatest dilution volume) at the upland disposal site is calculated (page D18), it has the following characteristics:

a. Volume of 13 cu ft/sec dilution water required.
b. Surface area projection negligibly small.
c. Plume length and width negligibly small.
d. Intermittent discharge with storms after completion of the dredging and disposal operation.
e. No municipal water intakes in Commencement Bay.
f. No potential drinking water aquifers recharge from the waterway or Commencement Bay.
g. No human water-contact activities in waterway, low activity in Commencement Bay.

h. Light recreational shellfishing along shore outside waterway about 3 miles away.

i. No fishing in waterway; year-round sport bottom fishing and seasonal drift netting of salmonids outside waterway about 3 miles away.

j. Nearest fish migration, spawning, or nursery area outside waterway about 5 miles away; migration overlaps dredging by approximately 2 weeks.

k. Major sewage and industrial discharges and nonpoint industrial runoff into nearby waterway.

Hypothetically, the RAD might be that such a mixing zone is acceptable (paragraph B13a) in view of the considerations of paragraph 35, and thus restrictions are not required by the bioassay results.

165. The conclusion of the hypothetical effluent (modified elutriate) assessment of paragraphs 163 and 164 is that there are NO RESTRICTIONS REQUIRED to prevent adverse impacts from the effluent of sediment B placed in the upland disposal site.

Surface runoff evaluation

166. Chemical evaluations. Hypothetically, the RAD might be to conduct a chemistry-based evaluation of the potential for surface runoff impacts (paragraph B14).

167. Chemical evaluation of contaminants for which acute water-quality criteria exist. Hypothetical surface runoff values (Table 13) for cadmium, mercury, and zinc do not require restrictions (paragraph B16b). The hypothetical surface runoff value for copper and PCB require a RAD (paragraph B16e). Hypothetically, the RAD might be for FURTHER EVALUATION by considering mixing, since there could be cause for concern in relation to subparagraphs B17b, c, d, and e. When the mixing zone required to dilute PCB (the contaminant of concern requiring the greatest dilution volume) in the discharge to the acute criterion at the upland disposal site (paragraphs 118 and 119) is calculated (page D19), it has the following characteristics:

a. Volume of 2,844 cu ft/sec dilution water required.

b. Surface area projection negligibly small.

c. Plume width 47 ft and length negligibly small.

d. Intermittent discharge with storms after completion of the dredging and disposal operation.

e. No municipal water intakes in Commencement Bay.

f. No potential drinking water aquifers recharge from the waterway or Commencement Bay.

g. No human water-contact activities in waterway, low activity in Commencement Bay.

h. Light recreational shellfishing along shore outside waterway about 3 miles away.

i. No fishing in waterway; year-round sport bottom fishing and seasonal drift netting of salmonids outside waterway about 3 miles away.

j. Nearest fish migration, spawning, or nursery area outside waterway about 5 miles away; migration overlaps dredging by approximately 2 weeks.

k. Major sewage and industrial discharges and nonpoint industrial runoff into nearby waterway.

Hypothetically, the RAD might be that such a mixing zone is acceptable (paragraph B18a) in view of the considerations of paragraph 35, and thus restrictions are not required by the results in relation to criteria.

168. Chemical evaluation of contaminants for which acute water-quality criteria do not exist. Hypothetical surface runoff values (Table 13) do not require restrictions for naphthalene, fluorene, phenanthrene, benzo(a)pyrene, hexachlorobutadiene, hexachlorobenzene, and pentachlorophenol (paragraph B19a). Hypothetical surface runoff values require a RAD for arsenic, lead, fluoranthene, and pyrene (paragraph B19b). Hypothetically, the RAD might be that restrictions are not required due to low concern in relation to subparagraphs B17a, c, and e. The conclusion of the hypothetical surface runoff assessments of paragraphs 166-168 is that there are NO RESTRICTIONS REQUIRED to prevent adverse impacts from the surface runoff of sediment B placed in the upland disposal site.

Leachate quality evaluation

169. The regional authority may choose to consider leachate quality in relation to drinking water since the area is suspected of being a recharge area for a shallow aquifer (paragraph 119). The RAD might be to conduct a leachate test due to the higher concentrations of metals in sediment B than in the reference sediment. Hypothetical test results (Table 15) indicate leachate concentrations of metals are greater than reference ground water and equal to or less than drinking water standards. Due to leachate cadmium concentration being equal to the drinking water standard, the regional authority may reach a DECISION FOR RESTRICTIONS (paragraph B35c).

Plant uptake evaluation

170. Hypothetically, the RAD might be that a DTPA extraction test (paragraph 72) is warranted due to the higher concentration of metals in sediment B than in the reference sediment. Hypothetical test results (Table 16) indicate a potential for plant uptake of cadmium, copper, lead, and zinc and lead to a DECISION FOR FURTHER EVALUATION (paragraph B48d) by conducting a plant bioassay (paragraphs 70 and 71).

171. Hypothetically, the plant bioassay results show growth (yield) (Table 17) that leads to a DECISION FOR FURTHER EVALUATION (paragraph B50a) by chemical analysis of plant tissue to assess bioaccumulation or plant content. Bioaccumulation or content results (Table 17) lead to a DECISION FOR RESTRICTION (paragraph B52f).

Animal uptake evaluation

172. Hypothetically, the RAD might be that an animal uptake/bioassay test (paragraph 75) is warranted due to the higher concentration of metals in sediment B than in the reference sediment. Hypothetical test results of 1-percent toxicity (Table 18) lead to a DECISION FOR FURTHER EVALUATION (paragraph B56b) by conducting a chemical analysis of earthworm tissues to evaluate bioaccumulation. Bioaccumulation results (Table 19) indicate animal contents for arsenic, cadmium, copper, lead, and zinc that exceed FDA-type limits (Table C1) and therefore lead to a DECISION FOR RESTRICTIONS (paragraph B57b).

Human exposure evaluation

173. Hypothetically, concentrations of metals in sediment B (Table 14) are less than tabulated values for soil-ingested metals (Tables C11 and C12) and therefore lead to a DECISION OF NO RESTRICTIONS (paragraph B59a).

Example Interpretation of Results-Nearshore Disposal of Sediment B

174. The foregoing test results and decisions for upland disposal will apply equally well to the nearshore disposal site. An additional aspect that needs to be considered is the leachate quality of dredged material placed in the saturated zone of the nearshore site (Table 20). Sediment B will be discussed in relationship to the previous paragraphs.

175. No restrictions would be required for effluent discharges (paragraphs 163-165). No restrictions would be required for surface runoff

discharge (paragraphs 166-168). Leachate for the upland portion of the site will require restrictions (paragraph 169). Hypothetical test results (Table 20) of sediment B leachate from the saturated zone indicate PCB concentrations substantially above the reference value and the chronic criterion. Therefore, these results lead to a DECISION FOR RESTRICTIONS (paragraph B27c). Restrictions would be required for plant uptake (paragraphs 170 and 171) and for animal uptake (paragraph 172). There would be no restrictions required for human exposure concerns (paragraph 173).

Example Interpretation of Results-Aquatic Disposal of Sediment C

Water-column evaluation

176. Hypothetically, the RAD might be that site- and sediment-specific water column testing is warranted (paragraph A3).

177. Chemical evaluation. Hypothetically, the RAD might be to conduct a chemistry-based evaluation of the potential for water-column impacts (paragraph A4) since water-quality criteria exist for many of the contaminants of concern present in highest concentrations.

178. Chemical evaluation of contaminants for which acute water-quality criteria exist. Hypothetical elutriate test values (Table 3) do not require restrictions for mercury (paragraph A6a), cadmium, copper, zinc, and PCB (paragraph A6b).

179. Chemical evaluation of contaminants for which acute water-quality criteria do not exist. Hypothetical elutriate test values (Table 3) for arsenic, naphthalene, fluorene, phenanthrene, fluoranthene, pyrene, benzo(a)pyrene, hexachlorbutadiene, hexachlorobenzene, and pentachlorophenol do not require restrictions (paragraph A9a). The hypothetical elutriate value for lead requires a RAD (paragraph A9b). Hypothetically, the RAD might be that restrictions are not required since there was low concern in relation to subparagraphs A7a, c, and e.

180. Biological evaluation. Biology-based evaluations were not originally selected (paragraph A4) and were not indicated by test results (paragraph A10).

181. The conclusion of the hypothetical water column assessment of paragraphs 176-179 is that there are NO RESTRICTIONS REQUIRED to prevent

unacceptable adverse water-column impacts from discharging sediment C into the aquatic environment under the conditions evaluated.

Benthic evaluation

182. Chemistry and toxicity evaluation. Hypothetical sediment chemistry values for all contaminants of concern (Table 14) and hypothetical *Pandalus*, *Macoma*, *Neanthes*, and *Parophrys* toxicity values (Table 7) and hypothetical *Grandifoxus* toxicity values (Table 6) require FURTHER EVALUATION by assessing the potential for bioaccumulation (subparagraphs A15c or d).

183. Bioaccumulation evaluation. Hypothetical concentrations of most contaminants of concern in tissues of *Macoma*, *Pandalus*, *Neanthes*, and *Parophrys* (Tables 8-11) require a RAD (subparagraphs A17d or e). Hypothetically, the RAD might be that restrictions are required due to high concern in relation to subparagraphs A18a, b, c, d, e, f, j, and l. Some potentially appropriate restrictions are described in paragraphs 92 and 94-96.

Overall conclusion

184. The conclusion of the hypothetical assessment of aquatic disposal in paragraphs 176-183 is that there are NO RESTRICTIONS REQUIRED to prevent adverse water-column impacts, and there are RESTRICTIONS REQUIRED to prevent unacceptable adverse benthic impacts from discharging sediment C into the aquatic environment under the conditions evaluated.

Example Interpretation of Results-Upland Disposal of Sediment C

Effluent evaluation

185. Chemical evaluation. Hypothetically, the RAD might be to conduct a chemistry-based evaluation of the potential for effluent impacts (paragraph B4) since water-quality criteria exist for many of the contaminants of concern present in the sediment in highest concentrations.

186. Chemical evaluation of contaminants for which acute water-quality criteria exist. Hypothetical effluent test values (Table 12) for cadmium and mercury (paragraph B6a) and zinc (paragraph B6b) do not require restrictions. Hypothetical effluent values require a RAD for copper and PCB (paragraph B6e). Hypothetically, the RAD might be for FURTHER EVALUATION by considering mixing due to some concern in relation to subparagraphs B7a, b, c, d, and e. The mixing zone required to dilute PCB (the contaminant of concern requiring the greatest dilution volume) in the discharge to the acute criterion at the

upland disposal site (paragraphs 118 and 119) has the following characteristics (calculations on page D22):

- a. Volume of 473 cu ft/sec dilution water required.
- b. Surface area projection is negligibly small.
- c. Plume 8 ft wide and of negligible length.
- d. Intermittent discharge with storms after completion of the dredging and disposal operation.
- e. No municipal water intakes in Commencement Bay.
- f. No potential drinking water aquifers recharge from the waterway or Commencement Bay.
- g. No human water-contact activities in waterway, low activity in Commencement Bay.
- h. Light recreational shellfishing along shore outside waterway about 3 miles away.
- i. No fishing in waterway; year-round sport bottom fishing and seasonal drift netting of salmonids outside waterway about 3 miles away.
- j. Nearest fish migration, spawning, or nursery area outside waterway about 5 miles away; migration overlaps dredging by approximately 2 weeks.
- k. Major sewage and industrial discharges and nonpoint industrial runoff into nearby waterway.

Hypothetically, the RAD might be that such a mixing zone is acceptable (paragraph B8a) in view of the considerations of paragraph 35, and thus restrictions are not required by the results in relation to criteria.

187. Chemical evaluation of contaminants for which acute water-quality criteria do not exist. Hypothetical effluent values (Table 12) for naphthalene, fluorene, phenanthrene, fluoranthene, pyrene, benzo(a)pyrene, hexachlorobutadiene, and hexachlorobenzene do not require restrictions (paragraph B9a). Hypothetical effluent values require a RAD for arsenic, lead, and pentachlorophenol (paragraph B9b). Hypothetically, the RAD might be for FURTHER EVALUATION by conducting bioassays due to moderate concern in relation to subparagraphs B7a, c, and e.

188. Biological evaluation. Hypothetical effluent (modified elutriate) toxicity values *Neomysis* and *Crassostrea* (Table 21) do not require restrictions (paragraph B11a). Results for *Cancer* require a RAD (paragraph B11c). Hypothetically, the RAD might be that restrictions are not required since there was low concern in relation to the factors in paragraph B12.

189. The conclusion of the hypothetical effluent (modified elutriate) assessment of paragraphs 185-188 is that there are NO RESTRICTIONS REQUIRED to prevent adverse impacts from the effluent of sediment C placed in the upland disposal site.

Surface runoff evaluation

190. Chemical evaluations. Hypothetically, the RAD might be to conduct a chemistry-based evaluation of the potential for surface runoff impacts (paragraph B14).

191. Chemical evaluation of contaminants for which acute water-quality criteria exist. Hypothetical surface runoff values (Table 13) do not require restrictions for cadmium, mercury, PCB (paragraph B16a), copper, and zinc (paragraph B16b).

192. Chemical evaluation of contaminants for which acute water-quality criteria do not exist. Hypothetical surface runoff values (Table 13) for arsenic, naphthalene, fluorene, phenanthrene, fluoranthene, pyrene, benzo(a)-pyrene, hexachlorobutadiene, hexachlorobenzene, and pentachlorophenol do not require restrictions (paragraph B19a). Hypothetical values require a RAD for lead (paragraph B19b). Hypothetically, the RAD might be that there are NO RESTRICTIONS REQUIRED (paragraph B20) since there is only low concern in relation to subparagraphs B17a and c.

Leachate quality evaluation

193. The regional authority may choose to consider leachate quality in relation to potable ground water since the area is suspected of being a recharge area for a shallow aquifer (paragraph 119). The RAD might be to conduct a leachate test due to the higher concentrations of metals in sediment C than in the reference sediment. Hypothetical test results (Table 15) indicate leachate concentrations of metals are greater than reference ground water and less than drinking water standards and therefore lead to a REGIONAL ADMINISTRATIVE DECISION (paragraph B35d). Hypothetically, the RAD might be a DECISION FOR NO RESTRICTIONS since four out of six metals exceeded reference standards (paragraph B36a), but only the level of zinc was 25 times the reference standard (paragraph B36c). Zinc is ranked first in toxicological importance and therefore of a low concern (paragraph B36c).

Plant uptake evaluation

194. Hypothetically, the RAD might be that a DTPA extraction test (paragraph 72) is warranted due to the higher concentrations of metals in

sediment C than the reference sediment. Hypothetical test results (Table 16) indicate a slight potential for plant uptake of cadmium, copper, lead, and zinc and lead to a DECISION FOR FURTHER EVALUATION (paragraph B48d). Hypothetically, plant yield results (Table 17) lead to a DECISION FOR FURTHER EVALUATION (paragraph B50a) by conducting a chemical analysis of plant tissues to evaluate bioaccumulation (paragraph B52). Bioaccumulation results (Table 17) indicate all tissue concentrations of contaminants of concern are equal to or less than the reference and demonstrated effects levels and lead to a DECISION OF NO RESTRICTIONS (paragraph B52a). In addition, the regional authorities should fully evaluate the potential for mass movement of contaminants into plants by considering total uptake, even though bioaccumulation was equal to or less than the reference. Total uptake of all contaminants of concern was less than that of the reference, which leads to a DECISION OF NO RESTRICTIONS (paragraph B54b).

Animal uptake evaluation

195. Hypothetically, the RAD might be that an animal uptake bioassay test is warranted (paragraph 75) due to the higher concentration of metals in sediment C than in the reference sediment. Hypothetical test results of 0 percent toxicity (Table 18) lead to a DECISION FOR FURTHER EVALUATION (paragraph B56b) by conducting a chemical analysis of earthworm tissues to evaluate bioaccumulation. Bioaccumulation results (Table 19) indicate animal contents for arsenic, cadmium, and lead that exceed FDA-type limits (Table C1) and therefore lead to a DECISION FOR RESTRICTIONS (paragraph B57b).

Human exposure evaluation

196. Hypothetically, concentrations of metals in sediment C (Table 14) are less than tabulated values for soil-ingested metals (Table C11) and therefore lead to a DECISION OF NO RESTRICTIONS (paragraph B59a).

Example Interpretation of Results-Nearshore Disposal of Sediment C

197. The foregoing test results and decisions for upland disposal will apply equally well to the nearshore disposal site. An additional aspect that needs to be considered is the leachate quality of dredged material placed in the saturated zone of the nearshore site (Table 20). Sediment C will be discussed in relationship to the previous paragraphs.

198. NO RESTRICTIONS would be required for effluent discharge (paragraphs 185-189) or for surface runoff discharges (paragraphs 190-192). NO RESTRICTIONS would be required for leachates from sediment C (paragraph 193) based on the hypothetical test results in Table 20. These latter test results would generally lead to a DECISION OF NO RESTRICTIONS (paragraph B27a). NO RESTRICTIONS would be required for plant uptake (paragraph 194). RESTRICTIONS on animal uptake would be required (paragraph 195). NO RESTRICTIONS would be required for human exposure (paragraph 196).

PART IV: SUMMARY

199. Part II of this document describes appropriate types of tests and the evaluation and interpretation of test results. These tests can be applied to <u>any</u> dredged material. Part III is a hypothetical example of the application of Part II to Commencement Bay, Washington, and is useful in conjunction with Part II to illustrate the actual mechanism of the decisionmaking process.

200. All of the comparisons made in the example Part III were based on a reference sediment or reference water representative of pristine background areas of Puget Sound in accordance with one possible goal being considered: that of returning Commencement Bay to a cleaner environment. Consequently, more dredged material will be found to exceed reference values by substantially wider margins and thus restrictions will be required in more cases than if a less pristine reference site were chosen.

201. A summary of the decisions reached using the example RADs discussed for disposal of sediments A, B, and C in aquatic, upland, and nearshore environments is presented in Table 22. These decisions resulted in the need for restrictions on disposal of sediment A in each of the three disposal environments; sediment B required restrictions in both upland and nearshore disposal environments while only needing restrictions for the benthic portion of the aquatic disposal site (no restrictions were required for the water-column portion); and sediment C required restrictions in the upland disposal environment for animal uptake and in the nearshore disposal environment for effluent water, leachate quality, and animal uptake, while only needing restrictions for the benthic portion of the aquatic disposal site. Hypothetical data were used for illustrating the actual implementation of the decisionmaking framework and should not be construed as factual. Actual data and test results for Commencement Bay sediments will no doubt give different conclusions than those presented in this report.

PART V: RECOMMENDATIONS

202. This document has been in continual evolution since its initiation and has been prepared on the basis of technically sound conceptual approaches. It requires a continuing thorough technical review, but it is suitable for initial use. Many of the issues evaluated require further consideration and possible refinement as the document is developed into a more comprehensive evaluation. Examples of some of these issues are listed below:

a. The appropriateness of developing additional quantitative guidance for acceptable contaminant concentrations in animal tissues from human health and biological impact perspectives should be examined. Initial bioaccumulation screening techniques based on partitioning theory should be further refined and incorporated where appropriate, and the potential for biomagnification should be considered in relation to both human health and environmental impacts. Evaluation of potential human health impacts based on FDA limits could be supplemented by a ranking of contaminants by their importance in mammalian toxicology, perhaps based on health tolerances and/or cancer risks. Assessment of potential biological impacts could be improved by tabulation of tissue contaminant concentrations in organisms from so-called "clean" sites worldwide and summarization of literature on biological effects associated with specific levels of tissue contamination.

b. The framework at present considers only chemical contaminant impacts. The same conceptual approach could be expanded to provide guidance on evaluation of the potential impacts of traditional parameters such as chemical oxygen demand (COD), etc.

c. Practical utility of the framework in interpreting all chemical evaluations is dependent upon, among other things, identification of a manageable number of contaminants of concern for each project. At present, identification of the appropriate contaminants remains largely a subjective matter. Additional guidance is needed for identifying appropriate contaminants of concern for a given project, perhaps considering such things as contaminants present, concentrations, toxicological importance, and bioavailability and mobility in the system in question.

d. Contaminants of concern must be analyzed with sufficient sensitivity to provide quantitation at concentrations of regulatory concern. The merits of specifying detection limits on the basis of (a) criteria or standards, (b) ability to quantitate clean reference materials, (c) technical attainability, and (d) routine availability should be considered and discussed. Different detection limits may be appropriate for different purposes or for different matrices (i.e., water, sediment, tissue) with the same contaminant.

e. Findings of ongoing research need to be incorporated into the decisionmaking framework. This would involve both quantitative test results and new insights regarding interpretation and evaluation of data. Programs such as the CE Research Program, CE/EPA FVP, EPA research on exposure and biological effects of in-place pollutants, other EPA research, and programs of other Federal and State agencies, particularly in the Puget Sound area, will provide useful input to the decisionmaking framework. The process of incorporation of findings of ongoing research must continue throughout the useful life of the document to keep it current.

f. Guidance on evaluating potential ground-water leachate should be reviewed and revised, if necessary, to ensure technical and regulatory compatibility with the proposed new EPA ground-water classification system when it is finalized.

g. The decisionmaking framework is dependent upon regional administrative decisions (RADs) whenever scientific understanding is insufficient to justify decisions on a technical basis alone. For this reason, quantitative guidance on reaching the RADs is difficult to provide and potentially controversial. Yet their importance necessitates the most complete and objective guidance possible. The guidance for making RADs needs to be made as complete, objective, and quantitative as possible.

h. Performance of all the tests required even for site-acceptability testing could exceed the cost of dredging for some small projects. Yet these projects could involve highly contaminated sediments. An effective means of adequately assessing potential environmental impacts of small projects without imposing prohibitive economic burdens needs to be identified.

i. The concept of tiered testing needs to be incorporated to a greater extent in the framework wherever possible. In this approach relatively simple procedures are used as screening tests, perhaps eliminating the need for more extensive testing. This could be part of a useful approach for small projects.

j. In order to document that the decisionmaking framework is, in fact, providing the degree of environmental protection expected of it, it is necessary to monitor the actual effects of discharge decisions reached by using the framework. These monitoring requirements and the interpretive guidance for evaluating the results will be generally similar to the testing and evaluation guidance in the decisionmaking framework. Monitoring and evaluative guidance need to be clearly described in an orderly fashion.

k. Although both aquatic and upland disposal operations can be designed and conducted so as to minimize transport of suspended particulates from the disposal site, it is inevitable that some particulate matter will leave the site. These particulates might conceptually be of concern if they were transported to and accumulated in appropriate areas such as beaches, spawning beds, etc.; if they concentrated contaminants to unacceptable levels in a depositional area away from the disposal site; or if there was a potential for particle-associated contaminants to impact the water column as they were being dispersed. Attention should be given to evaluation of the potential for impact by these routes.

l. The decisionmaking framework should be modified in the future, as appropriate, based on scientific and administrative experience with using it. The document has received technical review, and additional technical review at successive stages of its development is necessary. In addition, it should be used, perhaps in a dry-run sense, to evaluate several projects in order to identify problem areas and indicate potential improvements. The decisionmaking framework is intended to provide a useful first step with the full knowledge of the need for further technical and administrative refinement prior to actual implementation.

m. The decisionmaking framework should be modified in the future to include the concept of exposure assessment. At the present, the framework considers only biological effects in the biological component of the decisionmaking process. Inclusion of exposure assessment is needed to complete the risk-assessment capability of the decisionmaking framework.

n. The effects of bioaccumulation should be studied further and incorporated into the decisionmaking framework as part of the screening process.

o. Rapid, cost-effective screening tests need to be developed to address the problems of leaching and surface runoff from upland disposal sites. These protocols, once developed, should be incorporated into the decisionmaking framework as parts of the screening process.

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Table 1

Relative Time and Cost Estimates (1989 Dollars) for Conducting Test Protocols

Test Protocol	Time months	Cost/ Test Run* dollars	Number of Test Samples Analyzed	Cost of Chemical Analysis** dollars	Total Cost† dollars
Dissolved chemical analysis and mixing	2	150	6	6,000- 9,000	6,150- 9,150
Water-column bioassay and mixing	3	1,000-5,000	16		1,000- 5,000
Sediment comparison	2	150	8	8,000-12,000	8,150- 12,150
Benthic bioassay and bioaccumulation††	5	1,000-5,000	16	16,000-24,000	17,000- 29,000
Effluent quality	2	150	6	6,000- 9,000	6,150- 9,150
Runoff	6	5,000	15	15,000-22,500	20,000- 27,500
Leachate‡	12	30,000	50	50,000-75,000	80,000-105,000
Plant uptake (freshwater)‡‡	4	7,000	16	16,000-22,000	23,000- 29,000
(estuarine)	10	14,000	24	24,000-36,000	38,000- 50,000
Animal uptake§	4	5,000	12	12,000-18,000	17,000- 23,000

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* One sediment sample.

** Estimated cost for PCBs, pesticides, 10 metals, and suspended solids per analyzed sample ranged from $1,000 to $1,500.

† Does not include cost of equipment or facilities or sample collection and transport to lab.

†† Four species were used.

‡ Leaching test and serial batch tests are under development. Routine test cost will be lower.

‡‡ Plant bioassay of 45-day exposure (freshwater) and 120-day exposure (estuarine).

§ Earthworm bioassay of 28-day exposure.

Table 2

Detection Limits for a Preliminary List of Contaminants of Potential Concern in Commencement Bay*

Contaminants	Sediment mg/kg	Plant mg/kg	Animal mg/kg	Water µg/ℓ
Metals				
Ag	0.10	0.10	0.10	0.6
As	0.10	0.05	0.10	1.0
Be	0.50	0.50	0.50	5.0
Cd	0.01	0.01	0.01	0.1
Cr	0.10	0.05	0.10	1.0
Cu	0.10	0.10	0.10	1.0
Hg	0.10	0.10	0.10	0.2
Ni	0.30	0.05	0.30	3.0
Pb	0.10	0.10	0.10	0.1
Sb	0.50	0.50	0.50	5.0
Se	0.20	0.05	0.20	2.0
Tl	0.10	0.10	0.10	1.0
Zn	0.10	0.10	0.10	1.0
Volatiles				
Benzene**	0.05	NA	NA	10.0
Bromoform	↓	↓	↓	↓
Carbon tetrachloride				
Chloroform				
Chloroethane				
Chlorodibromomethane				
Dichloromethane				
Dichlorobromomethane				
Ethylbenzene**				
Formaldehyde				
Tetrachloroethane**				
1,1,1-Trichloroethylene				
Toluene				
1,1-Dichloroethane				
1,1-Dichloroethylene				
1,2-trans-Dichloroethylene				
Xylene**				
Base/Neutrals (except PCBs)				
Halogenated compounds				
Hexachloroethane	0.20	0.20	0.20	10.0

(Continued)

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* Priority pollutants and other significant substances detected in Commencement Bay sediments, waters, or point sources.

** Reported in waters but not in sediments (to date).

Reported only in point sources.

NA - Not applicable.

(Sheet 1 of 3)

Table 2 (Continued)

Contaminants	Sediment mg/kg	Plant mg/kg	Animal mg/kg	Water µg/ℓ
1,2-Dichlorobenzene	0.2	0.2	0.2	10
1,3-Dichlorobenzene	0.2	0.2	0.2	10
Base/Neutrals				
Halogenated compounds (Continued)				
1,4-Dichlorobenzene	0.2	0.2	0.2	10
1,2,4-Trichlorobenzene	↓	↓	↓	↓
2-Chloronaphthalene	↓	↓	↓	↓
Hexachlorobenzene	↓	↓	↓	↓
Hexachlorobutadiene	↓	↓	↓	↓
Misc. chlorinated butadienes**	↓	↓	↓	↓
Bis(2-chloroethyloxy) ether	↓	↓	↓	↓
Bis(2-chloroethyloxy) methane	↓	↓	↓	↓
Low molecular weight aromatics				
Azobenzene	0.2	0.2	0.2	10
Naphthalene	↓	↓	↓	↓
2-methylnaphthalene**	↓	↓	↓	↓
1-methylnaphthalene**	↓	↓	↓	↓
2,6-dimethylnaphthalene**	↓	↓	↓	↓
1,3-dimethylnaphthalene**	↓	↓	↓	↓
2,3-dimethylnaphthalene**	↓	↓	↓	↓
2,3,6-trimethylnaphthalene**	↓	↓	↓	↓
2,3,5-trimethylnaphthalene**	↓	↓	↓	↓
Acenaphthene	↓	↓	↓	↓
Acenaphthalene	↓	↓	↓	↓
Fluorene	↓	↓	↓	↓
Biphenyl**	↓	↓	↓	↓
Anthracene/phenanthrene	↓	↓	↓	↓
1-methylphenanthrene**	↓	↓	↓	↓
2-methylphenanthrene**	↓	↓	↓	↓
High molecular weight aromatics				
Fluoranthene	0.2	0.2	0.2	10
Pyrene	↓	↓	↓	↓
1-methylpyrene**	↓	↓	↓	↓
Benzo(a)anthracene	↓	↓	↓	↓
Chrysene/triphenylene	↓	↓	↓	↓
Dibenzo(a,h)anthracene	0.5	0.5	0.5	25
Benzofluoranthenes	0.2	0.2	0.2	10
Benzo(e)pyrene**	0.2	0.2	0.2	10
Benzo(a)pyrene	0.2	0.2	0.2	10
Indeno(1,2,3-cd)pyrene	0.5	0.5	0.5	25
Benzo(g,h,i)perylene	0.5	0.5	0.5	25

(Continued)

(Sheet 2 of 3)

Table 2 (Concluded)

Contaminants	Sediment mg/kg	Plant mg/kg	Animal mg/kg	Water µg/ℓ
Phthalate esters				
Diethylphthalate	0.2	0.2000	0.2000	10.000
Bis(2-ethylhexyl)phthalate	0.2	0.2000	0.2000	10.000
Base/Neutrals				
Phthalate esters				
Butylbenzylphthalate	0.2	0.2000	0.2000	10.000
Di-n-butylphthalate	↓	↓	↓	↓
Di-me-phthalate	↓	↓	↓	↓
Di-n-octylphthalate	↓	↓	↓	↓
Acid Extractables				
Cresol	0.5	0.5000	0.5000	25.000
Phenol	↓	↓	↓	↓
2-chlorophenol	↓	↓	↓	↓
2,4-dichlorophenol**	↓	↓	↓	↓
2,4,6-trichlorophenol	↓	↓	↓	↓
Pentachlorophenol	↓	↓	↓	↓
P-chloro-m-cresol	↓	↓	↓	↓
4-nitrophenol	↓	↓	↓	↓
Pesticides and PCBs				
A-chlordane	1.0	0.0010	0.0010	0.001
Aldrin	0.2	0.0002	0.0002	0.010
α-Hexachlorocyclohexane (HCH)*	↓	↓	↓	↓
β-HCH	↓	↓	↓	↓
γ-HCH (lindane)	↓	↓	↓	↓
4-4'-DDD	↓	↓	↓	↓
4,4'-DDE	↓	↓	↓	↓
4,4'-DDT	↓	↓	↓	↓
PCB-1242	2.0	0.0020	0.0020	0.010
PCB-1248	2.0	0.0020	0.0020	0.010
PCB-1254	2.0	0.0020	0.0020	0.010
PCB-1260	4.0	0.0040	0.0040	0.020
Miscellaneous substances				
Manganese (Mn)**	0.1	0.1000	0.1000	0.001
Molybdenum (Mo)**	0.1	0.0001	0.0001	0.001
A-endosulfan**	0.2	0.0002	0.0002	0.004
Cyanide**	1.0	1.0000	1.0000	1.000
Nitrosodiphenylamine	0.2	0.2000	0.2000	0.010

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* Hexachlorocyclohexane (HCH) is sometimes referred to elsewhere as BHC (benzene hexachloride), but this is a misnomer and is not used here.

(Sheet 3 of 3)

Table 3

Hypothetical Example of Concentrations of Dissolved Contaminants in Standard Elutriates of Three Puget Sound Sediments

Contaminants of Concern	Acute Criterion-Saltwater	Reference Site Water	Sediment A	Sediment B	Sediment C
As	--*	10.00	35.00	27.00	5.00
Cd	59.0	0.20	1.20	0.90	0.30
Cu	23.0	1.10	10.00	2.30	1.20
Pb	--	2.20	8.00	9.10	3.10
Hg	3.7	0.01	0.03	0.02	0.01
Zn	170.0	12.80	32.00	16.70	13.00
Base/neutrals					
Naphthalene	--	<1.00	3.00	2.00	<1.00
Fluorene	--	<1.00	3.00	2.00	<1.00
Phenanthrene	--	<1.00	2.00	1.00	<1.00
Fluoranthene	--	<1.00	1.00	<1.00	<1.00
Pyrene	--	<1.00	<1.00	<1.00	<1.00
Benzo(a)pyrene	--	<1.00	<1.00	<1.00	<1.00
Hexachlorobutadiene	--	<1.00	<1.00	<1.00	<1.00
Hexachlorobenzene	--	<1.00	<1.00	<1.00	<1.00
Acid extractable					
Pentachlorophenol	--	<1.00	<1.00	<1.00	<1.00
Pesticide fraction					
PCB (total)	0.030	0.005	0.04	0.03	0.02

Note: Values are in μg/ℓ.
* Criterion not established.

Table 4

Hypothetical Example of Toxicity of Elutriates of Three Puget Sound Sediments

Species	Treatment	Sediment A	Sediment B	Sediment C
Surf perch (*Cymatogaster aggregata* juveniles)	Control	0	0	0
	Reference site water	0	0	0
	10% elutriate	0	3	0
	50% elutriate	3	3	0
	100% elutriate	10	7	0
Mysid shrimp (*Neomysis americanus*)	Control	0	0	0
	Reference site water	0	3	0
	10% elutriate	10	3	0
	50% elutriate	55*	7	3
100% elutriate	72	12	0	
Dungeness crab (*Cancer magister* larvae)	Control	3	0	0
	Reference site water	7	0	3
	10% elutriate	7	0	3
	50% elutriate	42	18	7
	100% elutriate	81**	42	15

Note: Each treatment consisted of three replicates of 10 animals each. Values are mean percent mortality after 96 hr.

* 96-hr EC50 for mortality is 45-percent elutriate.

** 96-hr EC50 for mortality is 58-percent elutriate.

Table 5

Hypothetical Example of Toxicity of Elutriates of Three Puget Sound Sediments to Oyster Larvae (*Crassostrea gigas*)

Treatment	Sediment A	Sediment B	Sediment C
Control	0.5	2.9	2.0
Reference site water	4.7	5.8	3.2
10% elutriate	5.3	2.4	2.1
50% elutriate	32.9*	21.6	7.2
100% elutriate	69.6	39.0	21.3

Note: Values are mean percent abnormal larvae from two replicates per treatment after 48 hr.

* 48-hr EC50 for abnormality is 65-percent elutriate.

Table 6

Hypothetical Example of Toxicity of Deposits of Four Puget Sound Sediments to Amphipods *Grandifoxus grandis*

Treatment	Sediment			
	Reference	A	B	C
Control	0	0	0	0
Exposed	6	96	32	14

Note: Each treatment consisted of five replicates of 10 animals each. Values are mean percent mortality after 96 hr.

Table 7

Hypothetical Example of Toxicity of Deposits of Four Puget Sound Sediments to Four Benthic or Epibenthic Species

Species	Treatment	Sediment			
		Reference	A	B	C
Pandalus borealis	Control	0	0	0	1
	Exposed	0	15	5	0
Macoma balthica	Control	0	0	0	0
	Exposed	0	2	3	0
Neanthes arenaceodentata	Control	0	1	2	0
	Exposed	0	18	6	0
Parophrys vetulus (juvenile)	Control	0	0	0	0
	Exposed	1	2	1	0

Note: Each treatment consisted of five replicates of 20 animals each. Values are mean percent mortality after 10 days.

Table 8

Hypothetical Example of Contaminant Concentrations in Tissues of the Clam *Macoma balthica* Exposed to Deposits of Four Puget Sound Sediments for 30 Days

Contaminants of Concern	FDA Level*	Sediment			
		Reference	A	B	C
As	1.0	0.2300	23.370	8.870	0.317
Cd	1.0	0.0620	2.380	1.680	0.210
Cu	70.0	1.1100	7.770	3.110	0.950
Pb	2.5	0.6830	12.990	1.370	0.748
Hg	0.5	0.4780	7.100	0.790	0.281
Zn	150.0	16.6700	26.260	18.710	17.310
Base/neutrals					
Naphthalene	--**	0.0100	0.007	0.024	0.014
Fluorene	--	0.0003	0.011	0.014	0.083
Phenanthrene	--	0.0002	0.010	0.014	0.082
Fluoranthene	--	0.0005	0.010	0.015	0.080
Pyrene	--	0.0010	0.010	0.014	0.088
Benzo(a)pyrene	--	0.0001	0.013	0.009	0.005
Hexachlorobutadiene	--	0.0040	0.001	0.038	0.025
Hexachlorobenzene	--	0.0080	0.046	0.070	0.024
Acid extractable					
Pentachlorophenol	--	0.0010	0.006	0.008	0.014
Pesticides					
PCB (total)	2.0	0.0040	0.010	0.146	0.150

Note: Data are in µg/g on a whole body, wet weight basis.

* From Table C1.

** No value established.

Table 9

Hypothetical Example of Contaminant Concentrations in Tissues of the Shrimp *Pandalus borealis* Exposed to Deposits of Four Puget Sound Sediments for 30 Days

Contaminants of Concern	FDA Level*	Sediment			
		Reference	A	B	C
As	1.0	0.7100	8.620	1.630	0.270
Cd	--**	0.3500	2.380	0.165	0.017
Cu	10.0	8.7600	23.500	4.760	2.670
Pb	1.5	0.7980	6.420	0.619	0.581
Hg	0.5	0.0230	2.470	0.038	0.035
Zn	150.0	10.0900	9.410	9.990	11.270
Base/neutrals					
Naphthalene	--	0.0030	0.013	0.046	0.088
Fluorene	--	0.0010	0.021	0.027	0.047
Phenanthrene	--	0.0007	0.020	0.026	0.050
Fluoranthene	--	0.0010	0.020	0.029	0.057
Pyrene	--	0.0001	0.025	0.021	0.040
Benzo(a)pyrene	--	0.0002	0.025	0.020	0.041
Hexachlorobutadiene	--	0.0080	0.002	0.073	0.048
Hexachlorobenzene	--	0.1600	0.088	0.132	0.046
Acid extractable					
Pentachlorophenol	--	0.0030	0.008	0.015	0.026
Pesticides					
PCB (total)	2.0	0.0080	0.020	0.277	0.285

Note: Data are in µg/g on a whole body, wet weight basis.

* From Table C1.

** No value established.

Table 10

Hypothetical Example of Contaminant Concentrations in Tissues of the Polychaete Worm *Neanthes arenaceodentata* Exposed to Deposits of Four Puget Sound Sediments for 30 Days

Contaminants of Concern	FDA Level*	Sediment			
		Reference	A	B	C
As	1.0	0.3730	15.840	0.990	0.208
Cd	0.2	0.4500	6.420	0.780	0.180
Cu	10.0	7.8200	25.370	5.650	9.070
Pb	1.5	0.6200	13.270	0.970	0.960
Hg	0.5	0.1200	2.610	0.387	0.019
Zn	150.0	6.5800	18.630	5.620	9.940
Base/neutrals					
Naphthalene	--**	0.0060	0.009	0.030	0.017
Fluorene	--	0.0005	0.014	0.018	0.031
Phenanthrene	--	0.0005	0.013	0.017	0.030
Fluoranthene	--	0.0010	0.012	0.018	0.031
Pyrene	--	0.0010	0.013	0.020	0.370
Benzo(a)pyrene	--	0.0002	0.015	0.030	0.022
Hexachlorobutadiene	--	0.0060	0.001	0.048	0.031
Hexachlorobenzene	--	0.0100	0.058	0.097	0.030
Acid extractable					
Pentachlorophenol	--	0.0020	0.002	0.015	0.058
Pesticides					
PCB (total)	2.0	0.0050	0.013	0.182	0.018

Note: Data are in µg/g on a whole body, wet weight basis.

* From Table C1. See paragraph 27 for rationale for using these values with a nonfood type of organism.

** No value established.

Table 11

Hypothetical Example of Contaminant Concentrations in Tissues of the Juvenile English Sole *Parophrys vetulus* Exposed to Deposits of Four Puget Sound Sediments for 30 Days

Contaminants of Concern	FDA Level*	Sediment			
		Reference	A	B	C
As	1.0	0.1200	14.470	3.530	0.120
Cd	0.2	0.0260	7.810	1.980	0.070
Cu	10.0	1.8900	8.760	1.680	5.930
Pb	1.5	0.0860	18.160	1.830	1.150
Hg	1.0	0.0080	2.100	0.010	0.003
Zn	150.0	6.5500	12.540	5.260	7.020
Base/neutrals					
Naphthalene	--**	0.0030	0.018	0.061	0.035
Fluorene	--	0.0010	0.027	0.036	0.062
Phenanthrene	--	0.0007	0.028	0.038	0.060
Fluoranthene	--	0.0010	0.025	0.037	0.050
Pyrene	--	0.0005	0.030	0.020	0.060
Benzo(a)pyrene	--	0.0010	0.031	0.020	0.062
Hexachlorobutadiene	--	0.0110	0.003	0.096	0.063
Hexachlorobenzene	--	0.0210	0.116	0.174	0.060
Acid extractable					
Pentachlorophenol	--	0.0010	0.003	0.010	0.002
Pesticides					
PCB (total)	2.0	0.0100	0.260	0.364	0.375

Note: Data are in μg/g on a whole body, wet weight basis.

* From Table C1.

** No value established.

Table 12

Hypothetical Example of Concentrations of Dissolved Contaminants in Effluents of Confined Disposal Areas Containing Three Puget Sound Sediments

Contaminants of Concern	Acute Criterion-Saltwater	Reference Site Water	Sediment A	Sediment B	Sediment C
As	--*	3.20	525.00	70.00	25.00
Cd	59.000	1.60	180.00	80.00	1.50
Cu	23.000	2.10	1,800.00	120.00	28.00
Pb	--	1.50	380.00	12.00	6.00
Hg	3.700	<0.10	1.40	0.20	<0.10
Zn	170.000	10.00	2,000.00	130.00	42.00
Base/neutrals					
Naphthalene	--	<1.00	12.00	12.00	<1.00
Fluorene	--	<1.00	11.00	<1.00	<1.00
Phenanthrene	--	<1.00	<1.00	11.00	<1.00
Fluoranthene	--	<1.00	<1.00	<1.00	<1.00
Pyrene	--	<1.00	<1.00	11.00	<1.00
Benzo(a)pyrene	--	<1.00	<1.00	<1.00	<1.00
Hexachlorobutadiene	--	<1.00	<1.00	<1.00	<1.00
Hexachlorobenzene	--	<1.00	11.00	10.00	<1.00
Acid extractable					
Pentachlorophenol	--	<1.00	<1.00	<1.00	12.00
Pesticides					
PCB (total)	0.030	0.01	0.05	0.87	0.48

Note: Values are in μg/ℓ.
* Criterion not established.

Table 13

Hypothetical Example of Concentrations of Dissolved Contaminants in Surface Water Runoff of Confined Disposal Areas Containing Three Puget Sound Sediments

Contaminants of Concern	Acute Criterion-Saltwater	Reference Site Water	Sediment		
			A	B	C
As	--*	3.20	40.00	5.0	2.00
Cd	59.000	1.60	110.00	4.0	1.00
Cu	23.000	2.10	300.00	50.0	8.00
Pb	--	1.50	108.00	20.0	5.00
Hg	3.700	<0.10	10.00	1.0	<0.10
Zn	170.000	10.00	250.00	100.0	60.00
Base/neutrals					
Naphthalene	--	<1.00	<1.00	<1.0	<1.00
Fluorene	--	<1.00	<1.00	<1.0	<1.00
Phenanthrene	--	<1.00	<1.00	<1.0	<1.00
Fluoranthene	--	<1.00	<1.00	1.0	<1.00
Pyrene	--	<1.00	<1.00	1.0	<1.00
Benzo(a)pyrene	--	<1.00	<1.00	<1.0	<1.00
Hexachlorobutadiene	--	<1.00	<1.00	<1.0	<1.00
Hexachlorobenzene	--	<1.00	<1.00	<1.0	<1.00
Acid extractable					
Pentachlorophenol	--	<1.00	<1.00	<1.0	<1.00
Pesticides					
PCB (total)	0.030	0.01	0.05	0.5	<0.01

Note: Soil surface was dried to typical field moisture content prior to tests. Values are in μg/ℓ.

* Criterion not established.

Table 14

Hypothetical Example of Total or Bulk Contaminant Concentrations in Four Puget Sound Sediments

Contaminants of Concern	Sediment			
	Reference	A	B	C
As	5.500	9,700.000	90.000	14.000
Cd	0.240	184.000	3.600	1.600
Cu	54.000	11,400.000	239.000	115.000
Pb	10.000	6,250.000	181.000	81.000
Hg	0.100	52.000	0.500	0.180
Zn	50.800	3,320.000	242.000	107.000
Base/neutrals				
Naphthalene	0.029	0.540	1.012	0.350
Fluorene	0.007	0.835	0.600	0.625
Phenanthrene	0.070	0.760	1.210	0.600
Fluoranthene	0.030	0.870	12.250	1.500
Pyrene	0.065	1.350	8.800	0.150
Benzo(a)pyrene	0.060	1.050	6.190	0.190
Hexachlorobutadiene	0.029	0.025	0.480	0.180
Hexachlorobenzene	0.065	1.280	1.050	0.220
Acid extractable				
Pentachlorophenol	0.030	0.100	0.100	0.350
Pesticides				
PCB (total)	0.025	0.260	2.000	1.245
Sand, percent	30.000	66.700	20.200	38.700
Silt, percent	40.000	25.200	54.700	42.300
Clay, percent	30.000	7.800	25.100	19.000
TOC, percent	2.500	8.800	4.400	2.900

Note: Values are in mg/kg dry weight, except as otherwise indicated.

Table 15

Hypothetical Example of Concentrations of Dissolved Contaminants in Leachate of Confined Disposal Areas Containing Three Puget Sound Sediments

Contaminants of Concern	Chronic Criterion-Saltwater*	Drinking Water Standard**	Reference Water	Sediment		
				A	B	C
As	--	50	2.00	120.00	12.00	6.00
Cd	4.500	10	1.00	500.00	10.00	4.00
Cu	4.000	1,000	17.00	2,000.00	82.00	41.00
Pb	--	50	1.00	500.00	2.00	1.40
Hg	0.025	2	0.10	7.00	0.70	0.30
Zn	58.000	5,000	10.00	1,500.00	625.00	250.00
Base/neutrals						
Naphthalene	--†	--	<1.00	<1.00	12.00	<1.00
Fluorene	--	--	<1.00	<1.00	<1.00	<1.00
Phenanthrene	--	--	<1.00	<1.00	11.00	<1.00
Fluoranthene	--	--	<1.00	<1.00	15.00	12.00
Pyrene	--	--	<1.00	<1.00	11.00	<1.00
Benzo(a)pyrene	--	--	<1.00	<1.00	11.00	<1.00
Hexachlorobutadiene	--	--	<1.00	<1.00	<1.00	<1.00
Hexachlorobenzene	--	--	<1.00	<1.00	<1.00	<1.00
Acid extractable						
Pentachlorophenol	--	--	<1.00	<1.00	<1.00	<1.00
Pesticides						
PCB (total)	0.030	--	0.05	0.05	0.50	0.25

Note: Values are in μg/ℓ.
* Table C4.
** Table C6.
† Value not established.

Table 16

Hypothetical Example of DTPA-Extractable Metals from Four Puget Sound Sediments

Contaminants of Concern	Sediment							
	Reference		A		B		C	
	Saturated	Dried	Saturated	Dried	Saturated	Dried	Saturated	Dried
Cd	0.0024	0.0030	0.001	51.00	<0.0005	1.5100	0.0020	0.0120
Cu	<0.0250	0.6700	0.050	71.20	0.0400	39.6000	<0.0250	2.4100
Pb	0.0010	0.0012	0.910	388.00	9.7100	73.4000	0.7200	2.0100
Hg	<0.0010	0.0010	0.001	1.20	0.0010	0.0019	<0.0010	0.0014
Zn	0.0500	5.8000	0.100	954.00	0.3100	126.0000	0.2400	11.2000

Note: Values are in mg/kg dry weight.

Table 17

Hypothetical Example of Plant Growth, Tissue Content, and Total Uptake of Contaminants for Yellow Nutsedge, *Cyperus esculentus*, Grown in Four Puget Sound Sediments

Parameter of Concern	Effect Level*	Sediment											
		Reference			A			B			C		
		Yield	Content	Uptake	Yield	Content	Uptake	Yield	Content	Uptake	Yield	Content	Uptake
Growth		46			14			43			67		
As	--		0.041	2.00		1.450	20		0.380	16.00		0.030	2.00
Cd	8		1.050	48.00		21.050	295		5.320	229.00		0.710	47.00
Cu	20		2.540	117.00		9.510	133		4.410	203.00		1.700	113.00
Pb	--		1.580	73.00		4.100	57		1.800	77.00		1.050	70.00
Hg	--		0.010	0.50		0.900	13		0.016	0.70		0.008	0.50
Zn	200		81.000	3,726.00		290.000	4,060		90.000	3,870.00		54.100	3,625.00
Base/neutrals													
Naphthalene	--		< 0.080	< 4.00		< 0.080	< 1		< 0.080	< 3.00		< 0.080	< 5.00
Fluorene	--		< 0.080	< 4.00		< 0.080	< 1		< 0.080	< 3.00		< 0.080	< 5.00
Phenanthrene	--		< 0.080	< 4.00		< 0.080	< 1		< 0.080	< 3.00		< 0.080	< 5.00
Fluoranthene	--		< 0.080	< 4.00		< 0.080	< 1		< 0.080	< 3.00		< 0.080	< 5.00
Pyrene	--		< 0.080	< 4.00		< 0.080	< 1		< 0.080	< 3.00		< 0.080	< 5.00
Benzo(a)pyrene	--		< 0.080	< 4.00		< 0.080	< 1		< 0.080	< 3.00		< 0.080	< 5.00
Hexachlorobutadiene	--		< 0.080	< 4.00		< 0.080	< 1		< 0.080	< 3.00		< 0.080	< 5.00
Hexachlorobenzene	--		< 0.080	< 4.00		< 0.080	< 1		< 0.080	< 3.00		< 0.080	< 5.00
Acid extractable													
Pentachlorophenol	--		< 0.080	< 4.00		< 0.080	< 1		< 0.080	< 3.00		< 0.080	< 5.00
Pesticides													
PCB (total)	--		< 0.002	< 0.09		< 0.002	< 0.03		< 0.002	< 0.09		< 0.002	< 0.13

Note: Soil was maintained at typical field moisture content during plant growth. Values are on a dry-weight basis in g/pot for yield, µg/g for content, and µg/pot for uptake.

* Table C7.

Table 18

Hypothetical Example of Toxicity of Four Puget Sound Sediments to Earthworms, *Eisenia foetida*

	Sediment			
Treatment	Reference	A	B	C
Control	1	0	1	0
Exposed	0	98	1	0

Note: Soil was maintained at typical field moisture content during the test. Each treatment consisted of five replicates of 20 animals each. Values are mean percent mortality after 30 days.

Table 19

Hypothetical Example of Tissue Content of Contaminants for the Earthworm *Eisenia foetida* Exposed to Four Puget Sound Sediments for 30 Days

	Sediment* - Contaminant Uptake**		
Parameter of Concern	Reference	B	C
As	3.360	8.910	1.870
Cd	4.050	7.020	8.170
Cu	160.000	250.000	170.000
Pb	2.900	200.000	105.000
Hg	0.012	0.008	0.200
Zn	125.000	190.000	165.000
Base/neutrals			
Naphthalene	0.005	0.850	0.250
Fluorene	0.001	0.540	0.500
Phenanthrene	0.015	0.750	0.550
Fluoranthene	0.002	2.550	0.450
Pyrene	0.055	1.050	0.090
Benzo(a)pyrene	0.050	5.250	0.050
Hexachlorobutadiene	0.008	0.310	0.160
Hexachlorobenzene	0.050	0.650	0.210
Acid extractable			
Pentachlorophenol	0.060	0.090	0.080
Pesticides			
PCB (total)	0.050	0.320	0.350

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* Soil was maintained at typical field moisture content during the test. No bioaccumulation data are provided for sediment A because of toxicity and consequent loss of the earthworms.

** Values are expressed on a whole-body basis as µg/g dry weight.

Table 20

Hypothetical Example of Concentrations of Dissolved Contaminants in the Saturated Zone Leachate of a Nearshore Disposal Area Containing Three Puget Sound Sediments

Contaminants of Concern	Chronic Criterion-Saltwater*	Drinking Water Standard**	Reference Water	Sediment		
				A	B	C
As	--†	50	2.00	560.00	12.000	1.000
Cd	4.500	10	1.00	0.50	0.010	0.004
Cu	4.000	1,000	17.00	200.00	8.200	3.000
Pb	--	50	1.00	0.50	0.020	0.014
Hg	0.025	2	0.10	0.07	0.007	0.003
Zn	58.000	5,000	10.00	150.00	62.500	25.000
Base/neutrals						
Naphthalene	--	--	<1.00	<1.00	120.000	<1.000
Fluorene	--	--	<1.00	<1.00	10.000	<1.000
Phenanthrene	--	--	<1.00	<1.00	110.000	<1.000
Fluoranthene	--	--	<1.00	<1.00	150.000	12.000
Pyrene	--	--	<1.00	<1.00	11.000	<1.000
Benzo(a)pyrene	--	--	<1.00	<1.00	11.000	<1.000
Hexachlorobutadiene	--	--	<1.00	<1.00	10.000	<1.000
Hexachlorobenzene	--	--	<1.00	<1.00	10.000	<1.000
Acid extractable						
Pentachlorophenol	--	--	<1.00	<1.00	<1.000	<1.000
Pesticides						
PCB (total)	0.030	--	0.05	0.05	0.500	0.250

Note: Values are in μg/ℓ.
* Table C4.
** Table C6.
† Value not established.

Table 21

Hypothetical Example of Toxicity of Effluents (Modified Elutriates) of Three Puget Sound Sediments

Species	Treatment % Modified Elutriate	Reference Site Water	Sediment A	Sediment B	Sediment C
Surf perch (*Cymatogaster aggregata* juveniles)	0	0.0	0.0	0.0	0.0
	10	0.0	0.0	3.0	0.0
	50	1.0	13.0	6.0	1.0
	100	0.0	20.0	10.0	0.0
Mysid shrimp (*Neomysis americanus*)	0	0.0	0.0	0.0	0.0
	10	1.0	20.0	9.0	0.0
	50	1.0	65.0*	17.0	3.0
	100	3.0	83.0	22.0	0.0
Dungeness crab (*Cancer magister* larvae)	0	5.0	3.0	0.0	0.0
	10	0.0	7.0	4.0	3.0
	50	4.0	59.0**	28.0	7.0
	100	2.0	88.0	42.0	6.0
Oyster (*Crassostrea gigas* larvae)	0	2.1	1.6	2.9	1.8
	10	2.8	8.3	6.5	2.1
	50	4.4	58.4†	39.9	6.3
	100	6.4	91.2	68.2††	4.6

Note: Oyster data are mean percent abnormal larvae from two replicates per treatment after 48 hr. For other species, each treatment consisted of three replicates of 10 animals each. Values are mean percent mortality after 96 hr, or mean percent abnormality after 48 hr for oysters.

* 96-hr EC50 is 39-percent modified elutriate.

** 96-hr EC50 is 44-percent modified elutriate.

† 48-hr EC50 for abnormality is 45-percent modified elutriate.

†† 48-hr EC50 for abnormality is 55-percent modified elutriate.

Table 22

Summary of Tentative Commencement Bay Area RADs for Three Sediments and Three Potential Disposal Environments Using Hypothetical Test Results

Sediment	Potential Disposal Environment	Component	Tentative Decisions
A	Aquatic	Water column	Restrictions
		Benthic	Restrictions
	Upland	Effluent	Restrictions
		Runoff	Restrictions
		Leachate	Restrictions
		Plant uptake	Restrictions
		Animal uptake	Restrictions
		Human exposure	Restrictions
	Nearshore	Effluent	Restrictions
		Runoff	Restrictions
		Leachate	Restrictions
		Plant uptake	Restrictions
		Animal uptake	Restrictions
		Human exposure	Restrictions
B	Aquatic	Water Column	Restrictions
		Benthic	Restrictions
	Upland	Effluent	No restrictions
		Runoff	No restrictions
		Leachate	Restrictions
		Plant uptake	Restrictions
		Animal uptake	Restrictions
		Human exposure	No restrictions
	Nearshore	Effluent	No restrictions
		Runoff	No restrictions
		Leachate	Restrictions
		Plant uptake	Restrictions
		Animal uptake	Restrictions
		Human exposure	No restrictions
C	Aquatic	Water column	No restrictions
		Benthic	Restrictions
	Upland	Effluent	No restrictions
		Runoff	No restrictions
		Leachate	No restrictions
		Plant uptake	No restrictions
		Animal uptake	Restrictions
		Human exposure	No restrictions
	Nearshore	Effluent	Restrictions
		Runoff	No restrictions
		Leachate	Restrictions
		Plant uptake	No restrictions
		Animal uptake	Restrictions
		Human exposure.	No restrictions

APPENDIX A: DECISIONMAKING FRAMEWORK FOR AQUATIC DISPOSAL

CONTENTS

LIST OF FIGURES

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* NOTE: Alphanumeric identification of pages, paragraphs, and figures was used in the appendixes to distinguish them from the simple numbers used as identification in the main text. Thus references to simple numbers in the appendixes refer to similarly numbered items in the main text.

APPENDIX A: DECISIONMAKING FRAMEWORK FOR AQUATIC DISPOSAL

A1. Concerns about contaminant impacts from aquatic disposal have centered on short-term impacts in the water column during and immediately after disposal and on long-term impacts of the deposited sediment on the benthic environment after disposal. The tests appropriate for determining the possibility of these impacts occurring are different and are shown separately in Figures A1 and A2.

Water-Column Evaluation

A2. The possibility of water-column impacts of contaminants released by dredged material disposal has been recognized and intensively studied for years. These studies have included dredged material containing high concentrations of a wide variety of metals and organic contaminants discharged from hoppers, barges, and pipelines, and have included both laboratory and field investigations. *The overwhelming preponderance of evidence from these studies demonstrates no unacceptable adverse impacts on the water column from contaminants in dredged material* (Arimato and Feng 1983; Brannon 1978; Burks and Engler 1978; DeLoach and Waring 1984; Hirsch, DiSalvo, and Peddicord 1978; Stewart 1984; Sullivan and Hancock 1977; Sweeney 1977; Tatem and Johnson 1977; Tramontano and Bohlen 1984; US Army Engineer District, Buffalo 1983; Wright 1977 and 1978*). The most likely situations in which aquatic disposal may produce contaminant-associated impacts in the water column involve prolonged high volume discharges into small, poorly mixed water bodies or embayments. These make very poor disposal sites for reasons unrelated to contaminants and are very seldom proposed for such use.

A3. Studies such as those cited above do not prove that water-column impacts will not occur with aquatic disposal. However, they do indicate that such impacts are sufficiently unlikely that the regional authority must decide whether it is appropriate to divert funds for testing for potential water-column impacts in association with disposal in aquatic sites where rapid dispersion and dilution will occur. In many cases it will be possible to assess the potential for water-column impacts on the basis of previous water-column

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* References are listed at the end of the main text.

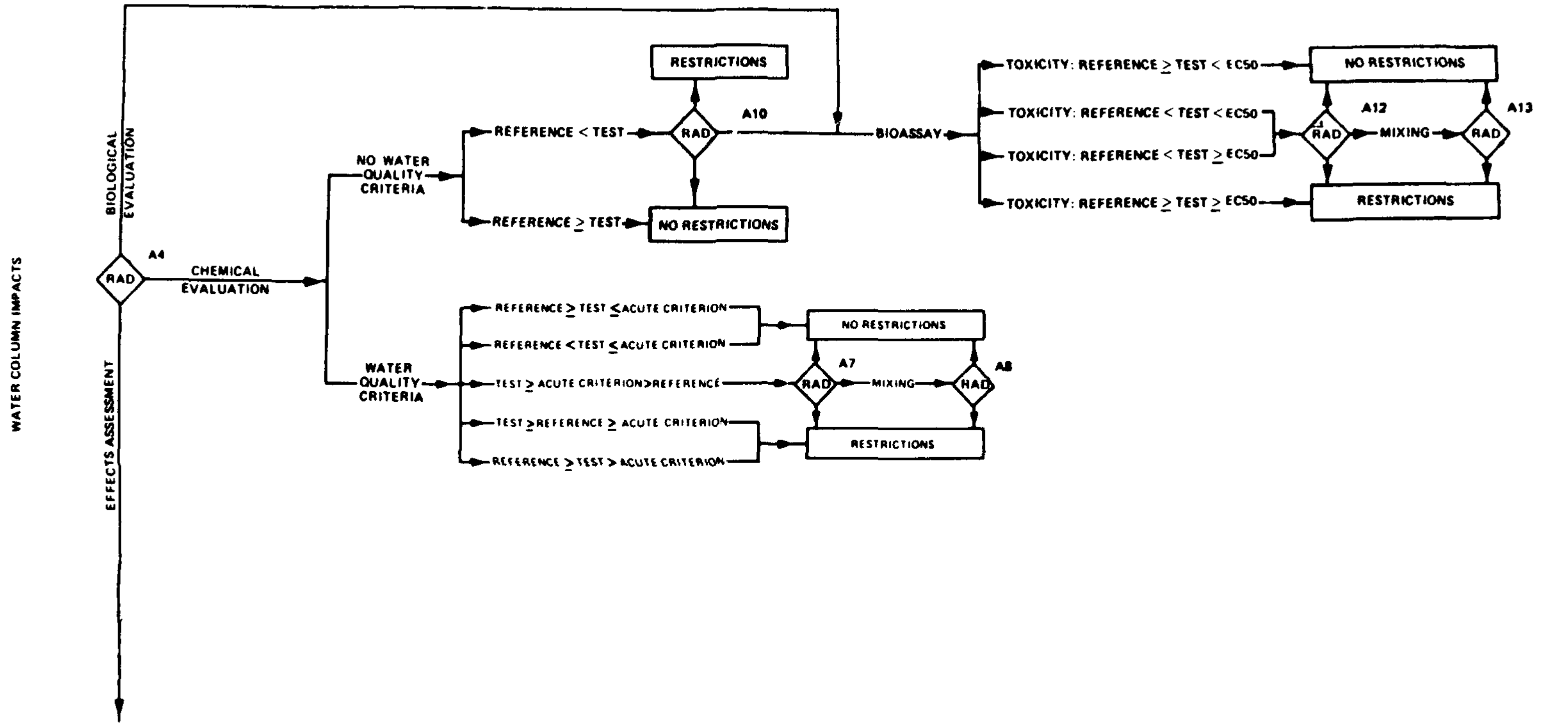

Figure A1. Flowchart for decisionmaking for aquatic disposal water-quality impacts (number near RAD (regional administrative decision) is paragraph discussing RAD)

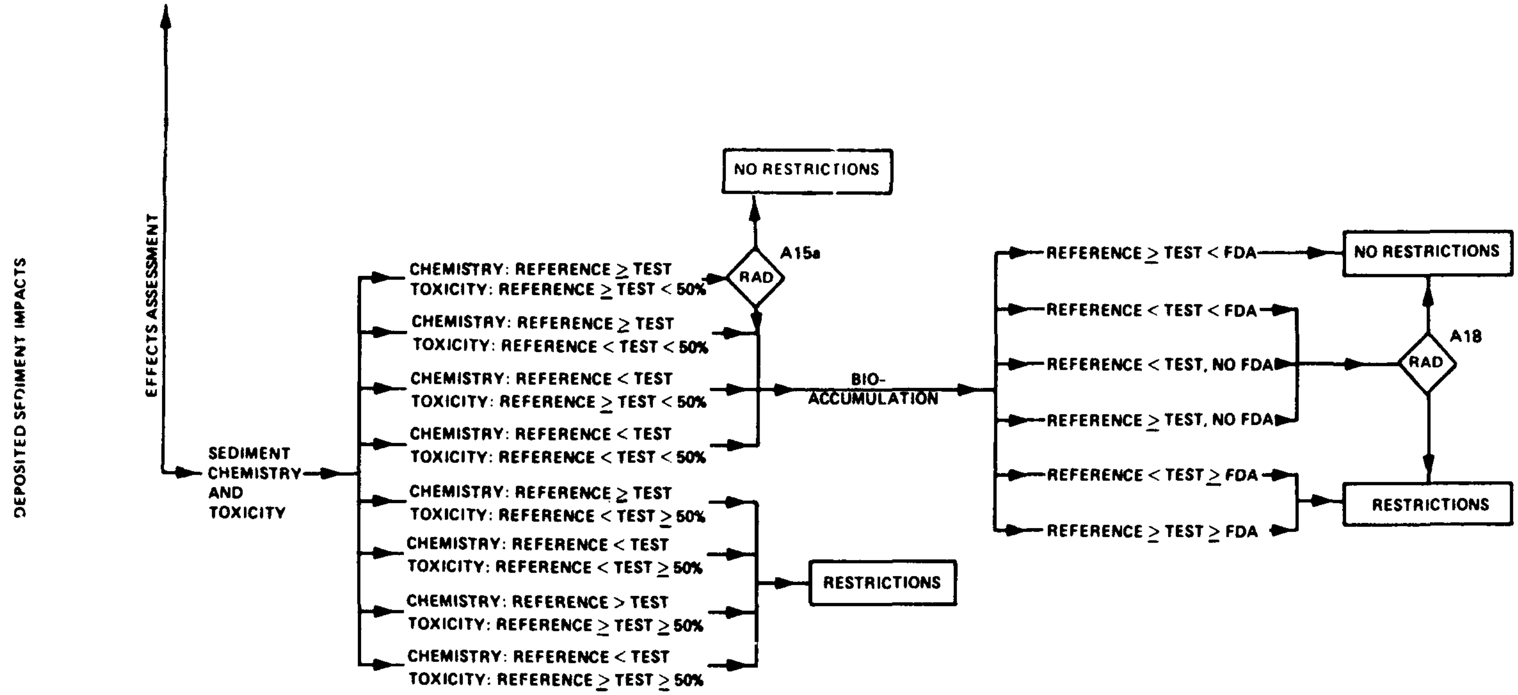

Figure A2. Flowchart for decisionmaking for aquatic disposal benthic impacts (number near RAD is paragraph discussing RAD) testing and characteristics of the disposal site without conducting additional sediment-specific testing.

A4. If the regional authority chooses to conduct additional tests to assess the potential for contaminant impacts in the water column, the procedures outlined in Figure A1 should be followed. Water-column evaluations are based on the standard elutriate (paragraph 29). However, the regional authority must decide whether to take a chemical- or biological-based approach to evaluating potential impacts on the water column. Chemical evaluations are appropriate when concern is primarily with chemicals for which water-quality criteria have been established (Table C4) and there is little concern about interactive effects of multiple contaminants. If the concern is primarily with chemicals for which water-quality criteria have not been established or if there is concern about interactive effects of multiple contaminants, a biological approach is preferred.

Phase 1 - Decisions from Chemical Evaluations

A5. Chemical analyses of the elutriate are evaluated in comparison to dissolved contaminant concentrations in reference water and to acute water-quality criteria for contaminants for which criteria exist (Table C4). Acute criteria are maximum concentrations that should not be exceeded and are appropriate because of the transient nature of dredged material contaminant releases to the water column. Contaminants for which criteria exist are evaluated separately from those for which criteria have not been established.

Water-quality criteria

A6. When acute water-quality criteria exist for the contaminants of concern, five conditions are possible (Figure A1):

a. Concentrations of all dissolved contaminants in the test water (elutriate) are *less than or equal to* the reference water and *less than or equal to* the acute water-quality criterion for each contaminant (Table C4).

b. Concentration of any dissolved contaminant in the test is *greater than* that in the reference water and *less than or equal to* the acute water-quality criterion (Table C4). Conditions a and b lead to a DECISION OF NO RESTRICTIONS required to protect against degradation of the water column beyond existing reference site conditions.

c. Concentration of any dissolved contaminant in the test is *less than or equal to* the reference water and *greater than* the acute water-quality criterion (Table C4).

d. Concentration of any dissolved contaminant in the test is *equal to or greater than* the reference water, and the reference water is *equal to or greater than* the acute water-quality criterion (Table C4).

Since dilution to the criterion cannot occur under conditions c and d (unless the receiving water for the discharge is not the reference water and is less than the criterion), they lead to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the water column due to the proposed discharge. Some potentially appropriate restrictions are described in paragraphs 92 and 93.

e. Concentration of any dissolved contaminant in the test is *equal to or greater than* the acute water-quality criterion (Table C4), and the reference water is *less than* the acute water-quality criterion.

Since dilution to the criterion can occur (if the receiving water for the discharge, which may or may not be the reference water, is less than the criterion), this leads to a REGIONAL ADMINISTRATIVE DECISION (RAD) as discussed in paragraph A7.

A7. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraph A6e, dilution will occur at the disposal site (if the receiving water for the discharge, which may or may not be the reference water, is less than the criterion). Therefore, mixing must be considered in order to scientifically assess the potential for water-column impacts to occur. However, in some cases, the regional authority may choose to reach a decision without considering mixing by assessing test results in light of the increasing concern about potential contaminant impacts in the water column in direct relation to the:

a. Number of contaminants (for which criteria have been established) exceeding reference concentrations.

b. Number of contaminants (with criteria) exceeding acute criteria.

c. Magnitude by which reference concentrations are exceeded.

d. Magnitude by which criteria are exceeded.

e. Toxicological importance of contaminants exceeding reference concentrations and/or acute criteria. Contaminants that can be objectively ranked in this manner are presented in Table C5.

f. Proportion of sediment sampling sites in the dredging area being evaluated that have elutriate exceeding reference concentrations and/or acute criteria. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

In the case of subparagraph A6e, the regional authority might choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount and are well below the acute criteria.* In addition to the preceding contaminant considerations, the discharge should also be subjectively assessed in light of the mixing considerations of paragraph 35 before a decision of no restrictions is reached. In the case of subparagraph A6e, the regional authority might also choose, without considering mixing, to reach a DECISION OF RESTRICTIONS required to protect against contaminant impacts in the water column. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference and the criteria by a substantial margin.* A decision for restrictions would be particularly appropriate in cases where the water at the disposal site already exceeded the criterion, making dilution to the criterion impossible. Some potentially appropriate restrictions are described in paragraphs 92 and 93. If the regional authority desires to fully evaluate the potential for water-column impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph A8.

A8. DECISION FOR FURTHER EVALUATION: CONSIDER MIXING. If the considerations of paragraph A7 lead to an evaluation of mixing, the regional authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to the water-quality criteria are acceptable. Mixing zone calculation is described in paragraphs 32-34 and Appendix D. *Note that mixing calculations must be based on the receiving water for the discharge, which may or may not be the reference water.* Mixing zone evaluation is discussed in paragraphs 35-36 and can result in:

a. A mixing zone of *acceptable* size and configuration within which the discharge will be diluted to *less than* the acute water-quality criterion (Table C4). Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph A7 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the water column.

b. The mixing zone within which the discharge will be diluted to less than the acute water-quality criterion (Table C4) is of *unacceptable* size and/or configuration. Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph A7 evaluated at the edge of the mixing zone. This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the water column. Some potentially appropriate restrictions are described in paragraphs 92 and 93.

No water-quality criteria

A9. When acute water-quality criteria do not exist for contaminant(s) of concern, two conditions are possible (Figure A1).

a. Concentrations of *all* dissolved contaminants of concern in the test water (elutriate) are *less than or equal to* the reference water. This leads to a DECISION OF NO RESTRICTIONS required to protect against degradation of the water column beyond existing reference site conditions.

b. Concentration of *any* dissolved contaminant in the test water is *greater* than in the reference water. This leads to a REGIONAL ADMINISTRATIVE DECISION.

A10. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraph A9b, the regional authority must decide whether to require bioassays. There is no basis for determining the environmental importance of a contaminant that exceeds the reference concentration unless bioassays are conducted. However, in some cases the regional authority could choose to reach a decision without conducting bioassays by assessing test results in light of the increasing concern about potential contaminant impacts in the water column in direct relation to the factors listed in paragraph A7. Regional authorities may wish to consider the lowest observable effects level (LOEL) as a pseudocriterion applicable for contaminants lacking water-quality criteria. The LOEL is available for many compounds for which there are insufficient data to develop criteria (Table C4). The regional authority could reach a DECISION FOR RESTRICTIONS if the concentrations of any contaminants of concern in the test water were equal to or greater than the LOEL for that contaminant. If the concentrations of all contaminants of concern in the test water were below the LOEL for the respective contaminants, the regional authority might reach a DECISION FOR FURTHER EVALUATION to conduct a bioassay. In the case of subparagraph A11b, the regional authority might choose, without conducting bioassays, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column. *This may be appropriate* *if samples from only a few sites have a small number of contaminants exceeding the reference by a small amount.* Since there are no criteria, if bioassays are not considered necessary on the above basis, there is no "target concentration" for a mixing calculation. However, in addition to the contaminant considerations of paragraph A7, the discharge should also be subjectively assessed in light of the mixing considerations of paragraph 35 before a DECISION OF NO RESTRICTIONS is reached. On the other hand, the regional authority might choose, without conducting bioassays, to reach a DECISION FOR RESTRICTIONS *if samples from a number of sites have several contaminants exceeding the reference by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 92 and 93. If the regional authority desires to fully evaluate the potential for water column impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by conducting bioassays as evaluated in paragraph A14. This will determine the effects of exceeding the reference for short periods and will indicate possible interactive effects of multiple contaminants.

Phase 2 - Decisions from Biological Evaluations

A11. From this point on, the evaluation of potential water column impacts is biological. It is at this point that testing begins if a biological approach is initially chosen in paragraph A4 (Figure A1). Water-column bioassays can result in four possible conditions:

a. Toxicity of the test water (elutriate) to all species is *less than or equal to* the reference water and *less than* the EC50 (i.e., 50-percent toxicity is not reached in the test water). This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column.

b. Toxicity of the test water to any species is *less than or equal to* the reference water and *equal to or greater than* the EC50 (i.e., at least 50-percent toxicity is reached in the test water). This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the water column. Some potentially appropriate restrictions are described in paragraphs 92 and 93.

c. Toxicity of the test water to any species is *greater than* the reference water and *less than* the EC50.

d. Toxicity of the test water to any species is *greater than* the reference water and *equal to or greater than* the EC50. (Therefore, dilution to the EC50 is possible if the receiving water for the discharge, which may or may not be the reference water, is less than the EC50.)

Conditions c and d lead to a REGIONAL ADMINISTRATIVE DECISION.

A12. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraphs A11c or d, dilution will occur at the disposal site (if the receiving water for the discharge, which may or may not be the reference water, is less than the EC50). Therefore, mixing must be considered in order to scientifically assess the potential for water-column impacts to occur. However, in some cases the regional authority could choose to reach a decision without considering mixing by assessing test results in light of the increasing concern about potential contaminant impacts in the water column in direct relation to the:

a. Number of species bioassayed with the elutriate with toxicity exceeding reference toxicity.

b. Magnitude of test toxicity.

c. Magnitude by which reference toxicity is exceeded.

d. Proportion of sediment sampling sites in the dredging area being evaluated that have elutriates whose toxicity exceeds reference toxicity. (If a single composite sample from the dredging area is bioassayed, this factor drops from consideration.)

In the case of subparagraph A11c, the regional authority might choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column. *This may be appropriate if samples from only a few sites are toxic to a low number of species and the toxicity only slightly exceeds reference toxicity and is well below the EC50.* In the case of subparagraph A11d, the regional authority might choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the water column. *This may be appropriate if samples from a number of sites are toxic to several species and the toxicity exceeds the reference toxicity and 50 percent by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 92-97. If the regional authority desires to fully evaluate the potential for water-column impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph A13.

A13. DECISION FOR FURTHER EVALUATION: CONSIDER MIXING. If the considerations of paragraph A12 lead to an evaluation of mixing, the regional authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to less than the EC50 concentration are acceptable. Mixing zone calculation is described in paragraphs 32-34 and Appendix D. *Note that mixing calculations must be based on the receiving water from the discharge, which may or may not be the reference water.* Mixing zone evaluation is discussed in paragraphs 35-36 and can result in:

a. A mixing zone of *acceptable* size and configuration within which the discharge will be diluted to less than the EC50. Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph A12 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the water column. (In the case of subparagraph A11c, the EC50 is not exceeded even without consideration of mixing, but if desired, the mixing zone to dilute to some lower value, such as EC20, can be calculated.)

b. A mixing zone (within which the discharge will be diluted to less than the EC50) that is of *unacceptable* size and/or configuration. Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph A12 evaluated at the edge of the mixing zone. This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the water column. Some potentially appropriate restrictions are described in paragraphs 92 and 93.

Benthic Evaluation

A14. A thorough assessment of potential impacts should include both chemical and biological evaluation of the material in question. This is accomplished in the water-column evaluation by comparing chemical concentrations to biologically derived water-quality criteria. However, in the case of nondissolved contaminants associated with deposited sediment, no biological-based criteria are available for evaluating sediment chemistry data. Therefore, chemical and biological data derived from the same sediment sample must be evaluated in conjunction with each other in order to arrive at an adequate assessment of potential impacts on the benthic environment (Figure A2). This is accomplished by using a bulk or total sediment analysis for the specific contaminants of concern identified for that particular sediment and a toxicity test of the whole sediment (paragraphs 41 and 42).

Phase 1 - Decisions from Chemistry and Toxicity Evaluations

A15. Chemical analyses of the test sediment are compared to similar analyses of a sedimentologically similar reference sediment. Toxicity of the test sediment is statistically compared to toxicity of the same reference sediment to the same appropriately sensitive aquatic organisms. Benthic chemistry and toxicity tests can result in eight possible combinations:

a. Concentrations of *all* contaminants of concern in the test sediment are *less than or equal to* those in the reference sediment, and toxicity of the test sediment to all species is *less than or equal to* the reference and *less than* 50 percentage points above the control.* This leads to a REGIONAL ADMINISTRATIVE DECISION. The RAD might be NO RESTRICTIONS. This may be appropriate if concentrations of all contaminants of concern in the test sediment were considerably *less than* the reference, and toxicity of the test sediment to all species was considerably *less than* the reference. The RAD might be a DECISION FOR FURTHER EVALUATION by assessing the potential for bioaccumulation as discussed in paragraph A17. This might be appropriate if concentrations of all contaminants of concern and toxicity to all species equal the reference.

b. Concentrations of *any* contaminant of concern in the test sediment are *less than or equal to* the reference sediment, and toxicity of the test sediment to any species is *greater than* the reference and *less than* 50 percentage points above the control,* or

c. Concentrations of *any* contaminant of concern in the test sediment are *greater than* the reference sediment, and toxicity of the test sediment to any species is *less than or equal to* the reference sediment and *less than* 50 percentage points above the control,* or

d. Concentrations of *any* contaminant of concern in the test sediment are *greater than* the reference sediment, and toxicity of the test sediment to any species is *greater than* the reference sediment and *less than* 50 percentage points above the control.

Conditions b, c, and d lead to a DECISION FOR FURTHER EVALUATION by assessing the potential for bioaccumulation of the contaminants of concern from the test sediment (Figure A2), as discussed in paragraph A17.

e. Concentrations of *any* contaminant of concern in the test sediment are *less than or equal to* the reference sediment, and toxicity of the test sediment to any species is *greater than*

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* For example, if 9 of 100 control animals (9 percent) show toxicity, then at least 59 of 100 test animals (59 percent) would have to show toxicity in order for toxicity of the test sediment to be 50 percentage points above the control.

the reference and *equal to or greater* than 50 percentage points above the control, or

f. Concentrations of *any* contaminant of concern in the test sediment are *greater than* the reference sediment, and toxicity of the test sediment to any species is *greater than* the reference and *equal to or greater* than 50 percentage points above the control, or

g. Concentrations of *any* contaminant of concern in the test sediment are *less than or equal to* the reference sediment, and toxicity of the test sediment to any species is *less than or equal to* the reference sediment and *equal to or greater than* 50 percentage points above the control, or

h. Concentrations of *any* contaminant of concern in the test sediment are *greater than* the reference sediment, and toxicity of the test sediment to any species is *less than or equal to* the reference sediment and *equal to or greater than* 50 percentage points above the control.

Conditions e, f, g, and h lead to a DECISION FOR RESTRICTIONS required to protect against possible contaminant degradation of the benthic environment beyond existing reference site conditions. Some potentially appropriate restrictions are described in paragraphs 95-97.

Phase 2 - Decisions from Bioaccumulation Evaluations

A16. The thermodynamically defined bioaccumulation potential (TBP) calculations (paragraph 39) may be used as a screen for the need to conduct bioaccumulation tests for persistent neutral organics such as polychlorinated biphenyls (PCBs), organochlorine pesticides, or polynuclear aromatic hydrocarbons (PAHs). TBP calculations can result in six conditions:

a. Maximum potential concentrations (TBP) of *all* neutral organic contaminants of concern in the tissues of *any* species if exposed to the test sediment are *less than or equal to* TBP calculated for the reference sediment and *less than* US Food and Drug Administration (FDA)-type limits (Table C1). This leads to a DECISION OF NO RESTRICTIONS required to protect against impacts due to these organic contaminants of concern in sediment deposits.

b. Maximum potential concentration (TBP) of *all* neutral organic contaminants of concern in the tissues of *any* species if exposed to the test sediment are *greater than* TBP calculated for the reference sediment and *equal to or greater than* FDA-type limits (Table C1).

c. Maximum potential concentrations (TBP) of *all* neutral organic contaminants of concern in the tissues of *any* species if exposed to the test sediment are *less than or equal to* TBP calculated for the reference sediment and *equal to or greater than* FDA-type limits (Table C1).

d. Maximum potential concentrations (TBP) of *all* neutral organic contaminants of concern in the tissues of *any* species if exposed to the test sediment are *greater than* TBP calculated for reference sediment and *less than* FDA-type limits (Table C1).

e. Maximum potential concentrations (TBP) of *all* neutral organic contaminants of concern in the tissues of *any* species if exposed to the test sediment are *greater than* TBP calculated for reference sediments and *no FDA-type limits have been established* (Table C1).

f. Maximum potential concentrations (TBP) of *all* neutral organic contaminants of concern in the tissues of *any* species if exposed to the test sediment are *less than or equal to* TBP calculated for reference sediments and *no FDA-type limits have been established* (Table C1).

Conditions b, c, d, e, and f lead to a DECISION FOR FURTHER EVALUATION BY CONDUCTING BIOACCUMULATION TESTS.

A17. The regional authorities must evaluate the potential for bioaccumulation of contaminants for sediments as indicated by the procedures of paragraphs 46 and 47. Bioaccumulation tests can result in six conditions:

a. Concentrations of *all* contaminants of concern in the tissues of *any* species exposed to the test sediment are *less than or equal to* concentrations in animals exposed to the reference sediment and *less than* FDA-type limits (Table C1). This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts due to sediment deposits.

b. Concentration of *any* contaminant of concern in the tissues of *any* test species are *greater than* reference animals and *equal to or greater than* FDA-type limits (Table C1), or

c. Concentrations of *any* contaminant of concern in the tissues of *any* test species are *less than or equal to* reference animals and *equal to or greater than* FDA-type limits (Table C1).

Conditions b and c lead to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts of sediment deposits. Some potentially appropriate restrictions are described in paragraphs 95-97.

d. Concentrations of *any* contaminant of concern in the tissues of *any* test species are *greater than* reference animals and *less than* FDA-type limits (Table C1), or

e. Concentrations of *any* contaminant of concern in the tissue of *any* test species are *greater than* reference animals and *no FDA-type limits have been established* (Table C1), or

f. Concentrations of *any* contaminant of concern in the tissues of *any* test species are *less than or equal to* reference animals and *no FDA-type limits have been established* (Table C1).

Conditions d, e, and f lead to a REGIONAL ADMINISTRATIVE DECISION.

A18. RAD: NEED FOR RESTRICTIONS. At present it is not possible to provide sufficient scientific basis for deciding on the need for restrictions on the cases of subparagraphs A17d, e, and f. Therefore, the regional authority must make an administrative decision using the available scientific information and regionally important concerns. In interpreting bioaccumulation data, scientific concern over potential adverse impacts associated with bioaccumulation increases in direct relation to:

a. Number of contaminants of concern bioaccumulated to concentrations exceeding reference levels.

b. Number of phylogenetic groups of species showing bioaccumulation to concentrations exceeding reference levels.

c. Magnitude of contaminant concentrations in tissues of test organisms.

d. Magnitude of bioaccumulation above reference levels.

e. Toxicological importance of contaminants bioaccumulated to concentrations exceeding reference levels. Contaminants that can be objectively ranked in this manner are presented in Table C5.

f. Number of species showing toxicity when exposed to the same test sediment.

g. Magnitude of toxicity caused by the same test sediment.

h. Proportion of sediment sampling sites in the area being evaluated that show toxicity exceeding reference or bioaccumulation to concentrations exceeding reference levels.

Regional authorities may wish to consider the target concentrations of priority pollutants (TCPP) as a pseudocriterion applicable to the bioaccumulation of contaminants for which no FDA-type action levels or tolerance limits have been established (Table C2). This TCPP is based upon US Environmental Protection Agency (EPA) acceptable daily intake (ADI) values (Table C3). The regional authorities could reach a DECISION FOR RESTRICTIONS if the concentration of any contaminant of concern in tissues exceeded the TCPP for that contaminant. If the concentrations of all contaminants of concern are below the TCPP for the respective contaminants, the regional authority might reach a DECISION FOR FURTHER EVALUATION. When bioaccumulation test results are those of subparagraphs A17d, e, and f, these considerations may lead the regional authority to a DECISION FOR RESTRICTIONS to protect from possible adverse contaminant impacts from sediment deposits on the aquatic environment. Some potentially appropriate restrictions for such cases are discussed in paragraphs 92 and 95-97. The regional authorities may also reach a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts from sediment deposits.

APPENDIX B: DECISIONMAKING FRAMEWORK FOR UPLAND DISPOSAL

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* NOTE: Alphanumeric identification of pages, paragraphs, and figures was used in the appendixes to distinguish them from the simple numbers used as identification in the main text. Thus, references to simple numbers in the appendixes refer to similarly numbered items in the main text.

LIST OF FIGURES

APPENDIX B: DECISIONMAKING FRAMEWORK FOR UPLAND DISPOSAL

B1. There are six aspects of upland disposal that require consideration as shown in Figure B1. At this time, there are only two simplified laboratory tests that indicate a potential for contaminant mobility from sediment to be dredged into two of these aspects: effluent water quality and plant uptake. There are no other existing simplified laboratory tests to address contaminant mobility into surface runoff, leachate water quality, or animal uptake. Research is needed to develop those tests. There are more sophisticated laboratory tests that are recommended for surface runoff and plant and animal uptake but no specified leachate tests. Research is being initiated at the US Army Engineer Waterways Experiment Station (WES) to address leachate testing. Potential human exposure can be evaluated by comparing the total concentration of contaminants in the dredged material to recently tabulated critical concentrations of contaminants of concern for human exposure.

B2. There are four flowcharts (Figures B2-B5, pp B6, B13, B21, B22) that show decision points for the three water-quality aspects of upland disposal. Two additional flowcharts (Figures B6 and B7, pp B34, B42) show decision points for plant and animal aspects of upland disposal. Figure B8 (p B45) shows decision points for potential human exposure.

B3. The first tests that should be conducted on a contaminated dredged material are a total bulk chemical analysis if not already performed (paragraph 88), a modified elutriate test (paragraph 55), and a diethylenetriaminepentacetic acid (DTPA) extraction procedure (paragraph 72). The results of these tests will give an indication of the need for restrictions on human exposure, restrictions on effluent quality control, and further testing of plant uptake. These test results are limited in relationship to estimating surface runoff quality, leachate quality, or animal uptake.

Effluent Quality Tests

B4. Concerns about contaminant impacts from upland disposal site effluent water have centered on short-term impacts in the receiving water during the disposal operation. The decision points and the tests appropriate for determining potential impacts from disposal site effluent water are shown in Figure B2 (p B6). The regional authority must decide whether to take a

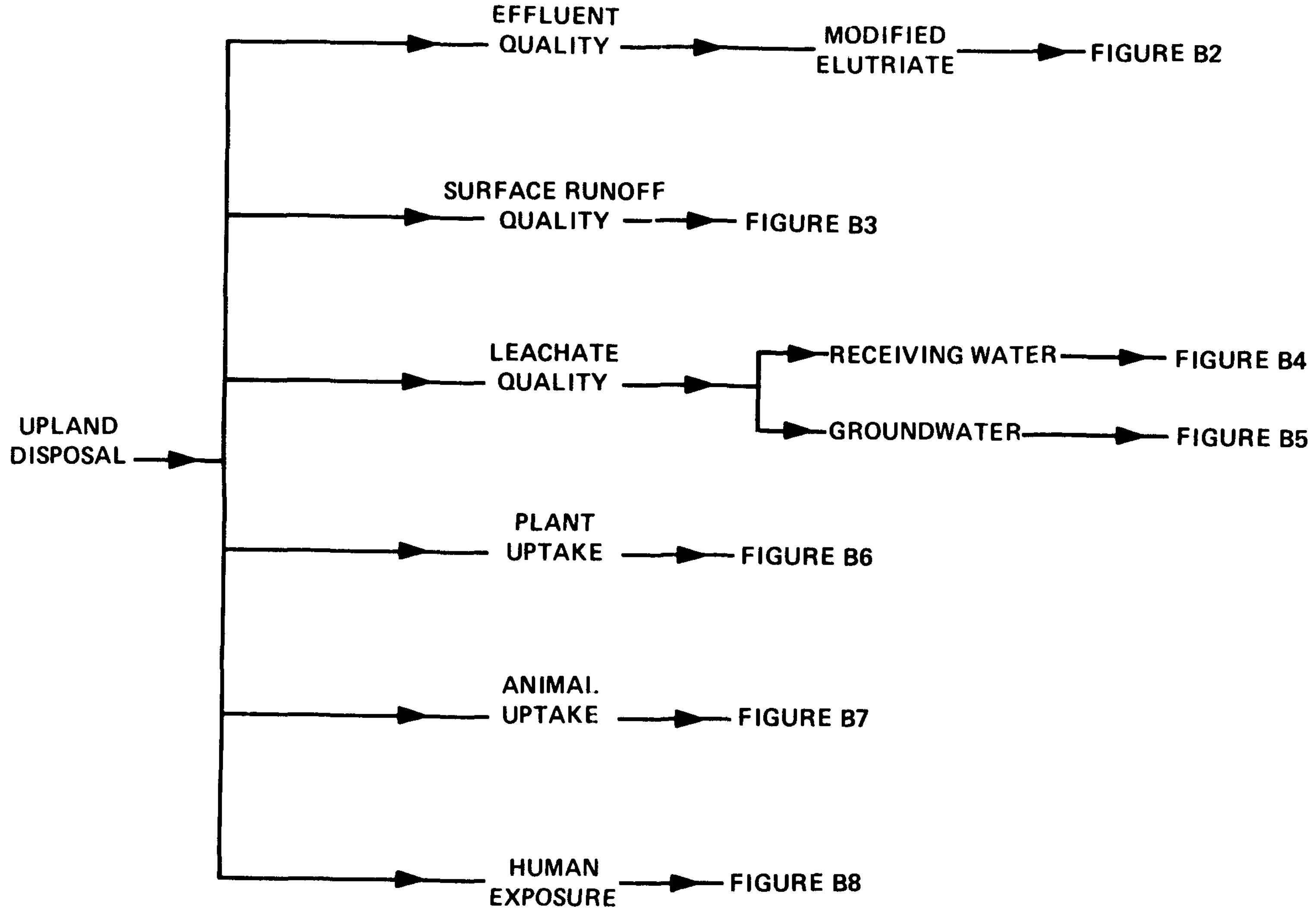

Figure B1. Summary flowchart for decisionmaking for upland disposal chemical- or biological-based approach to evaluating the potential impacts of the disposal site effluent on the receiving water. Chemical evaluations are appropriate when concern is primarily with contaminants for which water-quality criteria have been established (Table C4) and there is little concern about interactive effects of multiple contaminants. If the concern is primarily with chemicals for which water-quality criteria have not been established or if there is concern about interactive effects of multiple contaminants, a biological approach is preferred.

Phase 1 - Decisions from Effluent Chemical Evaluations

B5. Chemical analyses of the effluent (modified elutriate) are evaluated in comparison to dissolved contaminant concentrations in a reference water, which could be the receiving water or another appropriate reference water selected by regional authorities, and to acute water-quality criteria for contaminants for which criteria exist (Table C4). Acute criteria are maximum concentrations that should not be exceeded and are appropriate because of the transient nature of effluent water discharges into the receiving water. Contaminants for which criteria exist are evaluated separately from those for which criteria have not been established.

Water-quality criteria

B6. When acute water-quality criteria exist for the contaminants of concern, five conditions are possible (Figure B2, p B6):

a. Concentrations of *all* dissolved contaminants in the test effluent are *less than or equal to* the reference water and *less than* the acute water-quality criterion for each contaminant (Table C4).

b. Concentration of *any* dissolved contaminant in the test is *greater than* in the reference water and *less than* the acute water-quality criterion (Table C4).

Conditions a and b lead to a DECISION OF NO RESTRICTIONS required to protect against degradation of the water column beyond existing reference site conditions.

c. Concentration of *any* dissolved contaminant in the test is *equal to or greater than* the reference water, and the reference water is *equal to or greater than* the acute water-quality criterion (Table C4).

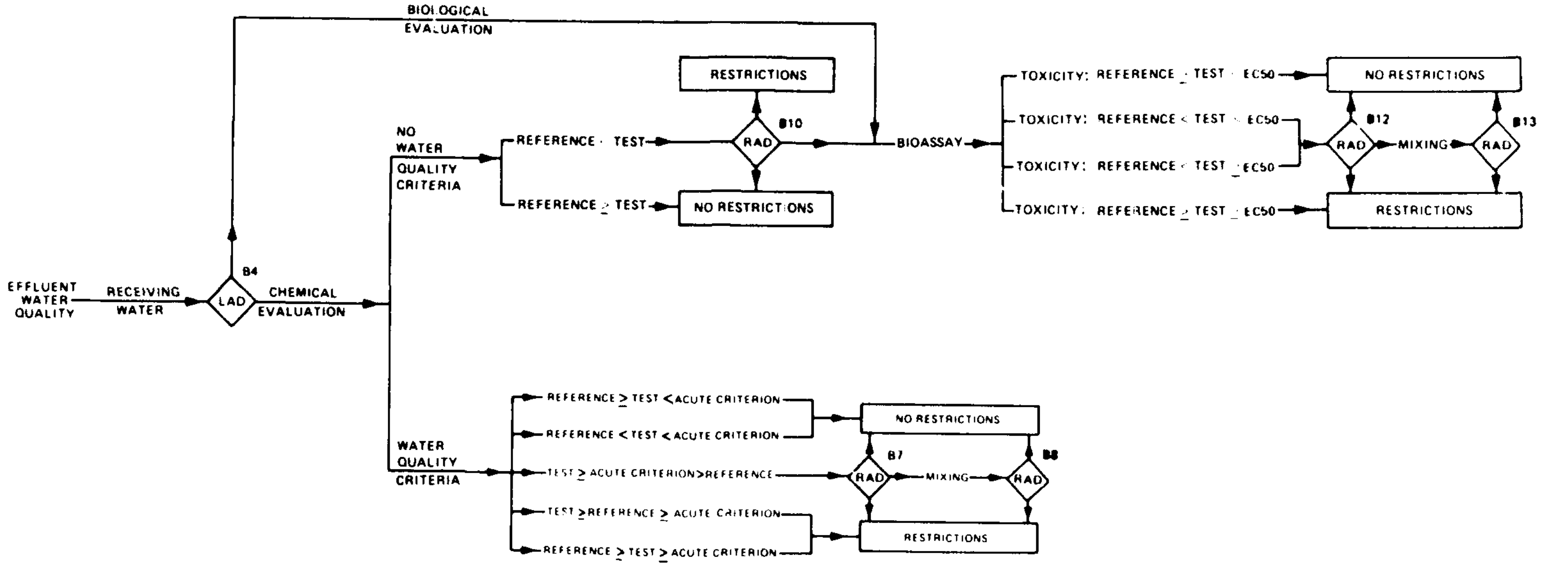

Figure B2. Flowchart for decisionmaking for effluent water quality (number near regional administrative decision (RAD) is paragraph discussing RAD)

d. Concentration of *any* dissolved contaminant in the test is *less than or equal to* the reference water and *equal to or greater than* the acute water-quality criterion (Table C4). Since dilution to the criterion cannot occur under conditions c and d (unless the receiving water for the discharge is not the reference water and is less than the criterion), condition c or d leads to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the water column due to the proposed discharge. Some potentially appropriate restrictions are described in paragraphs 98-110.

e. Concentrations of *any* dissolved contaminant in the test are *equal to or greater than* the acute water-quality criterion (Table C4) and the reference water is *less than* the acute water-quality criterion. Since dilution to the criterion can occur (if the receiving water for the discharge, which may or may not be the reference water, is less than the criterion), this leads to a REGIONAL ADMINISTRATIVE DECISION (RAD) as discussed in paragraph B7.

B7. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraph B6e, dilution will occur when the disposal site effluent enters the receiving water (if the concentration in the receiving water for the discharge, which may or may not be the reference water, is less than the criterion). Consequently, mixing must be considered in order to scientifically assess the potential for effluent discharge impacts to occur. However, in some cases the regional authority may choose to reach a decision without considering mixing by assessing test results in light of the increasing concern about potential contaminant impacts from the disposal site effluent discharge in direct relation to:

a. Number of contaminants (for which criteria have been established) exceeding reference concentrations.

b. Number of contaminants (with criteria) exceeding acute criteria.

c. Magnitude by which reference concentrations are exceeded.

d. Magnitude by which criteria are exceeded.

e. Toxicological importance of contaminants exceeding reference concentrations and/or acute criteria. Contaminants that can be objectively ranked in this manner are presented in Table C5.

f. Proportion of sediment sampling sites in the dredging area being evaluated that have test-modified elutriates exceeding reference concentrations and/or acute criteria. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

In the case of subparagraph B6e, the regional authority might choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount and are well below the acute criteria.* In the case of subparagraph B6e, the regional authority might also choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference and the criteria by a substantial margin.* A decision for restrictions would be particularly appropriate in cases where the concentration in the receiving water already exceeded the criterion, making dilution to the criterion impossible. Some potentially appropriate restrictions are described in paragraphs 99-111. If the regional authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B8.

B8. DECISION FOR FURTHER EVALUATION: CONSIDER MIXING. If the considerations of paragraph B7 lead to an evaluation of mixing, the regional authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to the water-quality criteria are acceptable. Mixing-zone calculation is described in paragraphs 32-34 and Appendix D. *Note that mixing calculations must be based on the receiving water for the discharge, which may or may not be the reference water.* Mixing-zone evaluation is discussed in paragraphs 35-36 and can result in:

a. A mixing zone of *acceptable* size and configuration within which the discharge will be diluted to less than the acute water-quality criterion (Table C4). Acceptability of the mixing zone is determined in light of the considerations of paragraph 35 and paragraph B7 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the receiving water.

b. A mixing zone within which the discharge will be diluted to less than the acute water-quality criterion (Table C4) is of *unacceptable* size or configuration. Acceptability of the mixing zone is determined in light of the considerations of paragraph 35 and paragraph B7 evaluated at the edge of the mixing zone. This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. Some potentially appropriate restrictions are described in paragraphs 98-110.

No water-quality criteria

B9. When acute water-quality criteria do not exist for contaminants of concern, two conditions are possible (Figure B2, p B6):

a. Concentrations of *all* dissolved contaminants of concern in the test effluent are *less than or equal to* the concentrations in the receiving water (or reference water). This leads to a DECISION OF NO RESTRICTIONS required to protect against degradation of the receiving water beyond existing reference site conditions.

b. Concentrations of *any* dissolved contaminant in the test effluent are *greater than* the concentration in the receiving water (or reference water). This leads to a REGIONAL ADMINISTRATIVE DECISION.

B10. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraph B11b, there is no available information for determining the environmental importance of a contaminant that exceeds the reference concentration. This can be determined with bioassays. However, in some cases the regional authority may choose to reach a decision without conducting bioassays by assessing test results in light of the increasing concern about potential contaminant impacts in the receiving water in direct relation to the factors listed in paragraph B7. Regional authorities may wish to consider the lowest observable effects level (LOEL) as a pseudocriterion applicable for contaminants lacking water-quality criteria. The LOEL is available for many compounds for which there are insufficient data to develop criteria (Table C4). The regional authority could reach a DECISION FOR RESTRICTIONS if the concentrations of any contaminants of concern in the test water were equal to or greater than the LOEL for that contaminant. If the concentration of all contaminants of concern in the test water were below the LOEL for the respective contaminants, the regional authority might reach a DECISION FOR FURTHER EVALUATION to conduct a bioassay. In the case of subparagraph B11b, the regional authority might choose, without conducting bioassays, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites have a small number of contaminants exceeding the reference by a small amount.* Since there are no criteria, if bioassays are not considered necessary on the above basis, there is no target concentration for a mixing-zone calculation. However, in addition to the contaminant considerations of paragraph B7, the effluent discharge should be subjectively assessed in light of the mixing zone considerations of paragraph 35 before a decision of no restrictions is reached. On the other hand, the regional authority might choose, without conducting bioassays, to reach a DECISION FOR RESTRICTIONS required to protect contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites have several contaminants exceeding the reference by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 99-111. If the regional authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by conducting bioassays as described in paragraph B11.

Phase 2 - Decisions from Effluent Biological Evaluations

B11. From this point on, the evaluation of potential effluent impacts on the receiving water is biological. It is at this point that testing begins if a biological approach is initially chosen in paragraph B4 (Figure B2). Effluent (modified elutriate) bioassays can result in four possible conditions:

a. Toxicity of the test effluent (modified elutriate) to *all* species is *less than or equal to* the reference water and *less than* the EC50 (i.e., 50-percent toxicity is not reached in the test water). This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water.

b. Toxicity of the test effluent to *any* species is *less than or equal to* the reference water and *equal to or greater than* the EC50 (i.e., at least 50-percent toxicity is reached in the test water). This leads to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. Some potential appropriate restrictions are described in paragraphs 98-110.

c. Toxicity of the test effluent to *any* species is *greater than* the reference water and *less than* the EC50, or

d. Toxicity of the test effluent to *any* species is *greater than* the reference water and *equal to or greater than* the EC50. (Therefore, dilution to the EC50 is possible if the receiving water for the discharge, which may or may not be the reference water, is less than the EC50.)

Conditions c and d lead to a REGIONAL ADMINISTRATIVE DECISION.

B12. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraphs B11c or d, dilution will occur when the disposal site effluent discharge enters the receiving water (if the toxicity of the receiving water, which may or may not be the reference water, is less than the EC50). Consequently, mixing must be considered in order to scientifically assess the potential for receiving water impacts to occur. However, in some cases the regional authority may choose to reach a decision, without considering mixing, by assessing test results in light of the increasing concern about potential contaminant impacts in the receiving water in direct relation to:

a. Number of species bioassayed with the effluent with toxicity exceeding reference toxicity.

b. Magnitude of test toxicity.

c. Magnitude by which reference toxicity is exceeded.

d. Proportion of sediment sampling sites in the dredging area being evaluated that have effluents whose toxicity exceeds reference toxicity. (If a single composite sample from the dredging area is bioassayed, this factor drops from consideration.)

In the case of subparagraph B11c, the regional authority may choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites are toxic to a low number of species and the toxicity only slightly exceeds reference toxicity and is well below 50 percent.* In the case of B11d, the regional authority may choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites are toxic to several species and the toxicity exceeds the reference toxicity and 50 percent by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 98-110. If the regional authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B8.

B13. DECISION FOR FURTHER EVALUATION: CONSIDER MIXING. If the considerations of paragraph B12 lead to an evaluation of mixing, the regional authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to less than the EC50 concentration are acceptable. Mixing-zone calculation is described in paragraphs 32-34 and Appendix D. *Note that mixing calculations must be based on the receiving water for the discharge, which may or may not be the reference water.* Mixing-zone evaluations as discussed in paragraphs 35-36 can result in:

a. A mixing zone of *acceptable* size and configuration within which the effluent discharge will be diluted to less than the EC50. Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph B12 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. (In the case of subparagraph B11c, the EC50 is not exceeded even without consideration of mixing, but if desired the mixing zone to dilute to some lower value, such as EC20, can be calculated.)

b. A mixing zone (within which the discharge will be diluted to less than the EC50) that is of *unacceptable* size and/or configuration. Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph B12 evaluated at the edge of the mixing zone. This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. Some potentially appropriate restrictions are described in paragraphs 98-110.

Surface Runoff Quality Tests

B14. Concerns about contaminant impacts from surface runoff quality after the upland disposal site is filled and the dredged material begins to dry out have centered on short-term impacts in the receiving water during rainfall events. The decision points and the tests appropriate for determining potential impacts from surface runoff water are shown in Figure B3, p B13. This flowchart is similar to that for effluent water and the discussion of decision points is exactly the same. Surface runoff test results should always be compared to the quality of a reference surface water and to existing water-quality criteria. The reference surface water must be selected by regional authorities and could be the receiving water into which the disposal site surface runoff flows or it could be a surface water from another reference site. The regional authority must decide whether to take a chemical- or biological-based approach to evaluating the potential impacts of the surface runoff on the receiving water. Chemical evaluations are appropriate when concern is primarily with contaminants for which water-quality criteria have been

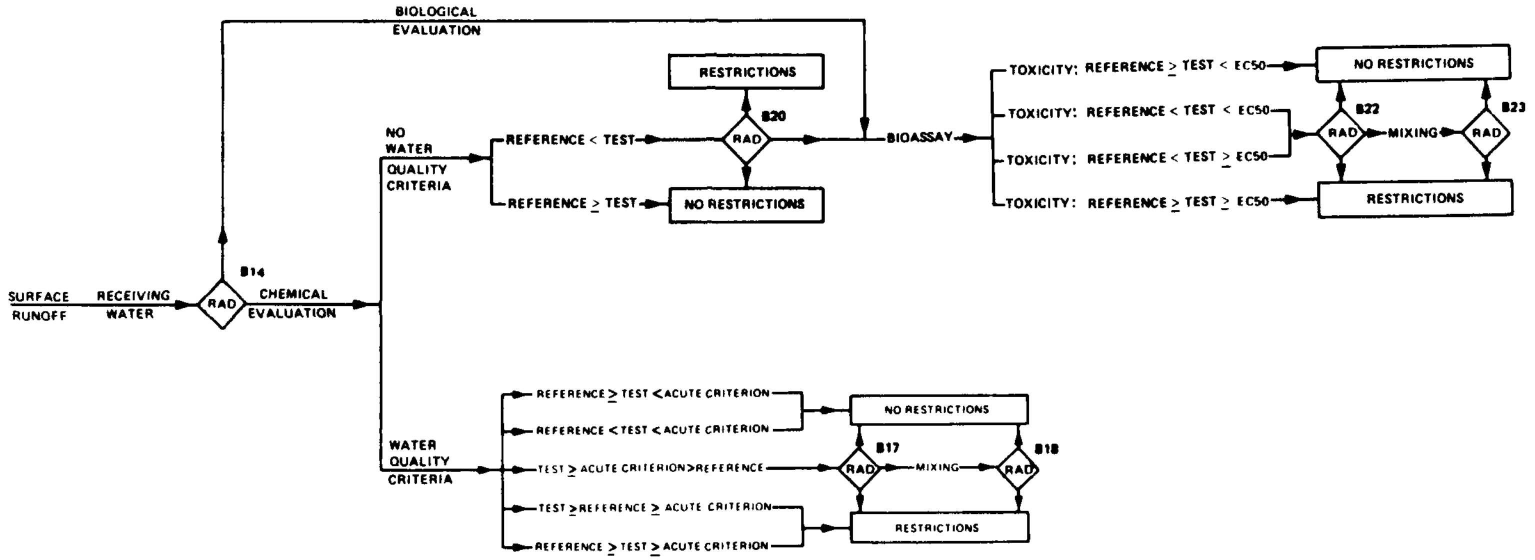

Figure B3. Flowchart for decisionmaking for surface runoff water quality (number near RAD is paragraph discussing RAD) established (Table C4) and there is little concern about interactive effects of multiple contaminants. If the concern is primarily with chemicals for which water-quality criteria have not been established or if there is concern about interactive effects of multiple contaminants, a biological approach is preferred.

Phase 1 - Decisions from Surface Runoff Chemical Evaluations

B15. Chemical analyses of the test surface runoff tests are evaluated in comparison to dissolved contaminant concentrations in an appropriate reference water and to acute water-quality criteria for contaminants for which criteria exist (Table C4). Acute criteria are maximum concentrations that should not be exceeded and are appropriate because of the transient nature of surface runoff discharges into the receiving water. Contaminants for which criteria exist are evaluated separately from those for which criteria have not been established.

Water-quality criteria

B16. When acute water-quality criteria exist for the contaminants of concern, five conditions are possible (Figure B3, p B13).

a. Concentrations of *all* dissolved contaminants in the test surface runoff are *less than or equal to* the reference water and *less than* the acute water-quality criterion for each contaminant (Table C4).

b. Concentration of *any* dissolved contaminant in the test is *greater than* in the reference water and *less than* the acute water-quality criterion (Table C4).

Conditions a and b lead to a DECISION OF NO RESTRICTIONS required to protect against degradation of the water column beyond existing reference site conditions.

c. Concentration of *any* dissolved contaminant in the test is *equal to or greater than* the reference water and the reference water is *equal to or greater than* the acute water-quality criterion (Table C4).

d. Concentration of *any* dissolved contaminant in the test is *less than or equal to* the reference water and *equal to or greater than* the acute water-quality criterion (Table C4).

Since dilution to the criterion cannot occur under conditions c and d (unless the receiving water for the discharge is not the reference water and is less than the criterion), these lead to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the water column due to the proposed surface runoff discharge. Some potentially appropriate restrictions are described in paragraphs 98-109 and 111.

e. Concentrations of *any* dissolved contaminant in the test is *equal to or greater than* the acute water-quality criterion (Table C4) and the reference water is *less than* the acute water-quality criterion.

Since dilution to the criterion can occur (if the receiving water for the discharge, which may or may not be the reference water, is less than the criterion), this leads to a REGIONAL ADMINISTRATIVE DECISION as discussed in paragraph B17.

B17. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraph B16e, dilution will occur when the disposal site surface runoff enters the receiving water (if the concentration in the receiving water for the discharge, which may or may not be the reference water, is less than the criterion). Consequently, mixing must be considered in order to scientifically assess the potential for surface runoff discharge impacts to occur. However, in some cases the regional authority may choose to reach a decision without considering mixing, by assessing test results in light of the increasing concern about potential contaminant impacts from the disposal site surface runoff discharge in direct relation to:

a. Number of contaminants (for which criteria have been established) exceeding reference concentrations.

b. Number of contaminants (with criteria) exceeding the acute criteria.

c. Magnitude by which reference concentrations are exceeded.

d. Magnitude by which criteria are exceeded.

e. Toxicological importance of contaminants exceeding reference concentrations and/or acute criteria. Contaminants that can be objectively ranked in this manner are presented in Table C5.

f. Proportion of sediment sampling sites in the dredging area being evaluated that have test surface runoff exceeding reference concentrations and/or acute criteria. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

In the case of subparagraph B16e, the regional authority might choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount and are well below the acute criteria.* In the case of subparagraph B16e, the regional authority might also choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference and the criteria by a substantial margin.* A decision for restrictions would be particularly appropriate in cases where the receiving water already exceeded the criterion, making dilution to the criterion impossible. Some potentially appropriate restrictions are described in paragraphs 98-109 and 111. If the regional authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B23.

B18. DECISION FOR FURTHER EVALUATION: CONSIDER MIXING. If the considerations of paragraph B17 lead to an evaluation of mixing, the regional authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to the water-quality criteria are acceptable. Mixing-zone calculation is described in paragraphs 32-34 and Appendix D. *Note that mixing calculations must be based on the receiving waters for the discharge, which may or may not be the reference water.* Mixing-zone evaluation as discussed in paragraphs 35-36 can result in:

a. A mixing zone of *acceptable* size and configuration within which the surface runoff will be diluted to less than the acute water-quality criterion (Table C4). Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph B17 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the receiving water.

b. A mixing zone within which the surface runoff will be diluted to less than the acute water-quality criterion (Table C4) that is of *unacceptable* size and/or configuration. Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph B17 evaluated at the edge of the mixing zone. This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. Some potentially appropriate restrictions are described in paragraphs 98-109 and 111.

No water-quality criteria

B19. When acute water-quality criteria do not exist for contaminants of concern, two conditions are possible (Figure B3, p B13):

a. Concentrations of *all* dissolved contaminants of concern in the test surface runoff are *less than or equal to* the reference water. This leads to a DECISION OF NO RESTRICTIONS required to protect against degradation of the receiving water beyond existing reference site conditions.

b. Concentrations of *any* dissolved contaminant in the test surface runoff is *greater than* in the reference water. This leads to a REGIONAL ADMINISTRATIVE DECISION.

B20. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraph B19b, there is no available information for determining the environmental importance of a contaminant that exceeds the reference concentration. This can be determined with bioassays. However, in some cases the regional authority may choose to reach a decision, without conducting bioassays, by assessing test results in light of the increasing concern about potential contaminant impacts in the receiving water in direct relation to the factors listed in paragraph B17. Regional authorities may wish to consider the lowest observable effects level (LOEL) as a pseudocriterion applicable for contaminants lacking water-quality criteria. The LOEL is available for many compounds for which there are insufficient data to develop criteria (Table C4). The regional authority could reach a DECISION FOR RESTRICTIONS if the concentrations of any contaminants of concern in the test water were equal to or greater than the LOEL for that contaminant. If the concentrations of all contaminants of concern in the test water were below the LOEL for the respective contaminants, the regional authority might reach a DECISION FOR FURTHER EVALUATION to conduct a bioassay. In the case of subparagraph B19b, the regional authority might choose, without conducting bioassays, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites have a small number of contaminants exceeding the reference by a small amount.* Since there are no criteria, if bioassays are not considered necessary on the above basis, there is no target concentration for a mixing-zone calculation. However, in addition to the contaminant considerations of paragraph B17, the surface runoff discharge should be subjectively assessed in light of the mixing zone considerations of paragraph 35 before a DECISION OF NO RESTRICTIONS is reached. On the other hand, the regional authority might choose, without conducting bioassays, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of* *sites have several contaminants exceeding the reference by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 98-109 and 111. If the regional authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by conducting bioassays as described in paragraph B21.

Phase 2 - Decisions from Surface Runoff Biological Evaluations

B21. From this point on, the evaluation of potential receiving water impacts is biological. It is at this point that testing begins if a biological approach is initially chosen in paragraph B4 (Figure B3, p B13). Surface runoff water bioassays can result in four possible conditions:

- a. Toxicity of the test water (surface runoff) to *all* species is *less than or equal to* the reference water and *less than* the EC50 (i.e., 50-percent toxicity is not reached in the test water). This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water.
- b. Toxicity of the test water to *any* species is *less than or equal to* the reference water and *equal to or greater than* the EC50 (i.e., at least 50-percent toxicity is reached in the test water). This leads to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. Some potentially appropriate restrictions are described in paragraphs 98-109 and 111.
- c. Toxicity of the test water to *any* species is *greater than* the reference water, and *less than* the EC50, or
- d. Toxicity of the test water to *any* species is *greater than* the reference water and *equal to or greater than* the EC50. (Therefore, dilution to the EC50 is possible if the receiving water for the discharge, which may or may not be the reference water, is less than the EC50).

Conditions c and d lead to a REGIONAL ADMINISTRATIVE DECISION.

B22. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraphs B21c or d, dilution will occur when the disposal site surface runoff enters the receiving water (if the toxicity of the receiving water, which may or may not be the reference water, is less than the EC50). Consequently, mixing must be considered in order to scientifically assess the potential for receiving water impacts to occur. However, in some cases the regional authority may choose to reach a decision, without considering mixing, by assessing test results in light of the increasing concern about potential contaminant impacts in the receiving water in direct relation to:

- a. Number of species bioassayed with surface runoff with toxicity exceeding reference toxicity.
- b. Magnitude of test toxicity.
- c. Magnitude by which reference toxicity is exceeded.
- d. Proportion of sediment sampling sites in the dredging area being evaluated that have surface runoff whose toxicity exceeds reference toxicity. (If a single composite sample from the dredging area is bioassayed, this factor drops from consideration.)

In the case of subparagraph B21c, the regional authority may choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites are toxic to a low number of species and the toxicity only slightly exceeds reference toxicity and is well below 50 percent.* In the case of subparagraph B21d, the authority may choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites are toxic to several species and the toxicity exceeds the reference toxicity and 50 percent by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 98-109 and 111. If the regional authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B23.

B23. DECISION FOR FURTHER EVALUATION: CONSIDER MIXING. If the considerations of paragraph B22 lead to an evaluation of mixing, the regional authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to less than the EC50 concentration are acceptable. Mixing-zone calculation is described in paragraphs 32-34 and Appendix D. *Note that mixing calculations must be based on the receiving water for the discharge, which may or may not be the reference water.* Mixing-zone evaluations as discussed in paragraphs 35-36 can result in:

- a. A mixing zone of *acceptable* size and configuration within which the surface runoff will be diluted to less than the EC50. Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and in paragraph B22 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. (In the case of subparagraph B21c, the EC50 is not exceeded even without consideration of mixing, but if desired, the mixing zone to dilute to some lower value, such as EC20, can be calculated.)

b. A mixing zone (within which the surface runoff will be diluted to less than the EC50) that is of *unacceptable* size and/or configuration. Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph B22 evaluated at the edge of the mixing zone. This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. Some potentially appropriate restrictions are described in paragraphs 98-109 and 111.

Leachate Quality Tests

B24. Leachate quality tests will indicate the potential of contaminants to move through and from a dredged material. Leachate quality evaluation has been divided into three parts: (a) impact of seepage through a dike into a receiving water body (Figure B4, p B21); (b) impact of subsurface drainage into an aquifer that is a source of drinking water (Figure B5, p B22); and (c) impact of subsurface drainage on nonpotable ground water (Figure B5, p B22). Test results should always be compared to the quality of an appropriate reference water. The regional authority must select a reference surface water such as the receiving water adjacent to the disposal site or another reference (background) surface water. Water quality criteria (Table C4) should be used to compare leachate test results to make a decision on relative biological impacts. In addition, the regional authority must select a reference ground water such as the ground water under the disposal site or another reference (background) to compare to leachate test results. Drinking water quality standards (Table C6) should be used to compare leachate test results to make a decision on relative human health effects. If drinking water quality standards do not exist, then leachate test results are compared to the appropriate reference water. The selection of each of these reference waters by regional authorities for the Commencement Bay area is governed by the overall goal established by the regional authority for the area as discussed in paragraph 85.

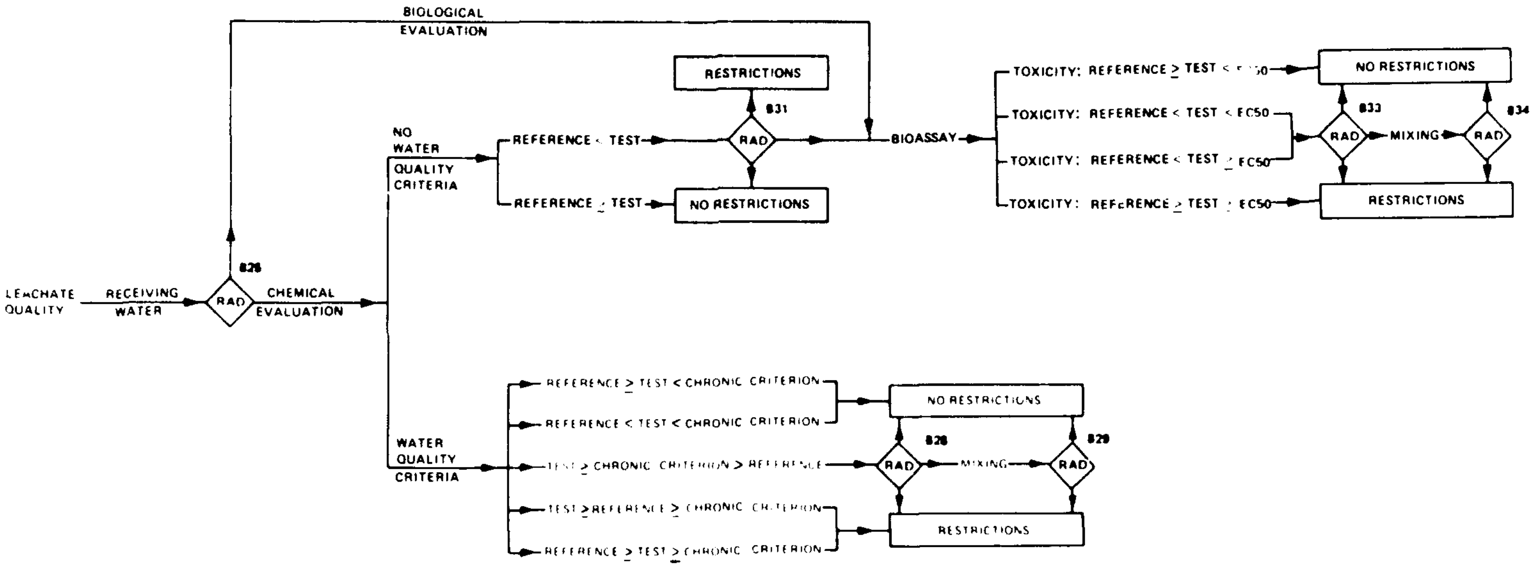

Figure B4. Flowchart for decisionmaking for leachate seepage quality impact to receiving water (number near RAD is paragraph discussing RAD)

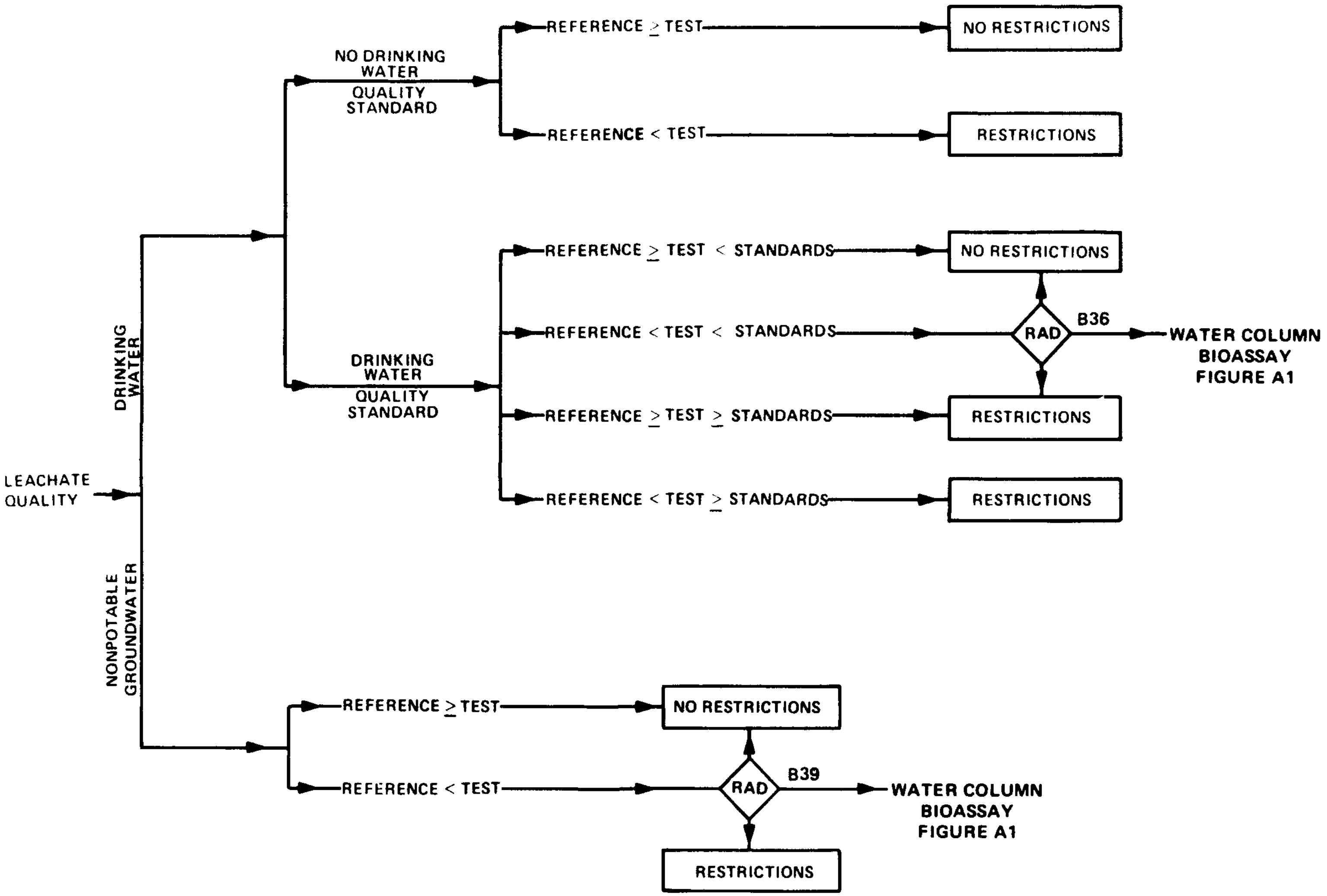

Figure B5. Flowchart for decisionmaking for leachate impacts to drinking water or nonpotable ground water (number near RAD is paragraph discussing RAD)

B25. The regional authority must decide whether to take a chemical- or biological-based approach to evaluating the potential impacts of the leachate seepage on the receiving water. Chemical evaluations are appropriate when concern is primarily with contaminants for which water-quality criteria have been established (Table C4) and there is little concern about interactive effects of multiple contaminants. If the concern is primarily with chemicals for which water-quality criteria have not been established or if there is concern about interactive effects of multiple contaminants, a biological approach is preferred.

Phase 1 - Decisions from Chemical Evaluations

B26. Chemical analyses of the leachate are evaluated in comparison to dissolved contaminant concentrations in a reference water and to chronic water-quality criteria for contaminants for which criteria exist (Table C4). The 24-hr average water concentration should not exceed the chronic criterion. Chronic criteria are appropriate because of the long-term nature of leachate seepage into the receiving water. Contaminants for which criteria exist are evaluated separately from those for which criteria have not been established.

Water-quality criteria

B27. When chronic water-quality criteria exist for the contaminants of concern, five conditions are possible (Figure B4, p B21).

a. Concentrations of *all* dissolved contaminants in the test leachate are *less than or equal to* the reference water and *less than* the chronic water-quality criterion for each contaminant (Table C4).

b. Concentration of *any* dissolved contaminant in the test is *greater than* in the reference water and *less than* the chronic water-quality criterion (Table C4).

Conditions a and b lead to a DECISION OF NO RESTRICTIONS required to protect against degradation of the water column beyond existing reference site conditions.

c. Concentrations of *any* dissolved contaminant in the test is *equal to or greater than* the reference water, and the reference water is *equal to or greater than* the chronic water-quality criterion (Table C4).

d. Concentration of *any* dissolved contaminant in the test is *less than or equal to* the reference water and *equal to or greater than* the chronic water-quality criterion (Table C4).

Since dilution to the criterion cannot occur under conditions c and d (unless the receiving water for the discharge is not the reference water and is less than the criterion), they lead to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the water column due to leachate from the proposed discharge. Some potentially appropriate restrictions are described in paragraphs 98-109 and 112.

e. Concentration of *any* dissolved contaminant in the test is *equal to or greater than* the chronic water-quality criterion (Table C4), and the reference water is *less than* the chronic water-quality criterion. Since dilution to the criterion can occur (if the receiving water for the discharge, which may or may not be the reference water, is less than the criterion), this leads to a REGIONAL ADMINISTRATIVE DECISION as discussed in paragraph B28.

B28. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraph B27e, dilution will occur when the disposal site leachate enters the receiving water (if the receiving water for the discharge, which may or may not be the reference water, is less than the criterion). Consequently, mixing must be considered in order to scientifically assess the potential for leachate impacts to occur. However, in some cases the regional authority may choose to reach a decision, without considering mixing, by assessing test results in light of the increasing concern about potential contaminant impacts from the disposal site leachate in direct relation to:

a. Number of contaminants (for which criteria have been established) exceeding reference concentration.

b. Number of contaminants (with criteria) exceeding chronic criteria.

c. Magnitude by which reference concentrations and/or chronic criteria are exceeded.

d. Magnitude by which criteria are exceeded.

e. Toxicological importance of contaminants exceeding reference concentrations and/or chronic criteria. Contaminants that can be objectively ranked in this manner are presented in Table C5.

f. Proportion of sediment sampling sites in the dredging area being evaluated that have test leachate exceeding reference concentrations and/or chronic criteria. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

In the case of subparagraph B27e, the regional authority might choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate* *if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount and are well below the chronic criteria.* In the case of subparagraph B27e, the regional authority might also choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference and the criteria by a substantial margin.* A DECISION FOR RESTRICTIONS would be particularly appropriate in cases where the receiving water already exceeded the criterion, making dilution to the criterion impossible. Some potentially appropriate restrictions are described in paragraphs 98-109 and 112. If the regional authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B29.

B29. DECISION FOR FURTHER EVALUATION: CONSIDER MIXING. If the considerations of paragraph B28 lead to an evaluation of mixing, the regional authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to the water-quality criteria are acceptable. Mixing-zone calculation is described in paragraphs 32-34 and Appendix D. *Note that mixing calculations must be based on the receiving water for the discharge, which may or may not be the reference water.* Mixing zone evaluation as discussed in paragraphs 35-36 can result in:

a. A mixing zone of *acceptable* size and configuration within which the discharge will be diluted to less than the chronic water quality criterion (Table C4). Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph B28 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the receiving water.

b. A mixing zone within which the discharge will be diluted to less than the chronic water-quality criterion (Table C4) that is of *unacceptable* size and/or configuration. Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph B28 evaluated at the edge of the mixing zone. This leads to a DECISION OF RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. Some potentially appropriate restrictions are described in paragraphs 98-109 and 112.

No water-quality criteria

B30. When chronic water-quality criteria do not exist for contaminants of concern, two conditions are possible (Figure B4, p B21):

a. Concentrations of *all* dissolved contaminants of concern in the test leachate are *less than or equal to* the receiving water (or reference water). This leads to a DECISION OF NO RESTRICTIONS required to protect against degradation of the receiving water beyond existing reference site conditions.

b. Concentration of *any* dissolved contaminant in the test leachate is *greater than* in the receiving water (or reference water). This leads to a REGIONAL ADMINISTRATIVE DECISION.

B31. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraph B30b, there is no available information for determining the environmental importance of a contaminant that exceeds the reference concentration. This can be determined with bioassays. However, in some cases the regional authority may choose to reach a decision, without conducting bioassays, by assessing test results in light of the increasing concern about potential contaminant impacts in the receiving water in direct relation to the factors listed in paragraph B28. Regional authorities may wish to consider the lowest observable effects level (LOEL) as a pseudo-criterion applicable for contaminants lacking water-quality criteria. The LOEL is available for many compounds for which there are insufficient data to develop criteria (Table C4). The regional authority could reach a DECISION FOR RESTRICTIONS if the concentrations of any contaminants of concern in the test water were equal to or greater than the LOEL for that contaminant. If the concentration of all contaminants of concern in the test water were below the LOEL for the respective contaminants, the regional authority might reach a DECISION FOR FURTHER EVALUATION to conduct a bioassay. In the case of subparagraph B30b, the regional authority might also choose, without conducting bioassays, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites have a small number of contaminants exceeding the reference by a small amount.* Since there are no criteria, if bioassays are not considered necessary on the above basis, there is no target concentration for a mixing-zone calculation. However, in addition to the contaminant considerations of paragraph B28, the leachate seepage should be subjectively assessed in light of the mixing-zone considerations of paragraph 35 before a decision of no restrictions is reached. On the other hand, the regional authority might choose, without conducting bioassays, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites have several contaminants exceeding the reference by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 98-109 and 112. If the regional authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by conducting bioassays as described in paragraph B32.

Phase 2 - Decisions from Biological Evaluations

B32. From this point on, the evaluation of potential receiving water impacts is biological. It is at this point that testing begins if a biological approach is initially chosen in paragraph B25 (Figure B4, p B21). Leachate bioassays can result in four possible conditions:

a. Toxicity of the test water (leachate) to *all* species is *less than or equal to* the reference water (receiving water) and *less than* the EC50 (i.e., 50-percent toxicity is not reached in the test water). This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water.

b. Toxicity of the test water to *any* species is *less than or equal to* the reference water and *equal to or greater than* the EC50 (i.e., at least 50-percent toxicity is reached in the test water). This leads to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. Some potential appropriate restrictions are described in paragraphs 98-109 and 112.

c. Toxicity of the test water to *any* species is *greater than* the reference water and *less than* the EC50, or

d. Toxicity of the test water to *any* species is *greater than* the reference water and *equal to or greater than* the EC50. (Therefore, dilution to the EC50 is possible if the receiving water for the discharge, which may or may not be the reference water, is less than the EC50.)

Conditions c and d lead to a REGIONAL ADMINISTRATIVE DECISION.

B33. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraphs B32c or d, dilution will occur when the disposal site effluent discharge enters the receiving water (if the receiving water for the discharge, which may or may not be the reference water, is less than the

EC50). Consequently, mixing must be considered in order to scientifically assess the potential for receiving water impacts to occur. However, in some cases the regional authority may choose to reach a decision, without considering mixing, by assessing test results in light of the increasing concern about potential contaminant impacts in the receiving water in direct relation to:

a. Number of species bioassayed with the leachate with toxicity exceeding reference toxicity.

b. Magnitude of test toxicity.

c. Magnitude by which reference toxicity is exceeded.

d. Proportion of sediment sampling sites in the dredging area being evaluated that have leachate whose toxicity exceeds reference toxicity. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

In the case of subparagraph B32c, the regional authority may choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites are toxic to a low number of species and the toxicity only slightly exceeds reference toxicity and is well below 50 percent.* In the case of subparagraph B32d, the authority may choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites are toxic to several species and the toxicity exceeds the reference toxicity and 50 percent by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 98-109 and 112. If the regional authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B34.

B34. DECISION FOR FURTHER EVALUATION: CONSIDER MIXING. If the considerations of paragraph B33 lead to an evaluation of mixing, the regional authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to less than the EC50 concentration are acceptable. Mixing-zone calculation is described in paragraphs 32-34 and Appendix D. *Note that mixing calculations must be based on the receiving water for the discharge, which may or may not be the reference water.* Mixing-zone evaluations as discussed in paragraphs 35-36 can result in:

a. A mixing zone of *acceptable* size and configuration within which the leachate will be diluted to less than the EC50. Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph B33 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. (In the case of subparagraph B32c, the EC50 is not exceeded even without consideration of mixing, but if desired, the mixing zone to dilute to some lower value, such as LC20, can be calculated.)

b. A mixing zone (within which the leachate will be diluted to less than the EC50) that is of *unacceptable* size and/or configuration. Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph B33 evaluated at the edge of the mixing zone. This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. Some potentially appropriate restrictions are described in paragraphs 98-109 and 112.

Subsurface drainage into drinking water

B35. Drinking water standards. When drinking water standards exist, four test results are possible (Figure B5, p B22):

a. Leachate concentrations of *all* contaminants are *less than or equal to* the reference ground water and *less than* the drinking water standard (Table C6). This leads to a DECISION OF NO RESTRICTIONS required to protect against degradation of ground water beyond existing reference ground water.

b. Leachate concentration of *any* contaminant is *less than or equal to* the reference ground water and *equal to or greater than* the drinking water standard (Table C6). This leads to a DECISION FOR RESTRICTIONS required to protect against degradation of ground water beyond existing reference ground water. Some potentially appropriate restrictions are described in paragraphs 98-109 and 112.

c. Leachate concentration of *any* contaminant is *greater than* the reference ground water and *equal to or greater than* the drinking water standard (Table C6). This leads to a DECISION FOR RESTRICTIONS required to protect against degradation of ground water beyond existing reference ground water. Some potentially appropriate restrictions are described in paragraphs 99-109 and 112.

d. Leachate concentration of *any* contaminant is *greater than* reference ground water and *less than* the drinking water standard (Table C6). This leads to a REGIONAL ADMINISTRATIVE DECISION.

B36. RAD: RESTRICTIONS/NO RESTRICTIONS. Under the conditions of subparagraph B35d, the reference ground water selected may be of exceptional high quality and contain extremely low concentrations of contaminants, substantially below drinking water standards. The regional authority may choose to assess test results in light of the increasing concern about potential contaminant impacts to ground water beyond existing reference ground water in relation to:

- a. Number of contaminants exceeding reference ground-water concentrations.
- b. Magnitude by which reference ground-water concentrations are exceeded.
- c. Toxicological importance of contaminants exceeding reference ground-water concentrations. Contaminants that can be objectively ranked in this manner are presented in Table C5.
- d. Proportion of sediment sampling sites in the area being evaluated that have test leachates exceeding reference ground-water concentrations. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

The regional authority might choose to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the ground water. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount and are well below drinking water standards.* In contrast, the regional authority might choose to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the ground water. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference ground water and approaching the drinking water standards.* Some potentially appropriate restrictions are described in paragraphs 98-109 and 112.

B37. No drinking water standards. When drinking water standards do not exist for contaminants of concern, two conditions are possible (Figure B5, B22):

- a. Leachate concentrations of *all* contaminants are *less than or equal to* the reference ground water. This leads to a DECISION OF NO RESTRICTIONS required to protect against degradation of the ground water beyond existing reference ground-water conditions.
- b. Leachate concentration of *any* contaminant is *greater than* the reference ground water. This leads to a DECISION FOR RESTRICTIONS required to protect against contaminant impact in the ground water due to the proposed leachate. Some potentially appropriate restrictions are described in paragraphs 98-109 and 112.

Subsurface drainage
into nonpotable ground water

B38. PHASE 1 - DECISIONS FROM CHEMICAL EVALUATIONS. Leachate test results should be compared to an appropriate reference ground water. Tests can result in the following conditions:

a. Leachate concentrations of *all* contaminants are *less than or equal to* the reference ground water. This leads to a DECISION OF NO RESTRICTIONS required to protect against degradation of the ground water beyond existing reference ground-water conditions.

b. Leachate concentration of *any* contaminant is *greater than* the reference ground water. This leads to a REGIONAL ADMINISTRATIVE DECISION.

B39. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraph B38b, the regional authority may choose to assess test results in light of the increasing concern about potential contaminant impacts to ground water beyond existing reference ground water in relation to:

a. Number of contaminants exceeding reference ground water.

b. Magnitude by which reference ground-water concentrations are exceeded.

c. Toxicological importance of contaminants exceeding reference ground-water concentrations. Contaminants that can be objectively ranked in this manner are presented in Table C5.

d. Proportion of sediment sampling sites in the area being evaluated that have test leachates exceeding reference ground-water concentrations. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

The regional authority might choose to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on the ground water. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount.* In contrast, the regional authority might choose to reach a DECISION FOR RESTRICTION required to protect against contaminant impacts on the ground water. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference ground water.* Some potentially appropriate restrictions are described in paragraphs 98-109 and 112. If the regional authority desires to fully evaluate the potential for ground-water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering bioassays as discussed in paragraph B40.

B40. PHASE 2 - DECISIONS FROM BIOLOGICAL EVALUATIONS. Water-column bioassays of the test leachate can give two possible results:

- a. Toxicity of the test leachate to all species is *less than 50 percent* of the reference ground water. This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on the ground water.
- b. Toxicity of the test leachate to any species is *equal to or greater than 50 percent* of the reference ground water. This leads to a REGIONAL ADMINISTRATIVE DECISION.

B41. RAD: RESTRICTIONS/FURTHER EVALUATION. In the case of subparagraph B40b, the regional authority might choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts on nonpotable ground water. Some potentially appropriate restrictions are described in paragraphs 98-109 and 112. If the ground water emerges into a surface water body and the regional authority desires to fully evaluate the potential for nonpotable ground-water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B42.

B42. DECISION FOR FURTHER EVALUATION: CONSIDER MIXING. Consideration of a mixing zone when nonpotable ground water emerges into a water body such as a river or bay can give two possible results:

- a. A mixing zone of *acceptable* size and/or configuration (paragraph 35) within which the nonpotable ground-water discharge will be diluted to *less than* an EC50. This leads to a DECISION FOR NO RESTRICTIONS required to protect against possible contaminant impacts on the receiving water body.
- b. A mixing zone of *unacceptable* size and/or configuration (paragraph 35) within which the nonpotable ground-water discharge will not be diluted and will still be *equal to or greater than* the EC50. This leads to a DECISION FOR RESTRICTIONS required to protect against degradation of the receiving water body. Some potentially appropriate restrictions are described in paragraphs 98-109 and 112.

Plant Uptake Tests

B43. Plant uptake/bioassay tests will indicate the potential for contaminants to impact plants colonizing the sediment to be dredged. Plant response is observed when index plants are grown in the sediment under both a flooded wetland condition and a dried upland condition as described in paragraph 71. Plant response is also observed in a reference sediment or soil selected according to paragraph 85. Both plant growth and bioaccumulation of contaminants are evaluated (Figure B6, p B34). Plant response to the contaminated sediment should always be compared to the plant response to the reference sediment or soil.

B44. Data from existing literature on demonstrated effects of contaminants on plants (Tables C7 and C8) can be used to indicate potential effects of contaminant concentrations in test plants in relation to other plants and can give some perspective to the magnitude of the impact. Available US Food and Drug Administration (FDA) action levels for contaminants in plants and foodstuffs (Table C9) and existing standards for contaminant levels in food plants for protection of human health (Table C10) can be used to get additional perspective on contaminant concentrations in plant tissues that have potential health effects.

B45. Total plant uptake of contaminants should also be evaluated. Total uptake is calculated by multiplying the plant tissue concentration of contaminant by the total dry weight of plant leaves produced. Total uptake indicates the total mobility of contaminants from the sediment into aboveground portions of the plant. A complete picture of the plant uptake of contaminants from sediments can only be obtained after consideration of both plant tissue content and total uptake values.

B46. Results of the DTPA-extraction procedure, which involves analysis of soluble contaminants in dredged material in flooded reduced condition and air-dried for upland condition, are used to predict the plant leaf tissue content of certain metals and thus to determine the necessity for restriction or for further evaluation. DTPA extraction is effective for metals, but cannot be used to predict potential organic contaminant mobility. There is no simplified laboratory extraction procedure that predicts potential organic contaminant mobility into plants. Research data to date have not indicated bioaccumulation of organic contaminants in test plants to any greater extent over reference plants.

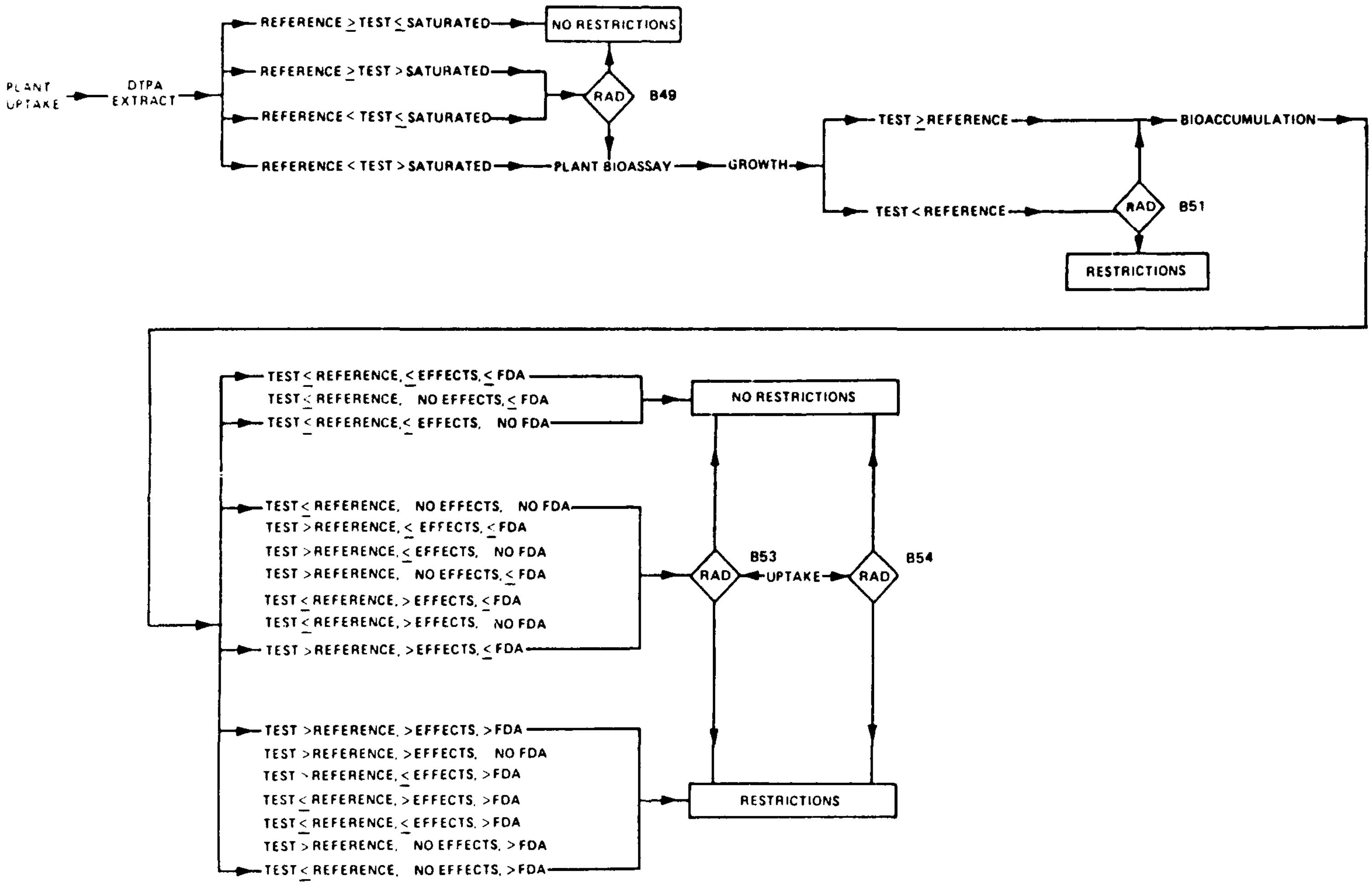

Figure B6. Flowchart for decisionmaking for potential plant uptake (number near RAD is paragraph discussing RAD). Bioaccumulation is assessed by chemical analysis of tissues from the plant growth bioassay and is not a separate test procedure

Phase 1 - Decisions from DTPA-Sediment Extraction Tests

B47. DTPA-extractable metals from air-dried contaminated sediment should always be compared to DTPA-extractable metals from the original wet contaminated sediment and from a reference sediment. The reference sediment or soil is selected according to paragraph 85.

B48. DTPA sediment extraction tests are described in paragraph 72 and can result in four possible conditions:

a. DTPA-extractable concentrations of *all* metals from the air-dried sediment are *less than or equal to* the reference and *less than or equal to* the saturated sediment. This leads to a DECISION OF NO RESTRICTIONS to protect against contaminant impacts on plants colonizing the dredged material.

b. DTPA-extractable concentration of *any* metal from the air-dried sediment is *less than or equal to* the reference and *greater than* the saturated sediment.

c. DTPA-extractable concentration of *any* metal from the air-dried sediment is *greater than* the reference and *less than or equal to* the saturated sediment. Conditions b and c lead to a REGIONAL ADMINISTRATIVE DECISION as discussed in paragraph B49.

d. DTPA-extractable concentration of *any* metal from the air-dried sediment is *greater than* the reference and *greater than* the saturated sediment. This leads to a DECISION FOR FURTHER EVALUATION by conducting a plant bioassessment as discussed in paragraph B50.

B49. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraphs B48b and c, there is some indication of potential for impacts of metals on plants colonizing the dredged material. Therefore, plant bioassays must be conducted in order to scientifically assess the potential for contaminant impacts to occur. However, in some cases the regional authority may choose to reach a decision without conducting plant bioassays by assessing test results in light of the increasing concern about potential impacts of metals in direct relation to the:

a. Number of DTPA-extracted metals in the air-dried dredged material exceeding concentrations in air-dried reference sediment or the saturated dredged material.

b. Magnitude by which DTPA-extracted metals in the air-dried dredged material exceed concentrations in the air-dried reference sediment on the saturated dredged material.

c. Toxicological importance (Table C5) of the DTPA-extracted metals in the dredged material that exceed concentrations in the air-dried reference sediment or the saturated dredged material.

d. Proportion of sediment sampling sites in the dredging area being evaluated that have DTPA-extracted metals exceeding concentrations in the air-dried reference sediment on the saturated dredged material. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

Under the conditions of subparagraph B48b, the regional authority might choose to reach a DECISION OF NO RESTRICTION required to protect against metals impacts on plants colonizing the contaminated dredged material. *This may be appropriate since plants will not be any more contaminated with metals than those grown on the reference sediment even though metals mobility appears to have increased in the air-dried sediment compared to the saturated sediment. This may also be appropriate if samples from only a few sites have only a small number of metals of relatively low toxicological concern exceeding the saturated sediment values by a small amount.* In the case of subparagraph B48c, the regional authority might choose to reach a DECISION OF NO RESTRICTIONS required to protect against metals impacts on plants colonizing the contaminated dredged material. *This may be appropriate if samples from only a few sites have only a small number of metals of relatively low toxicological concern exceeding the reference sediment values by a small amount.* If the regional authority desires to fully evaluate the potential for impacts of all contaminants on plants colonizing the contaminated dredged material to occur in light of the test results obtained in subparagraphs B48b and c, it will reach a DECISION FOR FURTHER EVALUATION by conducting a plant bioassay as discussed in paragraph B50.

Phase 2 - Decisions from Plant Bioassessment Evaluations

B50. Plant bioassessment, as discussed in paragraphs 70 and 71, is evaluated in three phases: growth tests, bioaccumulation, and total uptake (Figure B6). Plant growth tests can result in two conditions:

a. Acceptable levels of plant growth when air-dried sediment produces plant yield *equal to or greater than* that on the reference sediment (up to 25-percent reduction in plant yield would be acceptable if the test sediment has poor fertility). This leads to a DECISION FOR FURTHER EVALUATION and to proceed to the bioaccumulation phase of the bioassessment as discussed in paragraph B52.

b. Air-dried sediment produces a reduction in plant yield *25 percent or greater* than that on the reference sediment. This leads to a REGIONAL ADMINISTRATIVE DECISION as discussed in paragraph B51.

B51. RAD: RESTRICTIONS/FURTHER EVALUATION. Under the conditions of subparagraph B50b, the regional authority might choose to reach a DECISION FOR FURTHER EVALUATION by conducting the bioaccumulation phase (paragraph B52) of the plant bioassay. *This is appropriate if there is reason to believe the reduction in growth might be a result of low fertility in the sediment or a result of excess salt in the case of estuarine sediments.* On the other hand, the regional authority might choose to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts on plants colonizing the dredged material. *This is appropriate if there is reason to believe that the reduction in growth was due to toxic metals or phytotoxic organic contaminants and not a result of infertility or salinity.* Some potentially appropriate restrictions are described in paragraphs 98-109 and 113.

B52. Decisions from plant bioaccumulation evaluations. Plant bioaccumulation tests are described in paragraphs 70 and 71 and can give 17 possible sets of results grouped according to the appropriate decision to be made.

a. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues and *less than or equal to* demonstrated effects (Tables C7 and C8) and *less than or equal to* FDA action levels (Table C9) or other human health effects levels (Table C10).

b. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues (but *no demonstrated effects data* exist) and are *less than or equal to* FDA action levels (Table C9) or other human health effects levels (Table C10).

c. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues and *less than or equal to* demonstrated effects (Tables C7 and C8) but no FDA action levels or other human health effects levels exist.

Conditions a, b, and c lead to a DECISION OF NO RESTRICTIONS required to protect against contaminant impact on plants colonizing the dredged material.

d. Exposed plant tissue concentrations are *greater than* reference plant tissue and *greater than* demonstrated effects (Tables C7 and C8) and *greater than* FDA levels (Table C9) or other human health levels (Table C10).

e. Exposed plant tissue concentrations are *greater than* reference plant tissues and *greater than* demonstrated effects (Tables C7 and C8) and there are no FDA or other human health levels.

f. Exposed plant tissue concentrations are *greater than* reference plant tissues and *less than or equal to* demonstrated effects (Tables C7 and C8) and *greater than* FDA levels (Table C9) or other human health levels (Table C10).

g. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues and *greater than* demonstrated effects (Tables C7 and C8) and *greater than* FDA levels (Table C9) or other human health levels (Table C10).

h. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues and *less than or equal to* demonstrated effects (Tables C7 and C8) and *greater than* FDA levels (Table C9) or other human health levels (Table C10).

i. Exposed plant tissue concentrations are *greater than* reference plant tissues (but *no demonstrated effects data exist*) and are *greater than* FDA levels (Table C9) or other human health levels (Table C10).

j. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues (but *no demonstrated effects data exist*) and are *greater than* FDA levels (Table C9) or other human health levels (Table C10).

Conditions d-j lead to a DECISION FOR RESTRICTIONS required to protect against contaminant impact on plants colonizing the dredged material. Some potentially appropriate restrictions are described in paragraphs 98-109 and 113.

k. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues and there are *no effects data or no FDA levels*.

l. Exposed plant tissue concentrations are *greater than* reference plant tissues and *less than or equal to* demonstrated effects (Tables C7 and C8) and *less than or equal to* FDA action levels (Table C9) or other human health effects levels (Table C10).

m. Exposed plant tissue concentrations are *greater than* reference plant tissues and *less than or equal to* demonstrated effects (Tables C7 and C8) and there are *no FDA or other human health levels*.

n. Exposed plant tissue concentrations are *greater than* reference plant tissues (but *no demonstrated effects data exist*), and are *less than or equal to* FDA levels (Table C9) or other human health levels (Table C10).

o. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues and *greater than* demonstrated effects (Tables C7 and C8) and *less than or equal to* FDA levels (Table C9) or other human health levels (Table C10).

p. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues, and *greater than* demonstrated effects (Tables C7 and C8) but there are *no FDA* or other human health levels.

q. Exposed plant tissue concentrations are *greater than* reference plant tissues and *greater than* demonstrated effects (Tables C7 and C8) and *less than or equal to* FDA levels (Table C9) or other human health levels (Table C10).

Conditions k-q lead to a REGIONAL ADMINISTRATIVE DECISION as discussed in paragraph B53.

B53. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. At present it is not possible to provide sufficient scientific basis for deciding on the need for restrictions in the cases of subparagraphs B52k, l, m, n, o, p, and q. Therefore, the regional authority must make an administrative decision using the available scientific information and regionally important concerns. In interpreting plant bioaccumulation data, scientific concern over potential adverse impacts associated with bioaccumulation increases in direct relation to:

a. Number of contaminants bioaccumulated to concentrations exceeding reference and/or demonstrated effects levels.

b. Magnitude of bioaccumulation above reference and/or demonstrated effects levels.

c. Toxicological importance of contaminants bioaccumulated to concentrations exceeding reference and/or demonstrated effects levels. Contaminants that can be objectively ranked in this manner are presented in Table C5.

d. Proportion of sediment sampling sites in the area being evaluated that show bioaccumulation to concentrations exceeding reference and/or demonstrated effects levels.

In the cases of subparagraphs B52k, l, m, n, o, p, and q, the regional authority may choose, without considering total plant uptake, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on plants colonizing the dredged material. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount.* When many contaminants are present that have no FDA or human health levels and no demonstrated effects data, the regional authority may wish to consider bioaccumulation using the target concentration of priority pollutants (TCPP) values (Table C2) as pseudocriteria. If the tissue concentration of any contaminant was equal to or exceeded its TCPP value under any column in Table C2, the regional authority could reach a DECISION FOR RESTRICTIONS. If the tissue concentrations of all contaminants were below their respective TCPP values, the regional authority could reach a DECISION FOR FURTHER EVALUATION to consider total uptake. On the other hand, the regional authority may choose, without considering total plant uptake, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts on plants colonizing the dredged material. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 98-109 and 113. In addition, if the regional authority desires to fully evaluate the potential for mass movement of contaminants into plants, it will reach a DECISION FOR FURTHER EVALUATION by considering total plant uptake as discussed in paragraph B54.

B54. Decisions from total plant uptake evaluations. Total plant uptake of contaminants can indicate potential mass movement of contaminants from the dredged material into plants. This is done by comparing the total uptake of contaminants (plant tissue concentration multiplied by total plant yield) from the contaminated sediment to that from the reference sediment:

a. If total uptake is *greater* on the contaminated sediment than on the reference sediment, then the regional authority may choose to reach a DECISION FOR RESTRICTIONS. *This may be appropriate in relation to the factors discussed in paragraph B53 if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference by a substantial margin.* On the other hand, the regional authority might choose to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on plants colonizing the dredged material. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount.*

b. If total uptake is *less than or equal to* that from the reference sediment, then the regional authority might reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on plants colonizing the dredged material. *This may be appropriate since contaminant mobility from the contaminated sediment into plants will not be any greater than existing contaminant mobility from the reference sediment into plants colonizing it.*

Animal Uptake Tests

B55. Test animal response is observed after exposure to a contaminated sediment as described in paragraphs 73-75. Test animal response is also observed after exposure to a reference sediment or soil selected in accordance with paragraph 85. Both animal toxicity and bioaccumulation of contaminants are evaluated. Test animal response to contaminated sediment should always be compared to the response observed to the reference sediment or soil. Available FDA action levels for poisonous substances in human food (Table C1) can be used to get additional perspective on contaminant concentrations in organisms that have potential health effects. A direct correlation between earthworm content of contaminants and human health effects cannot be made. The earthworm bioassay only indicates the potential for contaminants to move from sediments into animals that come in contact with the sediment.

Decisions from animal bioassessment evaluations

B56. Decisions from animal toxicity evaluations. Animal toxicity tests are described in paragraphs 73-75 and can result in four conditions (Figure B7, p B42):

a. Exposed toxicity is *greater than* the reference sediment and *equal to or greater than* 50 percentage points above the control.* This leads to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts on sediment-dwelling animals beyond existing reference site conditions.

b. Exposed toxicity is *less than or equal to* the reference sediment and *less than* 50 percentage points above the control.

c. Exposed toxicity is *less than or equal to* the reference sediment and *equal to or greater than* 50 percentage points above the control.

d. Exposed toxicity is greater than the reference sediment and *less than* 50 percentage points above the control.

Conditions under subparagraphs B56b, c, and d lead to a DECISION FOR FURTHER EVALUATION by assessing the potential for bioaccumulation of contaminants of concern from the test sediment as discussed in paragraph B57.

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* For example, if 9 of 100 control animals showed mortality, then at least 59 of 100 test animals (59 percent) would have to show mortality in order for toxicity of the test sediment to be 50 percentage points above the control.

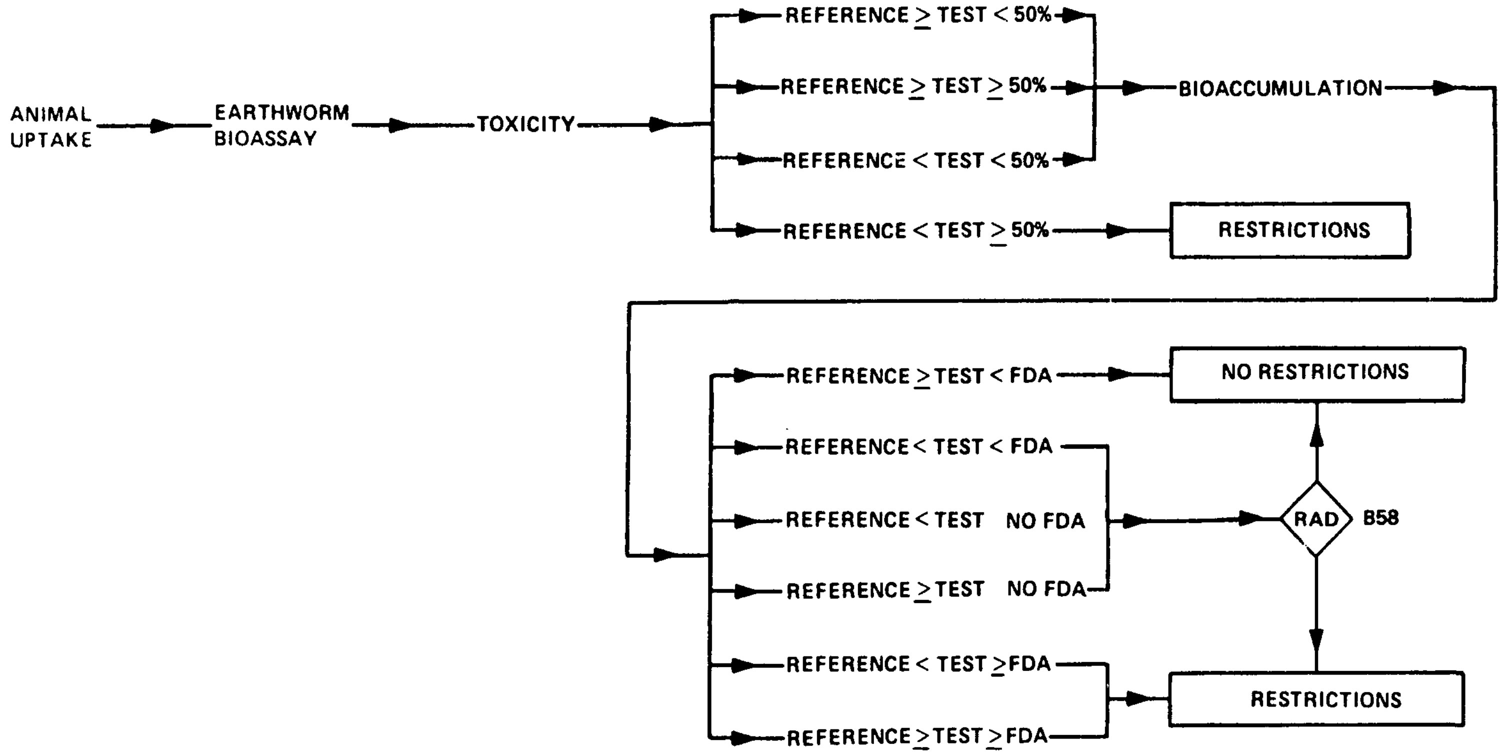

Figure B7. Flowchart for decisionmaking for potential animal uptake (number near RAD is paragraph discussing RAD). Bioaccumulation is assessed by chemical analysis of tissue from the earthworm toxicity bioassay and is not an independent test. This procedure can be done only if there is sufficient survival to permit tissue analysis

B57. Decisions from animal bioaccumulation evaluations. The regional authority must evaluate the potential for bioaccumulation of contaminants from sediment/dredged material. Bioaccumulation tests can result in six conditions (Figure B7, p B42).

a. Concentrations of *all* contaminants of concern in the tissues of animals exposed to the test sediment are *less than or equal to* concentrations in animals exposed to the reference sediment and *less than* FDA-type limits (Table C1). This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on soil-dwelling animals that colonize the dredged material.

b. Concentration of *any* contaminant of concern in the tissue of animals exposed to the test sediment is *greater than* reference animals and *equal to or greater than* FDA-type limits (Table C1).

c. Concentration of *any* contaminant of concern in the tissues of exposed animals is *less than or equal to* reference animals and *equal to or greater than* FDA-type limits (Table C1).

Conditions under subparagraphs B57b and c lead to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts on soil-dwelling animals that colonize the disposal site. Some potentially appropriate restrictions are described in paragraphs 98-109 and 113.

d. Concentration of *any* contaminant of concern in the tissues of animals exposed to the test sediment is *greater than* reference animals and *less than* FDA-type limits (Table C1).

e. Concentration of *any* contaminant of concern in the tissues of animals exposed to the test sediment is *greater than* reference animals and *no FDA-type limits have been established* (Table C1).

f. Concentration of *any* contaminant of concern in the tissues of animals exposed to the test sediment is *less than or equal to* reference animals and *no FDA-type limits have been established* (Table C1).

Conditions under subparagraphs B57d, e, and f lead to a REGIONAL ADMINISTRATIVE DECISION as discussed in paragraph B58.

B58. RAD: RESTRICTIONS/NO RESTRICTIONS/FURTHER EVALUATION. At present it is not possible to provide sufficient scientific basis for deciding on the need for restrictions on the cases of subparagraphs B57d, e, and f. Therefore, the regional authority must make an administrative decision using the available scientific information and regionally important concerns. In interpreting animal bioaccumulation data, scientific concern over potential adverse impacts associated with bioaccumulation increases in direct relation to:

a. Number of contaminants bioaccumulated to concentrations exceeding reference and/or demonstrated effects levels.

b. Magnitude of bioaccumulation above reference and/or demonstrated effects levels.

c. Toxicological importance of contaminants bioaccumulated to concentrations exceeding reference and/or demonstrated effects levels. Contaminants that can be objectively ranked in this manner are presented in Table C5.

d. Proportion of sediment sampling sites in the area being evaluated that show bioaccumulation to concentrations exceeding reference and/or demonstrated effects levels.

In the cases of subparagraphs B57d, e, and f, the regional authority may choose to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on soil-dwelling animals colonizing the dredged material. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount.* Regional authorities may wish to consider the TCPP as pseudocriteria applicable to the bioaccumulation of contaminants for which no FDA-type action levels or tolerance limits have been established (Table C2). This TCPP is based upon US Environmental Protection Agency (EPA) acceptable daily intake (ADI) values (Table C3). The regional authority could reach a DECISION FOR RESTRICTIONS if the concentration of any contaminants of concern in tissues was equal to or exceeded the TCPP for that contaminant. If the concentrations of all contaminants of concern were below the TCPP for the respective contaminants, then regional authority might reach a DECISION FOR FURTHER EVALUATION. On the other hand, the regional authority may choose to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts on soil-dwelling animals colonizing the dredged material. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 98-109 and 113.

Human Exposure Evaluation

B59. Soil ingestion can result from breathing dust and/or actual contact and intake of soil such as is the case with a child playing on the ground. In England surface soil contaminant limitations for human exposure are based on a child eating a handful of soil while playing on the ground. There are recommended limitations on the amount of sewage sludge metals that can be applied to agricultural cropland as related to background metal levels (Tables C11 and C12). Based on these limitations, a potential for human exposure to contaminants of concern in the test sediment under upland disposal environments could be evaluated by comparing total bulk chemical analysis data for the test sediment/dredged material to the values in Tables C11 and C12. Evaluation of human exposure could result in three conditions (Figure B8, p B46):

a. Concentrations of all contaminants of concern in the test sediment/dredged material are *less than* those specified in Tables C11 and/or C12. This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts due to human exposure to the test sediment/dredged material.

b. Concentrations of *any* contaminant of concern in the test sediment/dredged material is *equal to or greater than* that specified in Tables C11 and/or C12.

c. No value is tabulated for any of the contaminants of concern in Tables C11 or C12.

Conditions b and c lead to a REGIONAL ADMINISTRATIVE DECISION.

B60. RAD: NEED FOR RESTRICTIONS. At present it is not possible to provide sufficient scientific basis for deciding on the need for restrictions in the cases of subparagraphs B59b and c. Therefore, the regional authority must make an administrative decision using the available scientific information and regionally important concerns. While this approach to assessing human exposure may be crude and oversimplified, it can give some perspective to the potential human exposure that is evaluated for agricultural cropland and in Europe. This evaluation for human exposure could be used as guidance to the RAD for allowing the public access to the disposal site. In addition, the RAD might be to limit agricultural production of edible crops on test sediment/dredged material containing metal concentrations in excess of those allowed for sewage sludge application (Table C11).

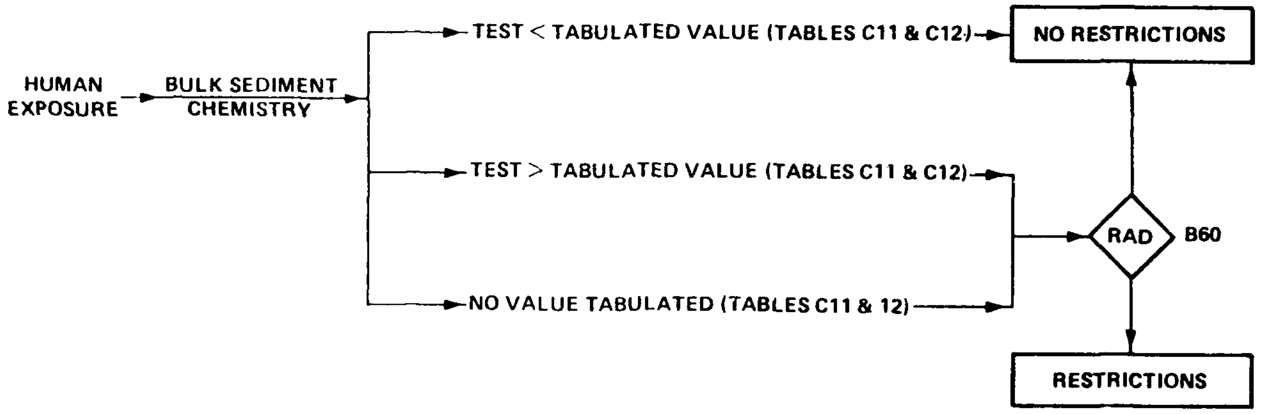

Figure B8. Flowchart for decisionmaking for potential human exposure

APPENDIX C: RELATED INFORMATION AND DATA TABLES

NOTE: All references cited in this appendix are included in the list of references that follows the main text.

Table C1

Action Levels and Maximum Concentrations for Contaminants in Aquatic Organisms for Human Consumption

Chemical	Food	Action Level* mg/kg (wet weight edible portions)	Maximum Concentration** mg/kg (wet weight edible portions)
Aldrin	Fish and shellfish	0.3	
Antimony	All nonspecified foods (including seafood)		1.5
Arsenic	Fish, crustacea, molluscs		1.0
Cadmium	Fish		0.2
	Molluscs		1.0
Chlordane	Fish	0.3	
Copper	Molluscs		70.0
	All nonspecified foods (including seafood)		10.0
DDT, DDE, TDE	Fish	5.0†	
Dieldrin	Fish and shellfish	0.3	
Endrin	Fish and shellfish	0.3	
Heptachlor, heptachlor epoxide	Fish and shellfish	0.3†	
Hexachlorocyclohexane (Benzene hexachloride)	Frog legs		0.5
Kepone (Chlordecone)	Fish and shellfish	0.3	
	Crabmeat	0.4	

(Continued)

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* US Food and Drug Administration (FDA) action levels for poisonous or deleterious substances in human food, CPG 7141.01, 1987.

** Australian National Health and Medical Research Council Standards for metals in food, May 1980.

† Action level is for these chemicals individually or in combination. However, in adding concentrations, do not count any concentrations below the following levels:

Chemical	Minimum Level, mg/kg
DDT, DDE, TDE	0.2
Heptachlor, heptachlor epoxide	0.3

Table Cl (Concluded)

Chemical	Food	Action Level mg/kg (wet weight edible portions)	Maximum Concentration mg/kg (wet weight edible portions)
Lead	Molluscs		2.5
	All nonspecified foods (including seafood)		1.5
Mercury	Fish, crustacea, molluscs		0.5
Methylmercury	Fish, shellfish, other aquatic animals	1.0	
Mirex	Fish	0.1	
PCB (total)	Fish and shellfish	2.0††	
Selenium	All nonspecified foods (including seafood)		1.0
Tin	Fish		50.0
Toxaphene	Fish	5.0	
Zinc	Oysters		1,000.0
	All nonspecified foods (including seafood)		150.0

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†† This is not an action level but is a tolerance limit established through the rulemaking process.

Table C2

Target Concentrations of Priority Pollutants

The target concentrations of priority pollutants (TCPP) given in the following tabulation were calculated from the acceptable daily intake (ADI) values in Table C3 (after Tetra Tech 1986) for selected rates of seafood consumption.

Tetra Tech (1986) states the following:

> The average ingestion rates used to calculate tissue contamination guidelines were 6.5 g/day, 20 g/day (which equals approximately 0.33 lb/wk, or about one average serving per week), and 165 g/day. Estimates of average seafood consumption rate were obtained from the literature. The 6.5 g/day estimate is the value used by USEPA (1980b) to derive water quality criteria. It represents the average per capita consumption of commercial fish and shellfish from estuarine and fresh waters in the U.S. based on data from National Marine Fisheries Service (1976). The U.S. Department of Agriculture (Johnson, E., 14 August 1984, personal communication) estimates that the average U.S. per capita consumption of commercial and recreational "seafood" from estuarine, marine, and freshwaters is about 20 g/day (also see National Marine Fisheries Service 1984). The 165 g/day estimate represents the average rate of consumption of commercial seafood by a small portion (about 0.1 percent) of the U.S. population (Finch 1973).

The choice of which target concentrations to use when FDA-type limits are not available depends upon the estimate of protection deemed necessary by the local authority. The 165 g/day values are the most conservative and, hence, the most protective. The use of TCPP and which values to use is a regional administrative decision (RAD).

(Continued)

Table C2 (Concluded)

Priority Pollutant No.	Pollutant	Consumption Rate, g/day-Target Concentration, mg/kg 6.5	20.0	165.00
126	Silver	2	0.8	0.10
123	Mercury	3	1.0	0.10
60	4,6-dinitro-o-cresol	4	1.0	0.20
127	Thallium	6	2.0	0.20
42	Bis (2-chloroisopropyl) ether	10	4.0	0.40
98	Endrin	10	4.0	0.40
59	2,4-dinitrophenol	20	7.0	0.80
33	1,3-dichloropropene	30	9.0	1.00
119	Chromium vi	30	9.0	1.00
95	Alpha-endosulfan	40	10.0	2.00
96	Beta-endosulfan	40	10.0	2.00
97	Endosulfan sulfate	40	10.0	2.00
114	Antimony	40	10.0	2.00
39	Fluoranthene	60	20.0	3.00
53	Hexachlorocyclopentadiene	60	20.0	3.00
125	Selenium	100	40.0	4.00
25	1,2-dichlorobenzene	100	50.0	6.00
26	1,3-dichlorobenzene	100	50.0	6.00
27	1,4-dichlorobenzene	100	50.0	6.00
7	Chlorobenzene	200	50.0	6.00
2	Acrolein	200	60.0	7.00
46	Bromomethane	200	80.0	9.00
124	Nickel	200	80.0	9.00
38	Ethylbenzene	200	80.0	10.00
64	Pentachlorophenol	300	100.0	10.00
31	2,4-dichlorophenol	1,000	400.0	40.00
65	Phenol	1,000	400.0	40.00
121	Cyanide	1,000	400.0	50.00
54	Isophorone	2,000	500.0	60.00
44	Dichloromethane	2,000	700.0	80.00
86	Toluene	5,000	1,000.0	200.00
11	1,1,1-trichloroethane	6,000	2,000.0	200.00
45	Chloromethane	6,000	2,000.0	200.00
56	Nitrobenzene	6,000	2,000.0	200.00
66	Bis(2-ethylhexyl)phthalate	6,000	2,000.0	300.00
68	Di-n-butyl phthalate	10,000	4,000.0	500.00
119	Chromium iii	20,000	6,000.0	800.00
71	Dimethyl phthalate	100,000	40,000.0	4,000.00
70	Diethyl phthalate	100,000	40,000.0	5,000.00

Table C3

Acceptable Daily Intake (ADI) Values for Priority Pollutants*

Priority Pollutant No.	Pollutant	CAS No.**	ADI		Criteria Page No.
			mg/day	mg/kg/day	
126	Silver		0.0160	0.0002	c-125
123	Mercury		0.0200	0.0003	c-106
60	4,6-dinitro-o-cresol	534-52-1	0.0270	0.0004	c-93
127	Thallium		0.0373	0.0005	c-39
42	Bis (2-chloroisopropyl) ether	39638-32-9	0.0700	0.0010	c-61
98	Endrin	72-20-8	0.0700	0.0010	b-12
59	2,4-dinitrophenol	51-28-5	0.1400	0.0020	c-92
33	1,3-dichloropropene	10061-02-6	0.1750	0.0020	c-27
119	Chromium VI		0.1750	0.0020	c-34
95	Alpha-endosulfan	115-29-7	0.2800	0.0040	c-87
96	Beta-endosulfan	115-29-7	0.2800	0.0040	c-87
97	Endosulfan sulfate	1031-07-8	0.2800	0.0040	c-87
114	Antimony		0.2900	0.0040	c-70
39	Flouranthene	206-44-0	0.4000	0.0060	c-47
53	Hexachlorocyclopentadiene	77-47-4	0.4180	0.0060	c-63
125	Selenium		0.7000	0.0100	c-66
25	1,2-dichlorobenzene	95-50-1	0.9400	0.0100	c-64
26	1,3-dichlorobenzene	541-73-1	0.9400	0.0100	c-64
27	1,4-dichlorobenzene	106-46-7	0.9400	0.0100	c-64
7	Chlorobenzene	108-90-7	1.0080	0.0100	c-20
2	Acrolein	107-82-8	1.1000	0.0200	c-53
46	Bromomethane	74-83-9	1.5000	0.0200	--
124	Nickel		1.5000	0.0200	--
38	Ethylbenzene	100-41-4	1.6000	0.0200	c-24
64	Pentachlorophenol	87-86-5	2.1000	0.0300	c-37
31	2,4-dichlorophenol	120-83-2	7.0000	0.1000	c-32
65	Phenol	108-95-2	7.0000	0.1000	c-37
121	Cyanide		7.6000	0.1000	--
54	Isophorone	78-59-1	10.5000	0.1500	c-20
44	Dichloromethane	75-09-02	13.0000	0.2000	--
86	Toluene	108-88-3	29.5000	0.4000	c-51
11	1,1,1-trichloroethane	71-55-6	37.5000	0.5000	c-77
45	Chloromethane	74-87-3	38.0000	0.5000	--
56	Nitrobenzene	98-95-3	40.0000	0.6000	c-30

(Continued)

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* Tetra Tech (1986).
Reference: US Environmental Protection Agency (EPA) (1980b).

** Chemical Abstract Service (CAS) identification number.
For each ADI, page citation for water-quality criteria document is shown in last column. Blanks in page citation column indicate that ADI values are errata to water-quality criteria (US EPA, 8 August 1984, personal communication to Tetra Tech, Inc.).

Table C3 (Concluded)

Priority Pollutant No.	Pollutant	CAS No.**	ADI		Criteria Page No.
			mg/day	mg/kg/ day	
66	Bis(2-ethylhexyl) phthalate	117-81-7	42.0	0.6	c-57
68	Di-n-butyl phthalate	87-74-2	88.0	1.0	c-57
119	Chromium III		125.0	2.0	--
71	Dimethyl phthalate	131-11-3	700.0	10.0	c-57
70	Diethyl phthalate	84-66-2	875.0	10.0	c-57

Table C4

Summary of EPA Water-Quality Criteria or Lowest Observed Effect Levels Where Criteria are Absent

Pollutant	Priority Pollutant (Carcinogen)**	Type Criteria - Concentration, μg/ℓ*			
		Fresh Water		Marine	
		Acute	Chronic	Acute	Chronic
Acenaphthalene	N				
Acenapthene	Y	1,700.000*	520.000*	970.0*	500*
Acrolein	Y	68.000	21.000*	55.0	
Acrylonitrile	Y (Y)	7,500.000*	2,600.000*		
Aldrin	Y (Y)	3.000		1.3	
Aluminum	N				
Ammonia, total	N	15.700	3.900		
Ammonia, unionized	N	0.092	0.022		
Analine	N				
Antimony	Y	9,000.000*	1,600.000*		
Arsenic	N	360.000	190.000		
Arsenic (V)	N	850.000*	48.000*	2,319.0*	13*
Arsenic (III)	Y (Y)	360.000	190.000	69.0	36
Asbestos	Y (Y)				
Barium	N				
Benzene	Y	5,300.000*		5,100.0*	700*
Benzidine	Y (Y)	2,500.000*			
Beryllium	Y (Y)	130.000*	5.300*		
BHC	Y	100.000*	0.340*		
Bis-2-chloroethoxy methane	N				

(Continued)

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* An asterisk (*) following a number indicates that the value represents the lowest observed effect level (LOEL); when no asterisk appears, the value is an established EPA water-quality criterion.

** The first letter indicates that the compound is (Y) or is not (N) an EPA priority pollutant; the letter in parentheses designates a known carcinogen (Y) or a suspected carcinogen (S).

(Sheet 1 of 5)

Table C4 (Continued)

Pollutant	Priority Pollutant (Carcinogen)	Type Criteria - Concentration, µg/ℓ*			
		Fresh Water		Marine	
		Acute	Chronic	Acute	Chronic
Boron	N				
Butybenzylpthalate	N				
Cadmium	Y	3.9	1.1000	43.000	9.300
Carbazole	N				
Carbon tetrachloride	Y (Y)	35,200.0*		50,000.000*	
Chloralkyl ethers	Y	238,000.0*			
Chlordane	Y	2.4	0.0043	0.004	0.090
Chlorinated benzenes	Y	250.0*	50.0000*	160.000*	129.000*
Chlorinated ethanes	Y (S)				
Chlorinated ethers	N				
Chlorinated naphthalenes	Y	1,600.0*		7.500*	
Chlorinated phenols	Y	500,000.0*			
Chlorine	N	19.0	11.0000	13.000	7.500
Chloro-4 methyl-3 phenol	N	30.0*			
Chloroform	Y	28,900.0*	1,240.0000*		
Chlorophenol	N			440.000*	
Chlorophenol 2	Y	4,380.0*	2,000.0000*		
Chlorophenol 4	N			29,700.000*	
Chlorophenoxy herbicides	N				
Chromium (VI)	Y	16.0	11.0000	1,100.000	50.000
Chromium (III)	Y	1,700.0*	210.0000*	10,300.000*	
Copper	Y	18.0*	12.0000*	2.900	2.900
Cyanide	Y	22.0	5.2000	1.000	1.000
DDE	Y	1,050.0*		14.000*	
DDT	Y (Y)	1.1	0.0010	0.130	0.001
DEHP	N				
Demeton	N		0.1000*		0.100*
Diamino toluene	N				

(Continued)

(Sheet 2 of 5)

Table C4 (Continued)

Pollutant	Priority Pollutant (Carcinogen)	Type Criteria - Concentration, µg/ℓ*			
		Fresh Water		Marine	
		Acute	Chronic	Acute	Chronic
Dibenzofurans	N				
Dichlorinated ethanes	N	118,000.00*	20,000.00000*	113,000.000*	
Dichlorobenzenes	Y	1,120.00*	763.00000*	1,970.000*	
Dichlorobenzidines	Y				
Dichloroethylene	Y (Y)	11,600.00*		224,000.000*	
Dichlorophenol 2,4	N	2,020.00*	365.00000*		
Dichloropropane	Y	23,000.00*	5,700.00000*	10,300.000*	3,040.0000*
Dichloropropene	Y	6,060.00*	244.00000*	790.000*	
Dieldrin	Y (Y)	2.50	0.00190	0.710	0.0019
Dimethyl phenol	Y				
Dimethyl phenol 2,4	Y	2,120.00*			
Dimethylsulfoxide	N				
Dinitrobenzene 1,3	N				
Dinitrotoluene 2,4	Y (Y)				
Dioxane P	N				
Dioxin	Y	0.01*	0.00001*		
Diphenylhydrazine	Y				
Endosulfan	Y	0.22	0.05600	0.034	0.0087
Endrin	Y	0.18	0.00230	0.037	0.0023
Ethylbenzene	Y	32,000.00*		430.000*	
Flouranthene	Y	3,980.00*		40.000*	16.0000*
Fluoride	N				
Guthion	N		0.01000*		0.0100*
Haloethers	Y	360.00*	122.00000*		
Halomethanes	Y (Y)	11,000.00*		12,000.000*	6,400.0000*
Heptachlor	Y (Y)	0.52	0.00380	0.053	0.0036

(Continued)

(Sheet 3 of 5)

Table C4 (Continued)

Pollutant	Priority Pollutant (Carcinogen)	Type Criteria - Concentration, µg/ℓ*			
		Fresh Water		Marine	
		Acute	Chronic	Acute	Chronic
Hexachlorobutadiene	Y (Y)	90.000*	9.300*	32.00*	
Hexachlorocyclohexane (Lindane)	Y (S)	2.000	0.080	0.16	
Hexachlorocyclopentadiene	Y	7.000*	5.200*	7.00*	
Hexachlorocycloethylenes	N				
Hexachlorinated ethanes	Y	980.000*	540.000*	940.00*	
Iron	N	1,000.000*			
Isophorone	Y	177,000.000*		12,900.00*	
Lead	Y	8.200	3.200	140.00	5.600
Malathion	N		0.100*		0.100*
Manganese	N				
Mercury	Y	2.400	0.012	2.10	0.025
Methoxychlor	N		0.030*		0.030*
Mirex	N		0.001*		0.001*
Naphthalene	Y	2,300.000*	620.000*	2,350.00*	
Nickel	Y	1,400.000	160.000*	75.00	8.300
Nitroaniline	N				
Nitrobenzene	Y	27,000.000*		6,680.00*	
Nitrophenols	Y	230.000*	150.000*	4,850.00*	
Nitrosamines	Y (S)	5,850.000*		3,300,000.00†	
Organotins	N				
Parathion	N	0.065	0.013*		0.040*
PCB	Y (Y)	2.000	0.014	10.00	0.030
Pentachlorinated ethanes	Y	7,240.000*	1,100.000*	390.00*	281.000*
Pentachlorophenol	Y	20.000†	13.000†	13.00*	7.900*
Phenol	Y	10,200.000*	2,560.000*	5,800.00*	

(Continued)

† Editor's note: This entry is questionable and is being verified.

(Sheet 4 of 5)

Table C4 (Concluded)

Pollutant	Priority Pollutant (Carcinogen)	Type Criteria - Concentration, µg/ℓ*			
		Fresh Water		Marine	
		Acute	Chronic	Acute	Chronic
Phosphorus	N				0.0100*
Phthalate esters	Y	940.00*	3.0000*	2,944.00*	3.4000
Polychlorinated diphenyl ethers	N				
Polynuclear aromatic hydrocarbons	Y (Y)			300.00*	
Pthalate esters	N				
Selenium	Y	260.00	35.0000	410.00	54.0000
Silver	Y	4.10	0.1200	2.30	
Styrene	N				
Sulfide-hydrogen sulfide	N		2.0000*		2.0000*
TDE	Y	0.60*		3.60*	
Tetrachlorinated ethanes	Y	9,320.00*	2,400.0000*	9,020.00*	
Tetrachlorobenzene 1,2,4,5	Y	250.00*	50.0000*	160.00*	129.0000*
Tetrachloroethylene	Y (Y)	5,280.00*	840.0000*	10,200.00*	450.0000*
Tetrachlorophenol 2,3,4,6	Y				
Tetramethyl lead	N				
Thallium	Y	1,400.00*	40.0000*	2.13*	
Toluene	Y	17,500.00*		6,300.00*	5,000.0000*
Toxaphene	Y (Y)	0.73	0.0002	0.21	0.0002
Trichlorinated ethanes	Y (Y)	18,000.00*	9,400.0000*	31,200.00*	
Trichlorobenzene	Y				
Trichlorobenzene 1,2,3	Y				
Trichloroethylene	Y	45,000.00*	21,900.0000*	2,000.00*	
Trichlorophenol 2,3,6	Y				
Trichlorophenol 2,4,5	Y				
Trichlorophenol 2,4,6	N (Y)		970.0000		
Vinyl chloride	Y (Y)				
Xylene	N				
Zinc	Y	120.00*	110.0000*	95.00	86.0000

(Sheet 5 of 5)

Table C5

Ranking of Toxicological Importance of Contaminants Based on EPA 24-hr Average (Chronic) Water-Quality Criteria for the Protection of Aquatic Life

Rank	Criteria Range μg/ℓ	Contaminant* Fresh Water**	Salt Water
6	0.0001-0.001	Mercury	
5	0.001-0.01	DDT Dieldrin Endrin Heptachlor Chlordane	DDT Dieldrin Endrin Heptachlor Chlordane Endosulfan
4	0.01-0.1	Toxaphene PCB (total) Cadmium Endosulfan Lindane	Mercury PCB (total)
3	0.1-1.0	Chromium	†
2	1-10	Cyanide Lead Copper	Copper Cadmium Nickel
1	10-100	Selenium Zinc Nickel	Selenium Zinc

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* Within each rank, contaminants are listed in order of increasing criterion values.

** Metals are ranked according to the criterion at a hardness of 100 mg/ $CaCO_3$.

† No saltwater chronic criteria fall in this range.

Table C6

Standards for Contaminant Concentrations in Drinking Water

Parameter, mg/ℓ (unless otherwise noted)	Drinking Water Standards	
	Federal	State of Washington
Arsenic	0.0500	0.0500
Barium	1.0000	1.0000
Cadmium	0.0100	0.0100
Chromium	0.0500	0.0500
Lead	0.0500	0.0500
Mercury	0.0020	0.0020
Selenium	0.0100	0.0100
Silver	0.0500	0.0500
Fluoride	1.4-2.4000	1.4-2.4000
Nitrate (as N)	10.0000	10.0000
Endrin	0.0002	0.0002
Lindane	0.0040	0.0040
Methoxychlor	0.1000	0.1000
Toxaphene	0.0050	0.0050
2,4-D	0.1000	0.1000
2,4,5-TP Silvex	0.0100	0.0100
Trihalomethanes	0.1000	0.1000
Turbidity (JU)	1.0000	1.0000
Coliform bacteria membrane filter test (lb/100 mℓ)	1.0000	1.0000
Gross alpha (pCi/ℓ)	15.0000	15.0000
Combined Radium 226 and Radium 228	5.0000	5.0000
Beta and photon particle activity (Mrem/yr)	4.0000	4.0000
Sodium	Monitor	250.0000
Chloride	250.0000	250.0000
Color (unit	15.0000	15.0000
Copper	1.0000	1.0000
Corrosivity	Noncorrosive	Noncorrosive
Foaming agents	0.5000	0.5000
Iron	0.3000	0.3000
Manganese	0.0500	0.0500
Odor (threshold number)	3.0000	3.0000
pH (units)	6.5-8.5000	6.5-8.5000
Sulfate	250.0000	250.0000
Total dissolved solids	500.0000	500.0000
Zinc	5.0000	5.0000

Table C7

Demonstrated Effects of Contaminants on Plants

Contaminant	Plant Growth Effect-Contaminant Content, mg/kg leaves				
	Normal*	Critical Content**	10% Yield Reduction**	25% Yield Reduction†	Phytotoxic*
Arsenic	0.1-1	--	--	--	3-10
Boron	775	--	--	--	75
Cadmium	0.1-1	8	15	Varies	5-700
Cobalt	0.01-0.3	--	--	--	25-100
Chromium (III), oxides	0.1-1	--	--	--	20
Copper	3-20	20	20	2040	25-40
Fluorine	1-5	--	--	--	--
Iron	30-300	--	--	--	--
Manganese	15-150	--	--	500	400-2,000
Molybdenum	0.1-3.0	--	--	--	100
Nickel	0.1-5	11	26	50-100	500-1,000
Lead	2-5	--	--	--	--
Selenium	0.1-2	--	--	--	100
Vanadium	0.1-1	--	--	--	10
Zinc	15-150	200	290	500	500-1,500

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* From Chaney (1983).

** From Davis, Beckett, and Wollan (1978); Davis and Beckett (1978); Beckett and Davis (1977).

† From Chaney et al. (1978).

Table C8

Maximum Recommended Application of Municipal Sludge-Applied Metals to Medium-Textured Cropland Soils to Prevent Phytotoxicity*

	Maximum Application		
Contaminant	kilograms/hectare	pounds/acre	milligrams/kilogram
Lead	1,000.0	891.0	500.0**
Zinc	560.0	446.0	250.0
Copper	280.0	223.0	125.0
Nickel	112.0	111.0	62.0
Cadmium	11.2	4.5	2.5

Note: Soil bulk density 1.33; potentially acidic soil. Recommended limits to prevent yield reduction in sensitive vegetable crops at pH ≥ 6.2 , or most crops and cover crops at pH ≥ 5.5 .

* EPA, US Department of Agriculture, USFDA (1981).

** Maximum allowable lead content in soil for human child exposure as related to direct soil ingestion in the United Kingdom and in the United States.

Table C9

Action Levels for Various Heavy Metals and Pesticides in Plants and Foodstuffs

Substance	Commodity	Data Source*	Action Level	Type of Limit**	Step†	Reference††
Aflatoxin	Cottonseed meal (non-dairy)		300.0000 ppb			
	Finished feeds	1	20.0000 ppb	--	--	CPG 7126.33
	Brazil nuts	1	20.0000 ppb	--	--	CPG 7112.07
	Peanuts	1	20.0000 ppb	--	--	CPG 7112.02
	Pistachio nuts	1	20.0000 ppb	--	--	CPG 7112.08
Aldrin and dieldrin	Grain (raw cereal)	2	0.0200 mg/kg	PRL	9	--
	Rice (in the husk)	2	0.0200 mg/kg	T	9	--
	Animal feed	1	0.0300 ppm	--	--	CPG 7141.01-B.1
	Vegetables	2	0.1000 mg/kg	T	9	--
	Artichokes	1	0.0500 ppm	--	--	CPG 7141.01-B.1
	Lettuce and carrots	2	0.1000 mg/kg	PRL	9	--
	Fruits	1	0.0500 ppm	--	--	CPG 7141.01-B.1
	Melons	1	0.1000 ppm	--	--	CPG 7141.01-B.1
	Sugarbeet pulp	1	0.1000 ppm	--	--	CPG 7141.01-B.1
Arsenic	Non-pulpy black-currant nectar	3	0.2000 mg/kg	--	--	CAC/RS 101-1978
	Fructose	3	1.0000 mg/kg			CAC/RS 102-1978
	Cocoa powders and dry cocoa-sugar mixtures	3	1.0000 mg/kg			CAC/RS 105-1978
Benzene hexachloride (BHC)	Grain (animal feed)	1	0.0500 ppm	--	--	CPG 7141.01-B.2
	Grain (human food)	1	0.0500 ppm	--	--	CPG 7141.01-B.2
	Vegetables	1	0.5000 ppm	--	--	CPG 7141.01-B.2
	Fruits	1	0.5000 ppm	--	--	CPG 7141.01-B.2
Cadmium	Provisional weekly tolerance intake for humans	2	0.0067- 0.0083 mg/kg body weight			

(Continued)

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* Data source:

1 - FDA action levels for poisonous or deleterious substances in human food and animal feed, March 1987.
2 - (1982) Food and Agricultural Organization (FAO)/World Health Organization (WHO) Guide to Codex Maximum Limits for Pesticide Residues
3 - List of maximum levels recommended for contaminants by the joint FAO/WHO Codex Alimentarius Commission. Joint FAO/WHO food standards programme Codex Alimentarius Commission CAC/FAL 4-1978.

** Type of limit:

CPG - Compliance policy guidelines
TT - Temporary codex tolerance
T - Codex tolerance
PRL - Practical residue limit

† Step - Step in the procedure for the elaboration of Codex Maximum Limits for Pesticide Residue given in the FAO/WHO Guide to CODEX M

†† Reference - Refers to CPG number

(Sheet 1 of 5)

Table C9 (Continued)

Substance	Commodity	Data Source	Action Level	Type of Limit	Step	Reference
Chlordane	Root and tuber vegetables	2	0.30 mg/kg	T	6	71(1)
	Sugar beet	2	0.30 mg/kg	T	9	--
	Leafy vegetables	2	0.20 mg/kg	T	6	71(1)
	Stem vegetables	2	0.20 mg/kg	T	6	71(1)
	Legume vegetables	2	0.02 mg/kg	T	9	--
	Fruiting vegetables	2	0.10 mg/kg	T	9	--
	Citrus fruits	2	0.02 mg/kg	T	9	--
	Assorted fruits	2	0.10 mg/kg	T	6	--
	Pineapple	2	0.10 mg/kg	T	9	--
	Passion fruit	2	0.10 mg/kg	T	6	72(1)
	Pome fruit	2	0.02 mg/kg	T	9	--
	Stone fruit	2	0.02 mg/kg	T	9	--
	Small fruits and berries	2	0.10 mg/kg	T	6	--
	Cottonseed oil, crude	2	0.10 mg/kg	T	9	--
	Cottonseed oil, edible	2	0.02 mg/kg	T	9	--
	Linseed oil, crude	2	0.50 mg/kg	T	9	--
	Soya bean oil, crude	2	0.50 mg/kg	T	9	--
	Soya bean oil, edible	2	0.02 mg/kg	T	9	--
	Grain, animal feed	1	0.10 ppm	--	--	CPG 7141.01-B.3
	Nuts	2	0.10 mg/kg	--	--	--
Copper	Non-pulpy black-currant nectar	3	5.00 mg/kg	--	--	CAC/RS 101-1978
	Fructose	3	2.00 mg/kg	--	--	CAC/RS 102-1978
	Cocoa powders and dry cocoa-sugar mixtures	3	50.00 mg/kg	--	--	CAC/RS 105-1978
	Edible acid casein	3	5.00 mg/kg	--	--	18th sessions-1976
	Edible caseinates	3	5.00 mg/kg	--	--	App. VI, CS 5/70 18th session-1976
Crotalaria Seeds	Grains and feeds	1	Avg of one whole seed/pound	--	--	CPG 7126.15
DDT, DDE, and TDE	Grain, animal feed	1	0.50 ppm	--	--	CPG 7141.01-B.5
	Grain, human food	1	0.50 ppm	--	--	CPG 7141.01-B.5
	Cocoa beans	1	1.00 ppm	--	--	CPG 7141.01-B.5
Endrin	Vegetables	1	0.05 ppm	--	--	CPG 7141.01-B.7
	Fruits	1	0.05 ppm	--	--	CPG 7141.01-B.7
	Oilseed meal, animal feed	1	0.03 ppm	--	--	CPG 7141.01-B.7
	Cottonseed oil, crude	2	0.10 mg/kg	T	9	--
	Cottonseed oil, edible	2	0.02 mg/kg	T	9	--
	Linseed oil, crude	2	0.50 mg/kg	T	9	--

(Continued)

(Sheet 2 of 5)

Table C9 (Continued)

Substance	Commodity	Data Source	Action Level	Type of Limit	Step	Reference
Endrin (Continued)	Soya bean oil, crude	2	0.50 mg/kg	T	9	--
	Soya bean oil, edible	2	0.02 mg/kg	T	9	--
	Vegetable oils and fats	1	0.30 ppm	--	--	CPG-7141.01-B.7
	Nuts	2	0.10 mg/kg	T	6	72 (1)
Fenthion	Root and tuber vegetables	2	0.10 mg/kg	TT	3	JMPR 1977
	Bulb vegetables	2	0.10 mg/kg	TT	3	JMPR 1977
	Squash	2	0.20 mg/kg	TT	6	--
	Leafy vegetables	2	2.00 mg/kg	TT	6	--
	Brassica leafy vegetables	2	1.00 mg/kg	TT	6	--
	Legume vegetables	2	0.10 mg/kg	TT	3	--
	Assorted fruits	2	2.00 mg/kg	TT	6	--
	Bananas	2	1.00 mg/kg	TT	3	JMPR 1977
	Stone fruits	2	0.20 mg/kg	TT	6	--
	Plums	2	0.10 mg/kg	TT	3	JMPR 1977
	Small fruits and berries	2	0.20 mg/kg	TT	3	JMPR 1977
	Grapes	2	0.50 mg/kg	TT	6	--
	Cereal grains	2	0.10 mg/kg	TT	6	--
	Oilseed	2	0.10 mg/kg	TT	6	--
Heptachlor and heptachlor-epoxide	Vegetables	2	0.05 mg/kg	PRL	9	--
	Vegetables	1	0.01 ppm	--	--	CPG 7141.01-B.9
	Tomato	2	0.02 mg/kg	PRL	9	--
	Carrot	2	0.20 mg/kg	PRL	9	--
	Sugar beet	2	0.05 mg/kg	PRL	9	--
	Fruits	1	0.01 ppm	--	--	CPG 7141.01-B.9
	Fruits	2	0.01 mg/kg	PRL	9	--
	Grain, animal feed	1	0.01 ppm	--	--	CPG 7141.01-B.9
	Rice, human food	1	0.03 ppm	--	--	CPG 7141.01-B.9
	Raw cereal	2	0.02 mg/kg	PRL	9	--
	Soya bean oil, crude	2	0.50 mg/kg	PRL	9	--
	Soya bean oil, edible	2	0.02 mg/kg	PRL	9	--
	Cottonseed	2	0.02 mg/kg	PRL	9	--
Iron	Non-pulpy black currant nectar	3	15.00 mg/kg	--	--	CAC/RS 101-1978, App. V., CX 5/70
	Edible acid casein	3	20.00 mg/kg	--	--	18th session-1976
	Edible caseinates	3	50.00 mg/kg	--	--	App. VI, CX 5/70 18th session-1976
Kelthane (*Didofol*)	*Animal feed*	*1*	*0.50 ppm*	--	--	*CPG 7141.01-B.6*
Kepone (Chlordecone)	--	--	--	--	--	CPG 7141.01-B.4

(Continued)

(Sheet 3 of 5)

Table C9 (Continued)

Substance	Commodity	Data Source	Action Level	Type of Limit	Step	Reference
Lead	Non-pulpy black currant nectar	3	0.3000 mg/kg	--	--	CAC/RS 101-1978
	Cocoa powders and dry cocoa-sugar mixtures	3	2.0000 mg/kg	--	--	CAC/RS 105-1978
	Edible acid casein	3	2.0000	--	--	App. V, CS 5/70 18th session
	Edible caseinates	3	2.0000	--	--	App. VI, CS 5/70 18th session
Lindane	Vegetables	1	0.5000 ppm	--	--	CPG 7141.01-B.10
	Root and tuber vegetables	2	0.0500 mg/kg	T	5	JMPR 1975
	Leafy vegetables	2	0.2000 mg/kg	T	3	JMPR 1975
	Brassica vegetables	2	0.5000 mg/kg	T	3	JMPR 1975
	Stem vegetables	2	0.5000 mg/kg	T	5	JMPR 1975
	Legume vegetables	2	0.1000 mg/kg	T	9	109 (1)
	Peas	2	0.1000 mg/kg	T	5	JMPR 1975
	Assorted fruits	2	0.5000 mg/kg	T	9	110 (1)
	Small fruits and berries	2	0.5000 mg/kg	T	3	111 (5)
	Cranberries	2	0.3000 mg/kg	T	5	
	Fruits	1	0.5000 ppm	--	--	CPG 7141.01-B.10
	Grain, animal feed	1	0.1000 ppm	--	--	CPG 7141.01-B.10
	Grain, human food	1	0.1000 ppm	--	--	CPG 7141.01-B.10
Mercury	Wheat (pink kernels only)	1	1.0000 ppm	--	--	CPG 7104.05
	Provisional tolerable weekly intake for humans	3	0.0050 mg total Hg/kg body weight 0.0033 mg methylmercury/kg body weight			
Methyl alcohol	Imported brandy	1	0.3500 percent	--	--	CPG 7119.09
Nitrosodimethylamine (NDMA)	Barley malt	1	10.0000 ppb	--	--	CPG 7104.07
	Malt beverages	1	5.0000 ppb	--	--	CPG 7101.07
Paralytic shellfish toxin	--	--	--	--	--	--
Polychlorinated biphenyls (PCB's)	Red meat fat		3.0000 ppm	--	--	21 CFR 109.30 (a) (9) and 509.30 (a) (9) tolerance used stayed on 8-24-73 (38 FR 22794) 21 CFR 109.6 (d) and 509.6 (d)

(Continued)

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Table C9 (Concluded)

Substance	Commodity	Data Source	Action Level	Type of Limit	Step	Reference
Tin	Canned fruit cocktail	3	250.0 mg/kg	--	--	CAC/RS 78-1974
	Canned mature processed peas	3	250.0 mg/kg	--	--	CAC/RS 81-1976
	Canned tropical fruit salad	3	250.0 mg/kg	--	--	CAC/RS 99-1978
	Non-pulpy black currant nectar	3	150.0 mg/kg	--	--	CAC/RS 101-1978
Toxaphene	Animal feed, processed	1	0.5 ppm	--		CPG 7141.01-B.12
	Vegetables	1	1.0 ppm	--	--	CPG 7141.01-B.12
	Fruits	1	1.0 ppm	--	--	CPG 7141.01-B.12
Zinc	Non-pulpy black currant nectar	3	5.0 mg/kg	--	--	CAC/RS 101-1978

(Sheet 5 of 5)

Table C10

Additional Action Levels for Contaminants in Foodstuffs Used by Various Countries

Source	Contaminant	Commodity	Content, mg/kg	References
Britain	Lead	All foods	1.00 (fresh wt)	MAFF (1972)
World Health Organization (WHO)	Lead	Root vegetables	0.10 (fresh wt)	WHO (1972)
		Cereal	0.10 (fresh wt)	
		Leafy vegetables	1.20 (fresh wt)	
	Cadmium	Root vegetables	0.05 (fresh wt)	WHO (1972)
		Leafy vegetables	0.10 (fresh wt)	
		Potatoes, cereal	0.10 (fresh wt)	
Dutch	Copper	Animal feed	20.00 (dry wt)	DMAFCMN (1973)
Dutch (unofficial)	Cadmium	Single animal feed	0.50 (dry wt)	European Community (1974)
		Mixed animal feed	1.00 (dry wt)	
		Roughage	1.00-2.00 (fresh wt)	
European Economic Community	Lead	Single animal feed	10.00 (dry wt)	Van Driel, Smilde, and Van Luit (1983)
		Mixed animal feed	5.00 (dry wt)	
		Roughage	40.00 (fresh wt)	
FDA (as of Sep 82)	Mercury	Wheat seed	1.00 (dry wt)	FDA (1987)
	Various pesticides	Vegetables, grains, and feeds	0.03-0.10	

Table C11

Background Levels and Allowable Applications of Several Heavy Metals for US Cropland Soils*

Parameter	Background Concentration in Surface Soils, mg/kg 5 percentile	median	95 percentile	No Effect Allowed Addition** kg/ha	Median + Allowed Application mg/kg
Lead	4.000	11.00	27.00	1,000	511.0
Zinc	7.300	54.00	129.00	500	304.0
Copper	3.700	19.00	96.00	250	144.0
Nickel	3.800	19.00	59.00	125	82.0
Cadmium	0.035	0.20	0.78	5	2.7
pH	4.600	6.10	8.1	--	--

* Holnigren et al. (1987) and Table C8.

** Allowed application is mixed into the 0-15 cm (0-6 in.) surface layer of soil.

Table C12

Recommended or Regulated Limitations on Potentially Toxic Constituents in Surface (0-15 cm) Soils

Basis for Limitation	Contaminant	Soil Concentration	Reference
Soil ingestion	Lead	500.00 mg/kg	EPA (1977)
	Mercury	5.00 mg/kg	
	PCBs, etc.	2.00 mg/kg	Fries (1982)
Plant uptake	Cadmium	2.50 mg/kg (pH 5.5)	EPA (1979)
Phytotoxicity	Zinc	250.00 mg/kg	Logan and Chaney (1983)
	Copper	125.00 mg/kg	
	Nickel	62.00 mg/kg	
	Cobalt	62.00	
Leaching	Cr (VI)	0.05 mg/ℓ	EPA drinking water standard (Table C4)

APPENDIX D: MIXING-ZONE PROCEDURES

LIST OF FIGURES

NOTES: Alphanumeric identification of pages, paragraphs, and figures was used in the appendixes to distinguish them from the simple numbers used as identification in the main text. Thus references to simple numbers in the appendixes refer to similarly numbered items in the main text.

Mixing zone procedures given in paragraphs D1-D36 were taken from a report prepared by the US Army Engineer Waterways Experiment Station (1976).

All references cited in this appendix are included in the list of references that follows the main text.

APPENDIX D: MIXING-ZONE PROCEDURES

Volume of Dilution Water

D1. 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 tests described in the main text to determine the concentration of the critical constituents of greatest concern in the elutriate and in disposal site water or to obtain appropriate results from bioassays.

D2. 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 elutriate resulting in a dilution factor D. Since the mass of the constituent of interest in one volume of standard elutriate is (1) (Ce), the mass of the constituent in D volumes of disposal site water is (D)(Ca), 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 values 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.

$$D = \frac{C_e - C_s}{C_s - C_a} \qquad \text{(D1)}$$

where

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

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

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

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

D3. The total volume of water necessary to dilute a discharge of dredged material to acceptable levels is equal to the volume calculated in Equation D1 times the total volume of dredged material. This can be expressed as:

$$M = D\ V_d \tag{D2}$$

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

V_d = volume of dredged material, cu yd

D4. 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 D1 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 Federal 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 A).

Initial Mixing Using Mathematical Models

D5. The first and most preferred method of evaluating the initial mixing requires use of comprehensive field data relevant to the proposed disposal operation in conjunction with an appropriate mathematical model for adequate prediction of initial mixing and dispersion. However, the amount of field data necessary for adequate prediction of dispersion and diffusion is substantial, and such predictions require a detailed understanding of tides, currents, waves, water column stratification, and climatic conditions at the disposal site. Appropriate models have been developed for discrete discharge from a barge, from a hopper dredge, and for a continuous pipeline disposal operation (Johnson 1988).

Simplified Approach for Shape of Mixing Zone

D6. For small projects with little anticipated impact, a simplified approach for calculation of mixing zones may be used. 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 simplified approach for mixing zone evaluation 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

D7. The general shape with greatest apparent applicability to discrete discharge operations is that of a conical frustum whose volume M is defined by:

$$M = \frac{d}{3} A_b + \sqrt{A_b A_t} + A_t \qquad (D3)$$

where

d = height of frustum

A_b = area of lower base of frustum

A_t = area of upper base of frustum

D8. Five different combinations of disposal operations and ambient current conditions are considered for discrete discharge operations (Figure D1). 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 D4-D13 in Figure D1 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

T = time required to empty vessel during discharge

V_w = water velocity at proposed disposal site

X = horizontal transport distance of dredged material

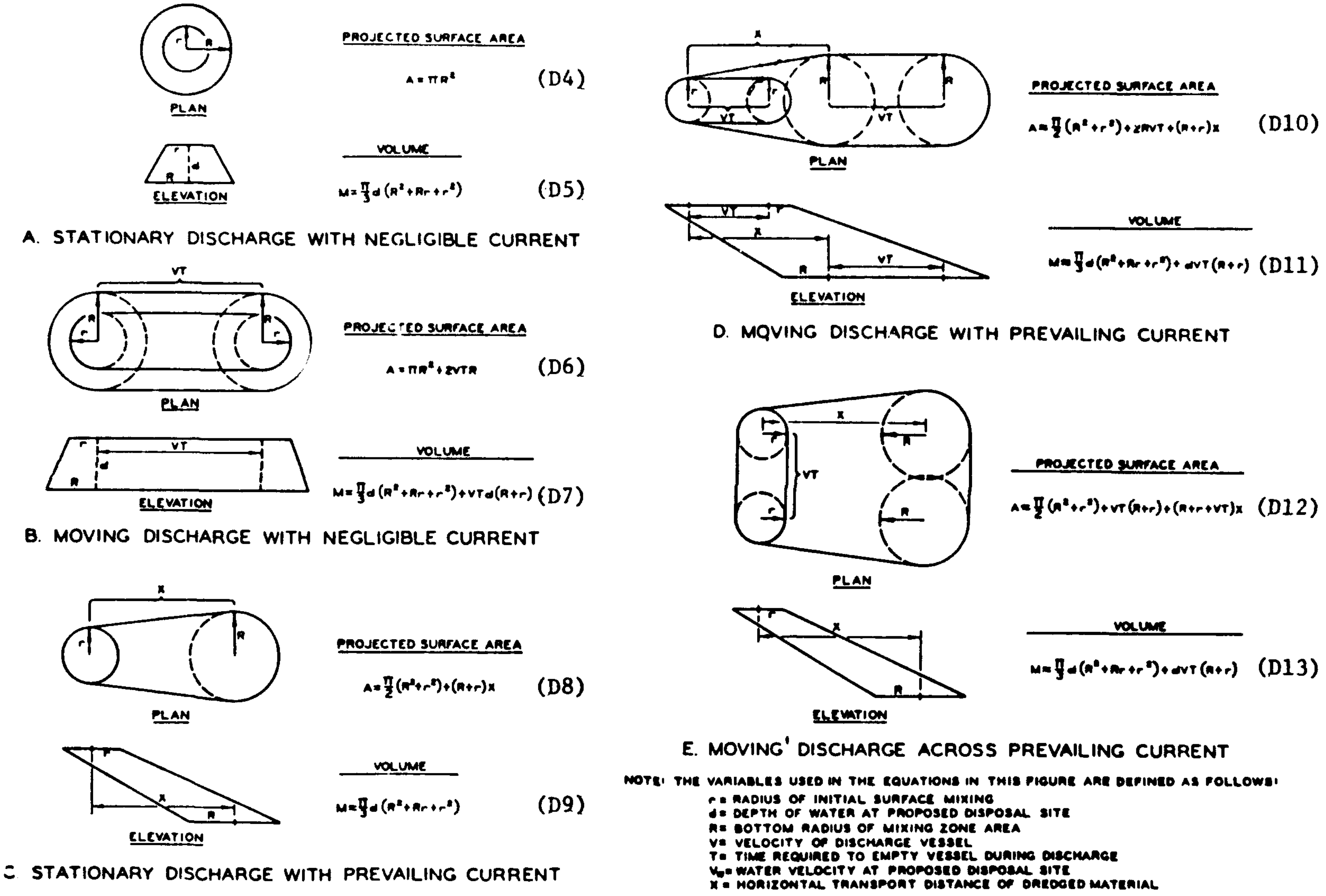
D9. The value r is intended to approximate the initial surface mixing that will occur at a disposal site. This value will be site-specific and will vary with the type of disposal operation. In the absence of better information, an upper value for r can be estimated as 100 m as suggested by the US Environmental Protection Agency (EPA) (1973) or as one half the length of the discharge vessel.

D10. 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.

D11. 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:

$$X = \left(\frac{\text{depth of water column}}{\text{appropriate settling velocity}}\right) \text{water velocity}$$

$$= \left(\frac{d}{V_s}\right) V_w \qquad \text{(D14)}$$



A. STATIONARY DISCHARGE WITH NEGLIGIBLE CURRENT

PROJECTED SURFACE AREA

$$A = \pi R^2 \tag{D4}$$

VOLUME

$$M = \frac{\pi}{3} d \left(R^2 + Rr + r^2\right) \tag{D5}$$

B. MOVING DISCHARGE WITH NEGLIGIBLE CURRENT

PROJECTED SURFACE AREA

$$A = \pi R^2 + 2VTR \tag{D6}$$

VOLUME

$$M = \frac{\pi}{3} d \left(R^2 + Rr + r^2\right) + VTd(R + r) \tag{D7}$$

C. STATIONARY DISCHARGE WITH PREVAILING CURRENT

PROJECTED SURFACE AREA

$$A = \frac{\pi}{2}\left(R^2 + r^2\right) + (R + r)x \tag{D8}$$

VOLUME

$$M = \frac{\pi}{3} d \left(R^2 + Rr + r^2\right) \tag{D9}$$

D. MOVING DISCHARGE WITH PREVAILING CURRENT

PROJECTED SURFACE AREA

$$A = \frac{\pi}{2}\left(R^2 + r^2\right) + 2RVT + (R + r)x \tag{D10}$$

VOLUME

$$M = \frac{\pi}{3} d \left(R^2 + Rr + r^2\right) + dVT(R + r) \tag{D11}$$

E. MOVING' DISCHARGE ACROSS PREVAILING CURRENT

PROJECTED SURFACE AREA

$$A = \frac{\pi}{2}\left(R^2 + r^2\right) + VT(R + r) + (R + r + VT)x \tag{D12}$$

VOLUME

$$M = \frac{\pi}{3} d \left(R^2 + Rr + r^2\right) + dVT(R + r) \tag{D13}$$

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
T = TIME REQUIRED TO EMPTY VESSEL DURING DISCHARGE
V_w = WATER VELOCITY AT PROPOSED DISPOSAL SITE
X = HORIZONTAL TRANSPORT DISTANCE OF DREDGED MATERIAL

Figure D1. Projected surface area and volume equations for discrete discharge operations

D12. The most difficult parameter to define in Equation D14 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.

D13. Each volumetric equation in Figure D1 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.

D14. 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 locations 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 shellfisheries are avoided or minimized.

Continuous pipeline discharges

D15. 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.

$$D = \frac{C_e - C_s}{C_s - C_a} \qquad \text{(D1)}$$

with all terms as defined earlier in paragraph D2. 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:

$$V_A = V_p D = V_p \left(\frac{C_e - C_s}{C_s - C_a} \right) \qquad \text{(D15)}$$

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

D16. It is assumed that the mixing zone associated with a pipeline discharge will resemble the shape in Figure D2. 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 follows (Equation D17 in Figure D2):

$$V_A = L\ dV_w \tag{D17}$$

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

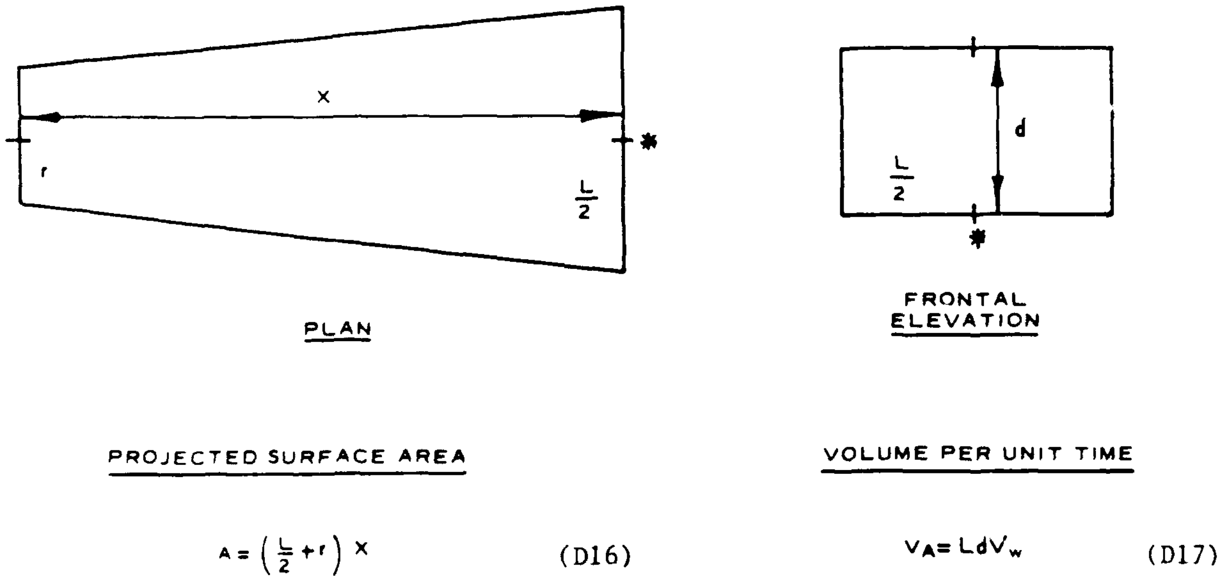


Figure D2. Projected surface area and volume equations for continuous pipeline discharge with prevailing current

D17. 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:

$$L = \frac{V_A}{dV_w} \tag{D18}$$

D18. Based on information presented by Brooks (1960), the time required for the front edge of the mixing zone to spread laterally to the required width L can be computed from:

$$t = \frac{1}{\lambda}\left[0.094\ L^{2/3} - 0.149(r^{2/3})\right] \tag{D19*}$$

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 (Bradsma and Divoky 1976). As discussed earlier, values for r will be influenced by the method of disposal and will be site-specific.

D19. It should be noted that Equation D19 calculates a time for spreading governed by turbulent diffusion processes. For continuous pipeline discharges, a considerable degree of initial mixing occurs in the immediate vicinity of the point of entry of the discharge due to jet momentum processes. The value of r used in Equation D19 should reflect the radius of the plume at the point of discharge after jet momentum has dissipated. If a negative value for t is calculated using Equation D19, all required mixing has occurred essentially instantaneously at the point of discharge due to jet momentum processes.

D20. 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:

$$X = V_w t \tag{D20}$$

---

* (Johnson and Boyd 1975).

where

X = longitudinal movement of discharge, ft

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

t = necessary time of travel, sec

D21. The results of Equations D19 and D20 can then be combined to estimate the projected surface area of the proposed discharge. This area can be computed as:

$$A = \left(\frac{L + 2r}{2}\right) X \tag{D21}$$

where

A = surface area, ft^2

L = width of front edge of mixing zone, ft

r = radius of initial surface mixing, ft

X = length of the mixing zone, ft

D22. 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.

D23. 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

D24. 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 D1, Case D) and a continuous discharge from a pipeline (Figure D2).

Discrete discharge

D25. The following input values were used in the sample computations:

Volume of dredged material V_d = 4,000 yd^3

Turbulent dissipation parameter λ = 0.005

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

Ambient concentration C_a = 0.1 mg/ℓ

Acceptable concentration C_s = 0.5 mg/ℓ

Settling velocity V_s = 10 ft/sec

D26. The dilution factor required to dilute concentration of interest to a concentration of equal volume C_s, vol/vol, would be:

$$D = \frac{C_e - C_s}{C_s - C_a} = \frac{(30 - 0.5)}{(0.5 - 0.1)} = 73.75 \tag{D1}$$

D27. The volume of water to dilute the discharge to acceptable levels would be:

$$\begin{aligned} M = D\,V_d &= (73.75)(4{,}000\ yd^3) = 2.95 \times 10^5\ yd^3 \\ &= 7.96 \times 10^6\ \text{cu ft} \end{aligned} \tag{D2}$$

D28. From Figure D1 (Case D), the equation for the volume of the mixing zone for a discrete discharge in the direction of a prevailing current is:

$$M = \frac{\pi}{3} d\ (R^2 + Rr + r^2) + dVT\ (R + r) \tag{D11}$$

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 D1 (Case D):

$$A = \frac{\pi}{2} (R^2 + r^2) + 2\ RVT + (R + r)\ X \qquad \text{(D10)}$$

where X is solved by Equation D14:

$$X = \left(\frac{\text{depth of water column}}{\text{settling velocity}}\right) \text{water velocity}$$

$$= \frac{50 \text{ ft}}{10 \text{ ft/sec}} (2 \text{ ft/sec}) = 10 \text{ ft}$$

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

D29. Thus, the proposed mixing zone would have the following dimensions:

Volume = 7.96×10^6 cu ft
Projected surface area = 208,212 sq ft
Maximum dimensions = 2,242 ft by 94 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

D30. 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

D31. The required volume per unit time will be:

$$V_A = V_p D = 44 \left(\frac{30 - 0.5}{0.5 - 0.1}\right) = 3{,}245 \text{ cu ft/sec} \qquad \text{(D15)}$$

---

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

D32. The required width of the mixing zone will be:

$$L = \frac{V_A}{dV_w} = \frac{3,245}{(10)\ (0.5)} = 649 \text{ ft} \qquad \text{(D18)}$$

D33. The time required to achieve the lateral spread L will be:

$$t = \frac{1}{0.005}\ [(0.094)(649)^{2/3} - (0.149)(15)^{2/3}] \qquad \text{(D19)}$$

$$= 1,228 \text{ sec}$$

D34. The length of the mixing zone will be:

$$X = (0.5 \text{ ft/sec})(1,228 \text{ sec}) = 614 \text{ ft} \qquad \text{(D20)}$$

D35. Thus the proposed mixing zone would have dimensions of:

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

Maximum dimensions = 614 ft by 649 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

D36. The surface area and volumetric equations in Figures D1 and D2 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 are 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.)

D37. 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.

D38. For the conditions where d is large, it may be more appropriate to specify a maximum portion of the water column (e.g., 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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Sediment A--Aquatic Disposal

Calculation of Hypothetical Mixing Zone for PCBs

Assumptions

Discrete discharge from barge moving in direction of prevailing current (Figure D1, case D). Barge holds 2,700 cu yd and is 190 ft long

C_s = water-quality criterion for PCBs = 0.03 μg/ℓ

C_a = PCB concentration in disposal site receiving water = 0.005 μg/ℓ

C_e = PCB concentration in elutriate = 0.04 μg/ℓ

V_d = volume of dredged material in barge = 2,700 cu yd (72,900 ft^3)

r = radius of initial surface mixing = 95 ft

d = depth of water at disposal site = 100 ft

V_w = current velocity at disposal site (presumed to be uniform speed and direction from surface to bottom) = 3 ft/sec

V = velocity of barge = 6 ft/sec

T = time to empty barge during discharge = 60 sec

V_s = mass descent velocity of discharge = 9 ft/sec

X = horizontal transport distances as result of currents = $(d/V_s)V_w$ = 33 ft

Calculations

Dilution factor D required to dilute PCBs in discharge to criterion may be calculated as (Equation D1):

$$D = \frac{C_e - C_s}{C_s - C_a} = \frac{0.04 - 0.03}{0.03 - 0.005} = 0.40$$

Volume of mixing zone M required to dilute PCBs in discharge to criterion may be calculated as (Equation D2):

$$M = D\,V_d = 0.40(72{,}900\ ft^3) = 29{,}160\ ft^3$$

Bottom radius of mixing plume R may be calculated as (Equation D11):

Calculations (Continued)

$$R = -\frac{1}{2} r + \frac{3VT}{\pi} + \frac{1}{2} \quad -3r^2 - \frac{6VTr}{\pi} + \frac{9V^2T^2}{\pi^2} + \frac{12M}{\pi d}$$

$$R = -47.01$$

This is physically impossible (paragraphs D8-D9). Since R must be greater than or equal to r, set $R = r = 95$ ft

Surface area projection A of mixing zone may be calculated as (Equation D10):

$$A = \frac{\pi}{2} (R^2 + r^2) + 2RVT + (R + r)X = 103{,}023 \text{ ft}^2$$

Length L of surface area projection of mixing zone of configuration of Figure D1, case D, may be calculated as:

$$L = r + X + VT + R = 583 \text{ ft}$$

Maximum width W of surface area projection of mixing zone of configuration of Figure D1, Case D, may be calculated as:

$$W = 2R = 190 \text{ ft}$$

Time required to achieve dilution T_d may be calculated as:

$$T_d = V_w L = 195 \text{ sec} = 3.25 \text{ min}$$

Description

The mixing zone required to dilute dissolved PCB in sediment A to the acute water-quality criterion would be as follows:

- Volume = 29,160 cu ft
- Surface area projection = 103,023 ft^2
- Length = 583 ft
- Maximum width = 190 ft
- Time to achieve dilution = 195 sec = 3.25 min

Sediment B--Upland Disposal Effluent

Calculation of Hypothetical Mixing Zone for *Crassostrea* Larvae Toxicity

Assumptions

Disposal site filled with an 18-in. hydraulic dredge operating continuously, discharge over weir into waterway (Figure D2)

C_s = EC50 effluent concentration = 62 percent

C_a = effluent concentration in receiving water = 0 percent

C_e = effluent concentration in discharge = 100 percent

V_p = rate of flow of discharge = 27 cu ft/sec

d = depth of water at discharge site = 40 ft

V_w = current velocity at discharge site (presumed to be uniform speed and direction from surface to bottom) = 1.5 ft/sec

r = radius of initial surface mixing = 24 ft

λ = turbulent dissipation parameter (paragraph D17) = 0.0005

Calculations

Dilution factor D required to dilute discharge to EC50 concentration may be calculated as (Equation D1):

$$D = \frac{C_e - C_s}{C_s - C_a} = \frac{100 - 62}{62 - 0} = 0.61$$

Mixing zone volume per unit time V_A required to dilute discharge to EC50 concentration may be calculated as (Equation D15):

$$V_A = V_p D = 13 \text{ cu ft/sec}$$

Maximum width L of mixing zone required to dilute discharge to EC50 concentration may be calculated as (Equation D18):

$$L = \frac{V_A}{dV_w} = 0.2 \text{ ft}$$

Calculations (Continued)

Time t required for plume to spread to maximum width may be calculated as (Equation D19):

$$t = \frac{1}{\lambda}\left[0.094L^{2/3} - 0.149(r^{2/3})\right] = -2,420 \text{ sec}$$

(A negative time for spreading is physically impossible. This indicates the necessary spreading would occur essentially instantaneously.)

Length X of mixing zone required to dilute discharge to EC50 may be calculated as (Equation D20):

$$X = V_w t = -3,630 \text{ ft}$$

(A mixing zone of negative length is physically impossible. This indicates the necessary mixing would occur essentially at the point of discharge.)

Surface area projection A of mixing zone of configuration of Figure D2 may be calculated as (Equation D21):

$$A = \left(\frac{L + 2r}{2}\right) X = -87,483 \text{ ft}^2$$

(A mixing zone of negative surface area is physically impossible. This indicates the necessary mixing would occur essentially at the point of discharge.)

Description

The mixing zone required to dilute the effluent of sediment B to the 48-hr EC50 for *Crassostrea* larvae would be as follows:

- Flow rate of dilution water required = 13 cu ft/sec
- Surface area projection = negligibly small
- Length = negligibly small
- Maximum width = 0.2 ft

Sediment B--Upland Disposal Surface Runoff

Calculation of Hypothetical Mixing Zone for PCBs

Assumptions

Disposal site of 60 acres, runoff from 2-in. rainfall in 1 hr flowing through weir and discharge pipe into a waterway (Figure D2)

C_s = water-quality criterion for PCBs = 0.03 $\mu g/\ell$

C_a = PCB concentration in receiving water = 0.01 $\mu g/\ell$

C_e = PCB concentration in effluent = 0.50 $\mu g/\ell$

V_p = rate of flow of discharge = 121 cu ft/sec

d = depth of water at discharge site = 40 ft

V_w = current velocity at discharge site (presumed to be uniform speed and direction from surface to bottom) = 1.5 ft/sec

r = radius of initial surface mixing = 24 ft

λ = turbulent dissipation parameter (paragraph D18) = 0.0005

Calculations

Dilution factor D required to dilute PCBs in runoff to criterion may be calculated as (Equation D1):

$$D = \frac{C_e - C_s}{C_s - C_a} = 23.50$$

Mixing zone volume per unit time V_A required to dilute PCBs in runoff to criterion may be calculated as (Equation D15):

$$V_A = V_p D = 2{,}844 \text{ cu ft/sec}$$

Maximum width L of the mixing zone required to dilute PCBs in runoff to criterion may be calculated as (Equation D18):

$$L = \frac{V_A}{dV_w} = 47 \text{ ft}$$

Time t required for mixing zone to spread to maximum width may be calculated as (Equation D19):

Calculations (Continued)

$$t = \frac{1}{\lambda}\left[0.094\ L^{2/3} - 0.149(r^{2/3})\right] = -32\ \text{sec}$$

(A negative time for spreading is physically impossible. This indicates the necessary spreading would occur essentially instantaneously.)

Length X of mixing zone required to dilute PCBs in runoff to criterion may be calculated as (Equation D20):

$$X = V_w t = -48\ \text{ft}$$

(A mixing zone of negative length is physically impossible. This indicates the necessary mixing would occur essentially at the point of discharge.)

Surface area projection A of mixing zone of configuration of Figure D2 may be calculated as (Equation D22):

$$A = \left(\frac{L + 2r}{2}\right)X = -2{,}280\ \text{ft}^2$$

(A mixing zone of negative surface area is physically impossible. This indicates the necessary mixing would occur essentially at the point of discharge.)

Description

The mixing zone required to dilute PCBs in sediment B upland disposal area surface runoff to the acute water-quality criterion would be as follows:

- Flow rate of dilution water required = 2,844 cu ft/sec
- Surface area projection = negligibly small
- Length = negligibly small
- Maximum width = 47 ft

Sediment C--Upland Disposal Effluent

Calculation of Hypothetical Mixing Zone for PCBs

Assumptions

Disposal site filled with 18-in. hydraulic dredge operating continuously, discharge over weir into waterway (Figure D2)

C_s = water-quality criterion for PCBs = 0.03 μg/ℓ

C_a = PCB concentration in receiving water = 0.01 μg/ℓ

C_e = PCB concentration in effluent = 0.48 μg/ℓ

V_p = rate of flow of discharge = 27 cu ft/sec

d = depth of water at discharge site = 40 ft

V_w = current velocity at discharge site (presumed to be uniform speed and direction from surface to bottom) = 1.5 ft/sec

r = radius of initial surface mixing = 24 ft

λ = turbulent dissipation parameter (paragraph D18) = 0.0005

Calculations

Dilution factor D required to dilute PCBs in discharge to criterion may be calculated as (Equation D1):

$$D = \frac{C_e - C_s}{C_s - C_a} = \frac{0.48 - 0.03}{0.03 - 0.01} = 22.50$$

Mixing zone volume per unit time V_A required to dilute PCBs in discharge to criterion may be calculated as (Equation D15):

$$V_A = V_p D = 473 \text{ cu ft/sec}$$

Maximum width L of the mixing zone required to dilute PCBs in discharge to criterion may be calculated as (Equation D18):

$$L = \frac{V_A}{dV_w} = 8 \text{ ft}$$

Time t required for plume to spread to maximum width may be calculated as (Equation D19):

Calculations (Continued)

$$t = \frac{1}{\lambda}\left[0.094\ L^{2/3} - 0.149(r^{2/3})\right] = -1,728 \text{ sec}$$

(A negative time for spreading is physically impossible. This indicates the necessary spreading would occur essentially instantaneously.)

Length X of mixing zone required to dilute PCBs in discharge to criterion may be calculated as (Equation D20):

$$X = V_w t = -2,592 \text{ ft}$$

(A mixing zone of negative length is physically impossible. This indicates the necessary mixing would occur essentially at the point of discharge.)

Surface area projection A of mixing zone of configuration of Figure B2 may be calculated as (Equation D21):

$$A = \left(\frac{L + 2r}{2}\right) X = -72,576 \text{ ft}^2$$

(A mixing zone of negative surface area is physically impossible. This indicates the necessary mixing would occur essentially at the point of discharge.)

Description

The mixing zone required to dilute PCBs in sediment C upland disposal effluent to the acute water-quality criterion would be as follows:

- Flow rate of dilution water required = 473 cu ft/sec
- Surface area projection = negligibly small
- Length = negligibly small
- Maximum width = 8 ft