DTIC FILE COPY

US Army Corps of Engineers
Seattle District

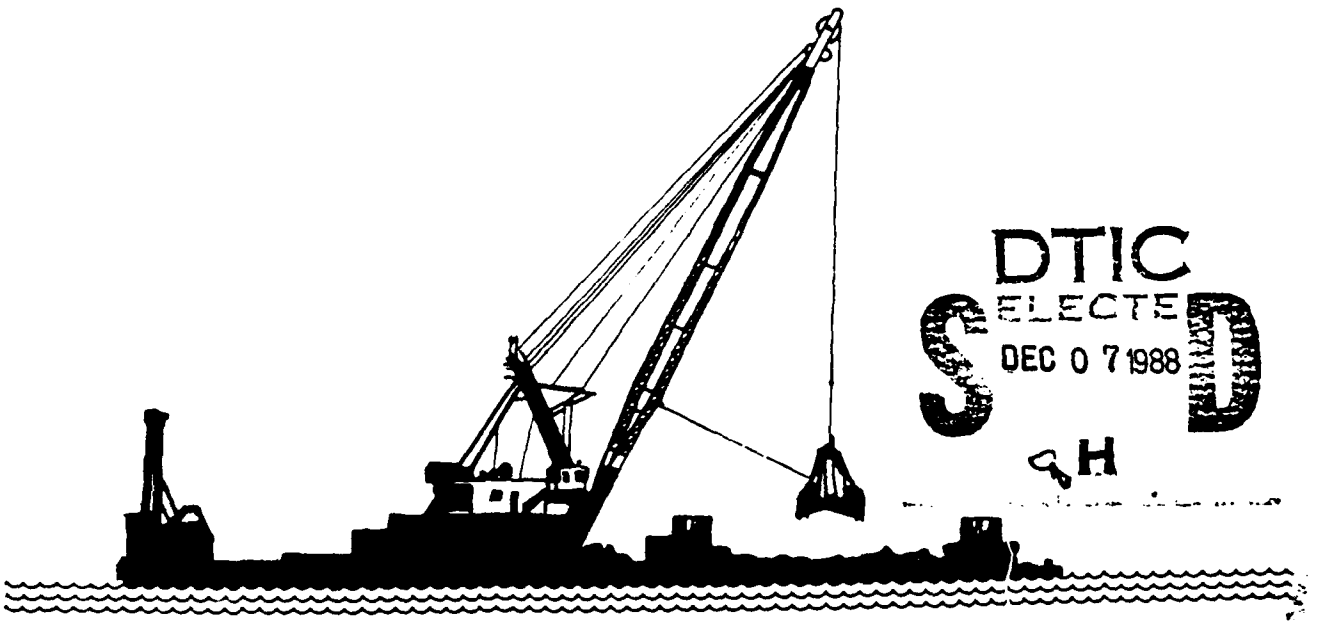
PSDDA Reports

Puget Sound Dredged Disposal Analysis

AD-A205 290

Washington State Dept. of Natural Resources

EVALUATION PROCEDURES TECHNICAL APPENDIX - PHASE I (CENTRAL PUGET SOUND)



DTIC
ELECTE
DEC 0 7 1988
S
D
H

88 12 7 034

JUNE 1988

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

EPA Region 10

ECOLOGY

SECURITY CLASSIFICATION OF THIS PAGE

ADA205290

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION / 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION US Army Corps of Engineers, Seattle District
6c. ADDRESS (City, State, and ZIP Code)	7b. ADDRESS (City, State, and ZIP Code) PO Box C-3755 Seattle, WA 98124-2255
8a. NAME OF FUNDING / SPONSORING ORGANIZATION / 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Unconfined open-water disposal sites for dredged material in Central Puget Sound, Phase I. Vol. 5.

12. PERSONAL AUTHOR(S)

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final EIS	FROM _____ TO _____	June 1988	5 volumes, various paging

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Dredging Open-water disposal Puget Sound

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This final environmental impact statement evaluates alternatives considered in identifying preferred sites for disposal of dredged material in Central Puget Sound. Three public multiuser disposal sites (Commencement Bay, Elliott Bay, and Port Gardner) are identified for use based on a site selection process which considered several alternative sites. Alternative biological effects conditions for site management have been considered and a site condition identified for purposes of dredged material management at the Phase I sites.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	unclass.

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
Pat J. Perry	(206)764-3728	CENPS-IM-CA-LB

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE

EVALUATION PROCEDURES TECHNICAL APPENDIX

Sampling, testing, and test interpretation
of dredged material proposed for
unconfined, open-water disposal
in central Puget Sound

Prepared by the Evaluation Procedures Work Group:

Keith Phillips, U.S. Army Corps of Engineers, Chair

Dr. David Jamison, State of Washington Department of Natural Resources

John Malek, U.S. Environmental Protection Agency

Brian Ross, U.S. Environmental Protection Agency

Catherine Krueger, U.S. Environmental Protection Agency

Jim Thornton, State of Washington Department of Ecology

Jim Krull, State of Washington Department of Ecology

Prepared for:

PUGET SOUND DREDGED DISPOSAL ANALYSIS

June 1988

ORGANIZATIONAL PREFACE

This document is a technical appendix to the Managment Plan Report (MPR) for the Puget Sound Dredged Disposal Analysis (PSDDA) study, and was prepared by the Evaluation Procedures Work Group (EPWG). Evaluation procedures are the sampling, testing, and test interpretation (disposal guidelines) of dredged material proposed for unconfined, open-water disposal in Puget Sound.

Part I of the technical appendix contains background and introductory information for dredged material management. The remaining parts are organized by disposal option and address the technical conclusions of EPWG. The PSDDA study focuses on unconfined, open-water disposal, discussed in detail in part II. In addition to technical recommendations, a detailed cost analysis is presented based on alternative chemical and biological guidelines for disposal of dredged material at unconfined, open-water sites.

In part III, disposal on land or intertidal areas using a conventional design is briefly addressed. Confined disposal of contaminated sediments is also discussed. Capping an aquatic disposal site is one method of confined disposal. Two other methods are diked nearshore (i.e., intertidal) and upland disposal. The technical appendix is concluded with a list of references, a glossary, and several exhibits.

Exhibits included in the technical appendix provide additional technical details or summary information, including a detailed documentation of the EPWG Plan of Study (exhibit A), Regional Administrative Decisions (exhibit B), U.S. Army Corps of Engineers Section 404(b)(1) Disposal Guidelines (exhibit C), and Cost Analysis Case Studies (exhibit D). Summaries of 21 technical reports relevant to the work of EPWG are provided in exhibit E. Additional background, literature review, and perspective on dredged material management is provided in an article by Engler (1980) included as exhibit F. Many of the issues surrounding dredged material disposal are addressed in these special reports and are incorporated, partly by reference, in the main body of the technical appendix.

The technical appendix is not intended to be a "user" manual, rather it is a document that explains the development and rationale for the evaluation procedures. A separate "user's manual" for regulatory agencies is being prepared by the Washington State Department of Ecology. The user's manual is scheduled to be available by the winter of 1988. It should be helpful to those planning dredging projects.

DTIC COPY INSPECTED 6

Accession For
NTIS GRA&I ☑
DTIC TAB ☐
Unannounced ☐
Justification
By perform 50
Distribution/
Availability Codes
Dist | Avail and/or Special
A-1

ACKNOWLEDGEMENTS

The Evaluation Procedures Work Group (EPWG) acknowledges the assistance of Resource Planning Associates, PTI Environmental Services, and Tetra Tech, Inc. in the preparation of this technical appendix. Dr. Gary Minton of Resource Planning Associates was the Program Manager. Principal contributors at PTI Environmental Services were Robert Barrick, Dr. Mike Johns, and Pieter Booth. Warren Hansen prepared the initial cost analysis at Tetra Tech. Dr. Jim Erkmann, Dr. Chuck Lytle, Brian O'Neal, Marcy Brooks-McAuliffe, Dr. Juanita Wagner, and Julia Wilcox provided technical and editorial assistance.

Summaries of technical reports comprising exhibit E were prepared by Shapiro & Associates, Inc., PTI Environmental Services, and Tetra Tech, Inc. under contract to Resource Planning Associates.

EPWG also recognizes the valuable feedback provided by the individuals who participated in and/or contributed to the work group meetings, including: Frank Urabeck (Corps), Carl Kassebaum (EPA), Don Moos (Wash. Public Ports Assn), Doug Hotchkiss (Port of Seattle), Gary Kucinski and Leslie Sacha (Port of Tacoma), Jim Heil (Puget Sound Alliance), Dennis McDonald (Northwest Indian Fisheries Comm.), Mary Lou Mills and Curtis Dahlgren (Wash. Dept. of Fisheries), Chuck Dunn and John Cooper (U.S. Fish and Wildlife Service), Carl Sagerser and Steve Norsted (Wash. Dept. of Social and Health Services), Mike Schiewe (National Marine Fisheries Service), John Dohrmann (Puget Sound Water Quality Authority), Philip Shadaro (Hart-Crowser, Inc.), John Vlastelicia (Ogden-Beeman Assoc., Inc.), Gerry Ervine (City of Everett), Pat Romberg (METRO), Don Weston (JRB/SAIC), Ed Long (National Oceanic and Atmospheric Administration), Dick Peddicord, Dick Lee, Stratford Kay, John Cullinane, and Tom Dillon (Corps of Engineers Waterways Experiment Station (WES)), Paul Dinnel (University of Washington), Jim Male (University of Masschusetts), Joe O'Connor (New York University), Dianne Robbins (Invert-Aid), Jay Spearman (consulting engineer), Bonnie Orme (citizen), and Jack Word and Jack Hardy (Battelle). This document would not have been possible without their assistance.

EXECUTIVE SUMMARY

This document is a technical appendix to the Management Plan Report (MPR) for the Puget Sound Dredged Disposal Analysis (PSDDA) study. The goal of PSDDA is to provide the basis for publicly acceptable guidelines governing environmentally safe unconfined, open-water disposal of dredged material[1/], and provide Puget Sound-wide consistency and predictability in decisions concerning dredged material disposal. This study is being conducted in two phases addressing two geographic regions of Puget Sound. Phase I, which began in April 1985, has been conducted over a 3-year period and involves the central portion of Puget Sound from Tacoma to Everett. Phase II overlaps the Phase I schedule and includes the balance of Puget Sound. This technical appendix, prepared by the Evaluation Procedures Work Group (EPWG), focuses on the Phase I area of PSDDA.

EPWG is an interagency committee composed of representatives from each of the PSDDA agencies: the U.S. Army Corps of Engineers, Seattle District (Corps) as lead agency, the U.S. Environmental Protection Agency, Region X (EPA), the Washington Department of Ecology (Ecology), and the Washington Department of Natural Resources (DNR). EPWG is responsible for developing procedures to evaluate dredged material, including requirements for sampling and testing dredged material and guidelines for dredged material disposal.

IMPLEMENTATION OF THE PSDDA EVALUATION PROCEDURES

Responsibilities of each of the PSDDA regulatory agencies under Section 404 or Section 401 of the Clean Water Act (CWA) will be accomplished in accordance with each agency's authorities and policies. The PSDDA dredged material evaluation procedures will be applied by each regulatory agency consistent with these authorities and policies. The procedures provide the basis for an overall approach which can meet the case-by-case requirements of both Section 404 and Section 401. Most elements of the PSDDA procedures are common to both authorities. However, some elements are unique to either Section 404 or Section 401 requirements. Those seeking approval for unconfined, open-water disposal will need to meet both requirements, i.e., to undertake the full suite of PSDDA tests as each agency determines they are applicable.

The Corps requirements for the evaluation of dredged material proposed for unconfined disposal in Puget Sound waters, as specifed in Subpart G of the Section 404(b)(1) Guidelines, will be met primarily by the Section 404 components of the PSDDA evaluation procedures. The Section 404 components of the PSDDA procedures are, and will be, applied consistent with the national Corps process described in the PMP. The Corps will address other aspects of the Section 404(b)(1) compliance, such as impacts on navigation and

1/Please see glossary (part V) for a definition of terms in text.

IMPLEMENTATION OF THE PSDDA EVALUATION PROCEDURES (con.)

national commerce and avoidance and minimization of impacts, including mitigation of unavoidable impacts and alternatives analysis on a case-by-case basis. Required national Corps procedures for implementation are reflected in 51 FR 19694 dated May 30, 1986 for Corps projects and 33 CFR 320-330 for the Corps regulatory program.

EPA will rely on the PSDDA evaluation procedures as the basis for preventing significant degradation of the aquatic environment, as required by the Section 404(b)(1) Guidelines. These procedures represent the testing approaches and procedures, allowed under the Guidelines, which EPA would require during the evaluation of dredged material. Other aspects of the Section 404(b)(1) compliance, such as avoidance and minimization of impacts, including mitigation of unavoidable impacts, will also be addressed by EPA, during comprehensive reviews, on a case-by-case basis.

Ecology will apply the appropriate PSDDA evaluation procedures in assessing applications for Section 401 Water Quality Certification. Initially, the procedures will be treated as guidelines. However, depending on actions that might be taken by the Puget Sound Water Quality Authority (PSWQA) in their adoption of the proposed PSDDA management plan as a feature of the PSWQA Water Quality Management Plan, the PSDDA evaluation procedures may later be adopted as State regulation.

ORGANIZATION OF REPORT

Part I of this document consists of an introduction to PSDDA and the different options for the management of dredged material. Part II contains the focus of the document, which is a discussion of the unconfined, open-water disposal option. Part III generically addresses other options for dredged material disposal. Part IV is a list of references. A glossary of terms is presented in part V.

INTRODUCTION AND BACKGROUND

Dredged material is a complex mixture of soil, minerals, water, organic matter (for example, dead and living plant and animal material), and inorganic and organic chemicals. These constituents can interact with the environment in ways that are both predictable and difficult to predict. These interactions may in some instances result in unacceptable adverse effects. For example, shrimp exposed to dredged material containing elevated levels of chemicals of concern may accumulate some of these chemicals, resulting in decreased reproduction. Beneficial effects from dredged material also may result, for example, from the addition of food material or enhancement of habitats.

Although all dredged material contains a mixture of chemicals, not all dredged material contains chemicals at concentrations that are of concern. Procedures for evaluating the potential for unacceptable adverse effects to occur from materials containing chemicals of concern is essential to proper dredged material management.

Procedures for evaluating potential effects include dredged material sampling and testing requirements, and disposal guidelines. These requirements and guidelines are used to determine if dredged material is acceptable for unconfined, open-water disposal, or if confined disposal (for example, capping) is warranted. EPWG considered the following five major approaches in developing these evaluation procedures:

1. A technology-based approach (relying exclusively on a single design/best available technology to manage dredged material).

2. An approach focused solely on restricting the environmental release or loading of dredged material chemicals of concern.

3. An approach based exclusively on avoiding human health effects.

4. A reference site approach (i.e, comparison with conditions at a site that is considered to be environmentally acceptable).

5. An approach based on avoiding biological effects.

The approach recommended by EPWG is a combination of these five approaches and is based on the following premises:

- The evaluation of dredged material and subsequent management decisions should be based primarily on avoiding unacceptable adverse biological effects.

- Biological and chemical tests should be used to characterize the dredged material, where needed.

- Results of bioassay tests should be interpreted relative to results for sediment samples from a acceptable reference area.

- Human health concerns should be considered in interpreting test results.

- If test results indicate a potential for unacceptable biological effects, measures should be taken to reduce or prevent these effects using appropriate technology.

- Project design and other project decisions must consider the potential for the release of dredged material outside the disposal site.

A testing sequence was developed to ensure consistent and predictable application of this approach. The testing sequence is a tiered process for reviewing existing information, selecting and interpreting appropriate biological and chemical tests, and defining disposal guidelines for dredged material. Disposal guidelines provide the basis for data analysis and indicate possible data interpretation.

The disposal guidelines are expected to apply in the majority of cases. However, the PSDDA evaluation procedures will be applied on a project-specific basis. "Exceptions" to the guidelines would be allowed with appropriate technical rationale and documentation, when such rationale warrants a different conclusion. In developing general procedures for use everywhere in Puget Sound, it was not possible to consider all individual project technical factors, or assess all the possible outcomes that might arise from the test results. Consequently, "professional judgment" is essential in reaching project-specific decisions, and the evaluation procedures (including the disposal guidelines) are designed to be sufficiently flexible to allow full consideration of all pertinent project factors. The technical rationale for any departures from the disposal guidelines will be documented by the permitting agencies.

PART II. UNCONFINED, OPEN-WATER DISPOSAL

In the period from 1985 to 2000, the volume of dredged material in the central portion of Puget Sound (the PSDDA Phase I area) could increase 35 percent over the previous 15-year period (1970 to 1985). The trend in dredging projects indicates that there will continue to be a great demand for open-water disposal sites. Unconfined, open-water disposal is generally preferred over other options because of substantial cost advantages. In addition, unconfined, open-water disposal maintains the dredged material in a water-saturated condition that can significantly limit the potential for release of certain chemicals of concern, such that it is environmentally preferred in some cases. Other disposal options include "conventional" (i.e., with no special restrictions for chemicals of concern) upland or nearshore disposal and "confined" (i.e., including restrictions for chemicals of concern) aquatic (capped), nearshore or upland disposal.

Part II of the report focuses on the development of evaluation procedures for the unconfined, open-water disposal option. These procedures were developed in light of regulations and guidelines summarized below.

Regulatory Background. Regulation of unconfined, open-water disposal of dredged material is based on the Clean Water Act (CWA; Public Law 92-500, as amended). The CWA establishes a permit process for dredged material disposal, with guidelines for designating disposal sites based on the following four requirements:

1. Alternatives to the dredged material disposal activity must be considered (e.g., disposal in another location, or disposal of smaller quantities of material).

2. The disposal activity must comply with Federal water quality criteria and State water quality standards (these criteria and standards are established to protect the aquatic environment by providing limits for certain water quality characteristics and permissible levels of chemicals of concern).

Regulatory Background (con.)

3. The discharge must not have significant adverse effects on human health or the receiving waters.

4. Appropriate steps must be taken to minimize adverse effects.

The PSDDA studies focus on the evaluation and testing procedures required by the CWA. The Section 404(b)(1) guidelines for specifying dredged material disposal sites are presented in Title 40 of the Code of Federal Regulations, Part 230 (40 CFR 230). Subpart G of 40 CFR 230 provides guidance for evaluating and testing dredged material. The Section 404(b)(1) Guidelines also specify numerous effects determinations, describe potential impacts that should be considered in the determination process, provide guidance on the evaluation and testing of dredged material, and suggest actions that can be taken to minimize adverse effects. The Corps determines if disposal in open water is consistent with Section 404 of the CWA. EPA reviews and comments on these consistency decisions. In addition to Section 404 Guidelines and requirements, Section 401 of the CWA (State water quality certification), requires Ecology to certify that dredged material disposal will not violate appropriate and applicable State water quality standards.

Historical Background. In Puget Sound, several approaches have been taken to evaluate the potential for unacceptable adverse effects due to the disposal of dredged material at unconfined, open-water sites. Prior to 1984, the Section 404(b)(1) Guidelines for testing and evaluation of dredged material were not consistently applied to non-Corps projects or interpretations varied among the regulatory agencies. Testing requirements and test interpretations were determined on a "case-by-case" basis for each project. Testing that was conducted usually emphasized water quality effects, using a procedure known as "elutriate testing" to determine if chemicals would be released into the water column during dredging. In Puget Sound, the effects of chemicals of concern that remained bound to the sediments in the disposal site were often not directly studied and, as a result, the potential consequences to the Sound's aquatic ecosystem were not known.

The lack of fully consistent evaluation procedures, or specific objective decision criteria led, in part, to the establishment of interim disposal criteria by EPA and Ecology for the Fourmile Rock disposal site in Seattle's Elliott Bay in 1984 and the Port Gardner site near Everett in 1985. The Fourmile Rock criteria became a condition of the local shoreline permit issued by the city of Seattle to DNR and the Port Gardner criteria a condition of the city of Everet permit for the existing Port Gardner site. Subsequently, in 1985, Ecology developed the Puget Sound Interim Criteria (PSIC) to ensure that the other Puget Sound disposal sites did not experience similar problems. These criteria have been used in the interim pending development of regional Sound-wide guidelines for dredged material disposal.

Historical Background (con.)

Test Sequence and Disposal Guidelines for Unconfined, Open-Water Disposal. Dredging and subsequent disposal at unconfined, open-water sites requires consideration of a number of environmental processes and pathways for the transport of chemicals of concern. Factors relating to dredging and disposal include:

- Losses of material dispersed during dredging.
- Losses of dredged material during transport (i.e., from barges), and volatilization of chemicals of concern.
- Losses of dredged material to the water column or along the bottom during disposal.
- Losses of material from the disposal mound.

Pathways for chemical transport from the disposal site include convection, diffusion, and bioturbation.

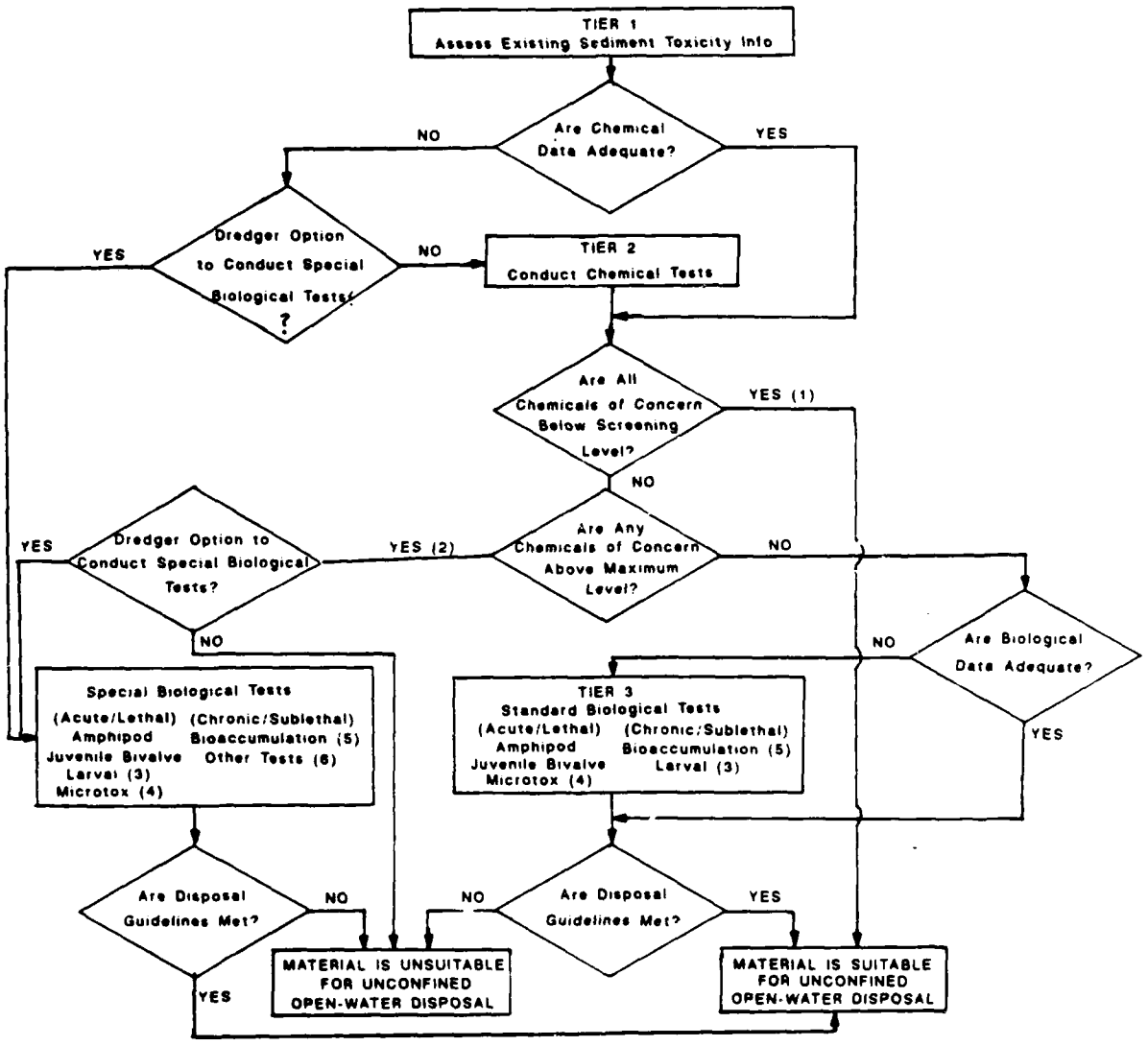
The evaluation procedures assessment sequence for unconfined open-water disposal includes three tiers:

- Tier 1 - assess existing sediment information.
- Tier 2 - conduct chemical testing, if necessary.
- Tier 3 - conduct biological testing, if necessary.

The use of these tiers in defining acceptability for disposal at unconfined, open-water sites is summarized in figure 1.

Preliminary Ranking and Review of the Dredging Site. Three steps taken by the dredger and regulatory agencies help determine whether chemical or biological testing is required to assess acceptability of dredged material for unconfined, open-water disposal. These three steps involve ranking a site based on:

1. Its location relative to chemical sources and historical data on chemicals of concern in sediments and water.
2. The proposed volume of sediment to be dredged.
3. An assessment of existing data for the site (e.g., how recently and frequently has the site been sampled, and whether quality assurance data are available).



(1) Biological testing may still be required if there is reason to believe that the sediment is highly anomalous and may represent a significant environmental risk even though all chemicals of concern are below screening levels for unconfined open-water disposal.

(2) Standard tier 3 biological testing can still be conducted when only a single chemical of concern exceeds the maximum level by < 100% Biological testing of material with chemical levels above maximum level is allowed as an option of the dredger(see footnote 6)

(3) The larval species can be used in either a sediment toxicity bioassy (for Section 401) and/or in a water column bioassy (for Section 404) The sediment larval test is required whenever biological testing is necessary, the water column larval test is only required when water column effects are of concern.

(4) Microtox testing is required only for Section 401 reviews; it is not required for Section 404 evaluations.

(5) The chemical screening level that determines when bioaccumulaton testing is required is higher than for other biological testing.

(6) Special biological testing under the "Dredger Option" will include additional, more sensitive sublethal biological tests (see EPTA).

Figure 1. PSDDA testing sequence.

Preliminary Ranking and Review of the Dredging Site (con.)

These steps constitute the first tier in evaluating a project to determine if there is a reason to believe that there is the potential, and the degree of that potential, for finding sediments containing chemicals of concern in the project area. EPWG has identified some areas in central Puget Sound which are considered to have a high, moderate, or low potential for finding chemicals of concern in area sediments. These rankings provide the project reviewer with initial guidance for sampling requirements. Actual project location within the area and project-specific factors would be considered in a final determination.

Previous sediment testing data can be used providing it is recent data and there is some assurance as to the quality of the data. EPWG has provided guidelines concerning how recency and quality of data should be considered in assessing a proposed project.

Sampling Issues and Concerns. Major issues addressed by EPWG include:

- Definition of dredged material management units.
- Sampling methods for characterizing sediment chemistry under conditions of a patchy distribution of chemicals of concern.
- Sampling sediment below the proposed dredging depth to characterize the sediment surface that will be exposed after dredging.
- Sampling methods and depths, and sample storage, archiving, and management.
- Other issues such as subsampling, compositing, documentation, push core sampling, grab sampling, and sample tracking.

Sampling and Testing Sequence. After a reason-to-believe evaluation (tier 1) of the project area and if there is a determination that the sediments may contain chemicals of concern, the next evaluation is to conduct sediment chemistry analysis (tier 2). Tier 2 involves bulk chemical testing for specific chemicals of concern. Biological testing of sediment (tier 3) is required only if chemical concentrations falls within a certain range. Tier 3 involves acute toxicity bioassays and bioaccumulation analyses.

Because the proposed procedures contain several features that have not received full implementation in a regulatory program prior to PSDDA, annual reviews of evaluation procedures will be undertaken once PSDDA is initiated. Based on these reviews, evaluation procedures will be revised as appropriate.

Future improvements in agency ability to characterize the distribution of chemicals of concern in Puget Sound sediments and to better understand the relationship between specific chemical concentrations and biological effects likely will result in an eventual reduction in sampling and analysis requirements.

Chemical Testing. During development of the PSDDA evaluation procedures, the role that Tier 2 (figure 1) chemical analyses should have in sediment testing and decisionmaking was considered at length. In most dredging programs throughout the country, sediment analysis, if conducted at all, is used for informational purposes only, providing an inventory of chemicals present in the sediments to be dredged. In the Puget Sound area, however, a comprehensive data base from urban and rural bays and waterways is available that indicates that sediment chemistry can be used for more than just providing general information on the sediment. When analyzed, the Puget Sound data can be interpreted to reveal general conclusions about the relation between concentrations of chemicals present in individual sediment samples and the biological effects that were associated with those sediments. However, the data do not elucidate cause and effect relationships, but rather provide empirical observations of biological impacts associated with certain levels of chemicals. Consequently, this data base can be used to determine if there is reason to believe that chemicals of concern are present which could potentially result in adverse biological effects.

Chemical testing would be used by decisionmakers according to the following two kinds of guidelines:

- A relatively low chemical screening level (SL) below which there is reason to believe the dredged material is acceptable for unconfined, open-water disposal without biological testing.

- A higher maximum level (ML) of chemical concentration above which there is reason to believe that dredged material would be unacceptable for unconfined, open-water disposal.

Biological testing is required to make a decision for all dredged material with chemical concentrations between the SL and ML. A dredger option to conduct biological tests on material that exceeds the ML values has been provided.

Once the chemicals of concern were identified for Puget Sound, screening and maximum levels were established for each chemical by EPWG. An evaluation of sediment quality values, which are chemical concentrations correlated with observed biological effects, was made in setting the SL and ML values. The sediment quality values derived by EPWG are based on primarily application of the Apparent Effects Thresholds (AET) method (Tetra Tech, 1985a). The AET method was originally developed for use in the identifying chemical concentrations in sediments that warrant containment or cleanup in Commencement Bay, a large Superfund site in Puget Sound. Before applying the AET method as a tool under PSDDA, the Puget Sound data base was expanded to include sediment chemistry and biological effects information from additional nearshore urban/industrial areas and multiple "clean" reference sites. Information contained in the data base included over 190 stations, sediment chemical analyses on 71 chemicals, a variety of conventional parameters, benthic community analyses, and the results of multispecies bioassays.

Chemical Testing (con.)

For a given set of field data, the AET is the sediment concentration of a chemical above which a particular biological effect was always observed. Biological effects for which AET were developed include depressions in the abundance of benthic infauna (e.g., decrease in the number of individuals) and several toxicity indicators (e.g., bioassay for amphipods, bacterial luminescence, oyster larvae). AET are developed on a chemical specific basis for each biological test independently. The range of AET for a given chemical may vary depending on the sensitivity of the various test species represented in the data base.

Because of uncertainties associated with bioassay sensitivity and the relationship between benthic community analysis and potential impacts at the disposal site, no single test AET was selected by EPWG as the basis for establishing the dredged material disposal guidelines. Rather, the decision was made to utilize all of the available information. Bioassay-based AET were incorporated because they provide foresight regarding material toxicity and the likely outcome of laboratory tests. They do so without resolving the specific cause of observed toxic effects and, as applied in the dredged material evaluation process, without implying that the laboratory toxicity will necessarily be expressed in the field at the ultimate disposal site. There are a variety of factors, including natural variability and nonsediment anthropogenic influences (e.g., ship passage, water quality, etc.) that can influence the condition of the bottom-community, benthic infaunal invertebrates. However, benthic community-based AET provide corroborative evidence, and a means of protecting against potential impacts that might not be measured by single species acute bioassays or limited chemical analysis.

In developing the sediment chemistry guidelines for use in PSDDA, the ML for a given chemical of concern was set by EPWG using the highest AET for a range of biological indicators. At sediment concentrations above the ML, there is reason to believe that the dredged material would be unacceptable for unconfined, open-water disposal. However, the dredger does have the option to conduct biological testing instead of relying on the indications of the ML.

ML's will be revised as needed during periodic reviews of the evaluation procedures. For most chemicals, ML's were set separately for individual chemicals. ML's were also set for certain groups of chemicals, including polychlorinated biphenyls (PCB's), DDT isomers, and low and high molecular weight polycyclic aromatic hydrocarbons (LPAH and HPAH).

The SL was set at 10 percent of the ML, provided:

- The value is equal to or exceeds the average concentration for the chemical in Puget Sound reference areas (areas in which adverse biological effects are not expected).
- The value is less than the lowest AET determined for a range of biological indicators.

Chemical Testing (con.)

Modified SL's were established for phthalate esters (common laboratory chemicals of concern) and pesticides (infrequently detected in Puget Sound). The use of a SL reduces the cost of testing dredged material for which there is little reason to believe that unacceptable adverse effects will result from its disposal at unconfined, open-water sites.

Only certain chemicals are routinely considered in the evaluation of dredged material. These chemicals of concern to be analyzed were identified by considering toxicological information available for chemicals known to be found in Puget Sound. These 58 chemicals of concern have the following characteristics:

- o A demonstrated or suspected effect on ecology or human health.
- o A widespread distribution or high concentration relative to natural conditions.
- o A potential for remaining toxic for along time in the environment.
- o A potential to bioaccumulate and enter the foob web.

Standard protocols were adopted for metals and metalloids, organic chemicals, and conventional tests (e.g., for total volatile sulfides). Detection limits were specified for metals and metalloids, and organic chemicals.

Biological Testing. EPWG addressed several biological testing issues, including use of reference sites for interpreting biological data. Data on grain size, percent solids, and total organic carbon are available for the six sites listed. In addition, data from these sites indicate low or undetected levels of chemicals of concern.

The biological testing program was designed to address both whole sediment toxicity and potential water column effects. Under Tier 3 (figure 1) several acute bioassays are specified: an amphipod test, a juvenile bivalve test, larval tests (used for sediment toxicity and/or for assessing water column effects), and a bacterial bioluminescence test (commonly referred to as the Microtox test). Use of multispecies tests attempts to account for the diversity of aquatic species present in Puget Sound. Of these tests, the amphipod, juvenile bivalve, and larval tests pertain to conducting ecological evaluations pursuant to both the Section 404(b)(1) Guidelines and Section 401 water quality certification reviews. The Microtox test is only required for Section 401 reviews.

A bioaccumulation test, required under certain circumstances, is intended to provide information about the potential of chemicals to be of concern to human health. The test consists of a 30-day sediment exposure of bivalves with subsequent analysis of their tissues for chemicals of human health concern. In addition to their use for bioaccumulation, bivalve mortality will be monitored during the 30-day exposure period to provide data on potential chronic exposures.

Biological Testing (con.)

The proposed biological tests were chosen because they are considered available, proven, sensitive, generally accepted, and provide interpretable endpoints (e.g., mortality, or quantitative tissue concentrations that can be incorporated into a health risk analysis) for assessing sediment toxicity and/or the effects of dredged material disposal. Multiple tests have been recommended to provide animal diversity that might address the different sensitivities of various species to different chemicals.

Dredger Option to Conduct Biological Testing. When dredged material chemicals of concern exceed the ML values, the dredger will have two options. First, he may elect to accept the indication of the ML that the material is unacceptable for unconfined, open-water disposal. Biological testing is not required for this decision. However, it is recognized that chemical levels in dredged material provide a relatively indirect measurement of possible adverse biological effects, as several factors can influence the bioavailability of these chemicals (e.g., sediment grain size, presence of organic carbon, etc.). Accordingly, the dredger will have a second option to conduct biological testing rather than rely on the indications of the ML. For this option, the dredger would conduct both the standard bioassays (five acute bioassays and bivalve bioaccumulation) and other additional, more sensitive sublethal tests in order to determine final biological acceptability of the material for unconfined, open-water disposal. Appropriate biological tests and test interpretation would be determined by the PSDDA agencies on a project-by-project basis. If the project material meets the test interpretation requirements, the dredged material will be considered acceptable for unconfined, open-water disposal.

For dredging projects involving dredged material with high concentrations of chemicals of concern, the dredger may opt to proceed directly to biological testing rather than conduct chemical tests. If adequate chemical test data were not available for the project, it would be assumed that the material contained chemical levels exceeding the ML values, and that it warranted complete biological testing (both standard and other, sublethal biological tests; i.e., the "dredger option" in figure 1), analyzing for all human health chemicals of concern in the bioaccumulation test.

For any dredged material exceeding the ML values that is found to be acceptable for unconfined, open-water disposal based on biological test results, the use of the PSDDA disposal sites may not be appropriate or allowable. For these projects, locating an appropriate site, and determining site use requirements, and disposal site monitoring needs, will be addressed on a case-by-case basis. Any needed identification and designation of special unconfined, open-water disposal sites would be the responsibility of the dredger.

In summary, unconfined, open-water disposal of dredged material with chemicals exceeding the ML values is generally considered to be outside of the scope of the PSDDA study and sites, and will necessarily be considered on a project-by-project basis (as required by the Clean Water Act). Overall, unconfined, open-water disposal of sediments containing high concentrations of chemicals of concern into Puget Sound waters is not very likely to occur.

Dredger Option to Conduct Biological Testing (con.)

An additional benefit of the optional biological testing can occur when the test data are added to the chemical/biological effects data base. The standard biological tests (five acute bioassays and bivalve bioaccumulation) may provide information which could result in changes to the ML guidelines during the annual reviews of the evaluation procedures. This information will be considered along with other dredged material test results, field monitoring data and pertinent research results, during the annual review of the PSDDA management plan. These reviews will include an assessment of possible changes to the ML guidelines.

ALTERNATIVE BIOLOGICAL EFFECTS CONDITIONS FOR SITE MANAGEMENT

In determining appropriate test interpretation (disposal guidelines) for dredged material, EPWG considered seven possible "site conditions," representing the relative severity of potential on-site effects at the disposal site. Four of these alternatives were extreme options that were excluded from detailed analysis due to impracticability and inconsistency with the intent of environmental laws. The remaining three alternatives were evaluated in detail to determine the preferred condition for site management. In field terms, Site Condition I represents "no adverse effects due to sediment chemicals of concern." Site Condition II is defined as "minor adverse effects;" Site Condition III as "moderate adverse effects." In laboratory terms, Site Condition I would allow "no significant sublethal, chronic toxicity" of any kind within the site. Site Condition II would allow "no significant acute toxicity" onsite. Site Condition III would allow "no severe acute toxicity" onsite.

Chemical and biological laboratory tests of dredged material are used to measure and predict these different levels of possible effects. In relating laboratory tests to field conditions, EPWG fully recognized that lab exposure conditions are more severe than those that would occur at the disposal site. However, lab tests can indicate a potential for field consequences, especially when the disposal sites are nondispersive (as they are in central Puget Sound). Though pertinent to the Phase I area, the alternative site conditions defined for the central Sound sites are not necessarily appropriate for the dispersive sites being considered for the Phase II PSDDA study area.

In setting biological disposal guidelines for the site conditions, EPWG developed specific interpretation for acute bioassay responses, and for bioaccumulation studies as an indicator of potential human health effects (table 1). The biological guidelines take into consideration comparisons of test results with appropriate reference conditions. Also, different possible ML's for chemicals of concern were established by EPWG to correspond to the alternative site conditions.

TABLE 1. BIOLOGICAL AND CHEMICAL DISPOSAL GUIDELINES FOR ALTERNATIVE SITE MANAGEMENT CONDITIONS

	Biological Disposal Guidelines	Chemical Disposal Guideliines
Site Condition I - "No adverse effects" In lab: "No sublethal or acute toxicity"	No one bioassay (a) exhibiting a statistically significant (P less than 0.05) response over reference conditions and exceeding 20 percent absolute mortality over control; water column larval response does not exceed 0.01 of the LC50 after 4-hour mixing; and no bioaccumulation levels exceeding a human health tissue guideline value.	ML1 (b), defined as the lowest AET (b) for a series of biological indicators (i.e., higher concentrations are expected to result in effects measured by at least one biological indicator).
Site Conditon II - "Minor adverse effects" In lab: "No significant acute toxicity"	No two bioassays exhibiting the above conditions; or no one bioassay response greater than 30 percent (c) over reference conditions and statistically significant with respect to reference conditions; water column larval response does not exceed 0.01 of the LC50 after 4-hour mixing; and no bioaccumulation levels exceeding a human health tissue guideline value.	ML2, defined as the highest AET for a series of biological indicators (i.e., higher concentrations are expected to result in effects measured by all of the biological indicators).
Site Condition III - "Moderate adverse effects" In lab: "No severe acute toxicity"	No two bioassay responses greater than 30 percent over reference and statistically significant with respect to reference conditions; or no one bioassay response greater than 70 percent over reference and statistically significant with respect to reference conditions; water column larval response does not exceed 0.01 of LC50 after 4-hour mixing; and no bioaccmulation levels exceeding human health tissue guidelines value.	ML3, defined as twice ML2; although artitrary, this higher concentration of contaminants is expected to result in more severe effects than ML2 (based on the observation that toxicity curves continue to increase sharply above the level that toxicity curves continue to increase sharply above the level that toxicity is statistically significant).

TABLE 1 (con.)

	Biological Disposal Guidelines	Chemical Disposal Guideliines
Site Condition IV - "Major adverse effects" In lab: "No dangerous waste"	No biological disposal guidelines (defined only by state chemical guidelines)	ML4, defined according to Ecology Dangerous Waste regulations (book review procedures).

(a) Biological tests used in the disposal guidelines are discussed in section II-6.
(b) ML - maximum chemical levels established for Site Conditions I, II, III, and IV are discussed in section II-8.2; numerical values for each maximum levels are given in table II.8-3. AET = Apparent Effects Threshold; see section II.7-2.
(c) Greater than 30 percent over reference": e.g., if reference/mortality is 12 percent, test mortality cannot exceed 42 percent.

EFFECTS ANALYSIS OF ALTERNATIVE SITE CONDITIONS

Final site conditions for unconfined, open-water disposal sites were established via a review of environmental effects and cost factors. For this analysis, it was assumed that all dredging would occur regardless of the alternative site condition selected for management. However, EPWG recognized that in some instances the high cost of disposal may preclude some projects (though project-specific assessments, beyond the scope of PSDDA, would be required to identify these cases). Therefore, given the assumption, the environmental analysis at the dredging site is not a major consideration. However, environmental analysis is important at the disposal sites.

At open-water disposal sites, the chemical pathway of primary concern is the direct contact between organisms and the biologically active surface layer of the bedded dredged material (material below this layer is largely unavailable to organisms). Exposure of organisms to significant or harmful concentrations of chemicals released into the water column during dredging operations is unlikely to occur in most instances, although water column testing remains an option under PSDDA if warranted by project evaluation. The major laboratory tests recommended by EPWG as adequate models of potential sediment or water column effects include bulk sediment chemistry, acute toxicity bioassays, and bioaccumulation.

EFFECTS ANALYSIS OF ALTERNATIVE SITE CONDITIONS (con.)

Although Site Condition I provides the lowest level of biological effects at the unconfined, open-water disposal site, the volume of material that might be acceptable with this condition is small. In addition, if Site Condition I were applied to unconfined, open-water disposal sites, habitat losses and possible adverse effects in confined shore and land sites would be high compared to the deepwater impacts, due to the large volume of dredged material that would be disposed of in these environments.

Aquatic effects associated with the disposal of material under Site Condition II guidelines could include sublethal effects at the disposal site and potentially a small (though not significant) increase in the mortality of the more sensitive, but less abundant, benthic infauna (e.g., crustaceans). Material acceptable under Site Condition III would likely result in acute toxicity to marine organisms at the disposal site. Under Site Conditions II and III, effects associated with disposal on land and nearshore would be less than with Site Condition I because of the increased unconfined, open-water sites.

The PSDDA draft Environmental Impact Statement (DEIS) provides a detailed analysis of the environmental consequences of the alternative site management conditions.

COST ANALYSIS

EPWG performed a analysis of the cost impacts that the evaluation procedures may have on dredging and dredged material disposal. The analysis focuses primarily on comparing the total costs of unconfined, open-water disposal and confined disposal options for each of the alternative site management conditions. Though many combinations of disposal technology and types of disposal sites are possible, only the following disposal options and technology assumptions were included in the cost analysis:

- o Unconfined, open-water disposal
- o Confined aquatic disposal (capped to restrict contact with, or loss of, chemicals of concern)
- o Confined nearshore disposal (intertidal diking, with some restrictions for chemicals of concern)
- o Upland, intermediate secure disposal (using some special technology to restrict chemical losses)
- o Upland, secure disposal (using advanced and extensive chemical contaminant).

COST ANALYSIS (con.)

Using best-available information, dredged material volumes were allocated as acceptable or unacceptable for unconfined, open-water disposal based on average chemical concentrations and comparison to chemical ML's for each alternative site condition. This allocation enabled analysis of the cost of selecting each alternative site condition. Testing costs included field sampling costs and laboratory analysis costs. Disposal cost estimates included costs of dredging, transport, and disposal (for each site condition). The costs of monitoring and compliance were also included in the analysis.

The total estimated cost of accepting existing Puget Sound Interim Criteria for sediment from the Phase I area is approximately $331 million (most of the material is unacceptable under the chemical guidelines) over the 15-year period of analysis (1985 through 2000). The total estimated cost of accepting Condition I is approximately $268 million. Using the disposal guidelines represented by Condition II, the total estimated cost is approximately $204 million. The total estimated cost represented by Condition III is approximately $150 million. The estimated cost of disposing of all material at unconfined, open-water disposal sites is approximately $65 million.

SELECTED BIOLOGICAL EFFECTS CONDITION FOR SITE MANAGEMENT

Condition II is the selected management condition for unconfined, open-water disposal at the central Puget Sound sites. This site condition was selected based primarily on the following factors:

- Environmental Protection and Accountability - Material that is acceptable at Condition II is not expected to produce adverse effects outside of the disposal site due to relatively low concentrations of chemicals of concern and the use of relatively nondispersive sites. By definition, "no significant acute toxicity" would be allowed at the disposal site, and any long-term, sublethal adverse effects would be confined to the disposal site where they can be monitored and managed as needed. Also, site Condition II is consistent with State water quality standards.

- Costs - The total estimated dredged material disposal costs associated with Condition II are significantly lower than those estimated using Condition I; and are comparable to the costs associated with Condition III.

- Precedents - Condition II reflects the way that the Section 404(b)(1) Guidelines have been historically applied, avoiding "significant acute toxicity" from material that was approved for unconfined, open-water disposal.

Several procedural and management requirements are suggested to ensure periodical review of the evaluation procedures. Also, research needs to resolve outstanding issues concerning unconfined, open-water disposal have been outlined.

EXHIBITS

The technical appendix includes the following exhibits.

A. EPWG Plan of Study - presents a synopsis of tasks undertaken by EPWG.

B. Regional Administrative Decisions (RAD's) - presents an outline of RAD's that formed the basis for development of the evaluation procedures.

C. Corps of Engineers Section 404 Disposal Guidelines - contains additional background information, consisting of the current Corps national guidelines for dredged material evaluation pursuant to 40 CFR Part 230.

D. Cost Analysis Case Studies - presents a comparison of actual sampling and testing costs for evaluating a dredging project to the costs of doing the same project under proposed PSDDA evaluation procedures.

E. Abstracts of Reports Prepared for or Related to EPWG.

F. Engler, R. 1980. Prediction of pollution potential through geochemical and biological procedures: Development of regulation guidelines and criteria for the discharge of dredged and fill material. In: R.A. Baker, Ed. Contaminants and sediments. Volume 1: Fate, transport, case studies, modeling, toxicity. Ann Arbor Science. Ann Arbor, Michigan.

TABLE OF CONTENTS

Paragraph		Page
	ORGANIZATIONAL PREFACE	i
	ACKNOWLEDGEMENTS	ii
	EXECUTIVE SUMMARY	ES-1
	TABLE OF CONTENTS	TC-1
	PART I. INTRODUCTION	
1.	STUDY GOALS, DESCRIPTION, AND ORGANIZATION	I-1
1.1	Puget Sound Dredged Disposal Analysis	I-2
1.2	Evaluation Procedures Work Group (EPWG)	I-3
1.3	Concepts	I-6
1.4	Implementation of the PSDDA Evaluation Procedures	I-8
1.5	Management of the Evaluation Procedures Work Group	I-9
1.5.1	Participants and Coordination of Work	I-9
1.5.2	Public Involvement	I-9
2.	BACKGROUND AND OVERVIEW	I-12
2.1	Introduction	I-12
2.2	Definition of Dredged Material	I-12
2.3	New Sediment Surface Exposed by Dredging	I-12
2.4	The Need for Consistency in Dredged Material Evaluation	I-15
2.5	The Need for Flexibility in Application of Evaluation Procedures	I-15
2.6	Critical Characteristics of Evaluation Procedures	I-16
3.	STRATEGY	I-18
3.1	Overview of Evaluation Procedures Workgroup Strategy	I-18
3.2	Chemical Characterization of Dredged Material	I-18
3.3	Biological Characterization of Dredged Material	I-19
3.4	Development of a Test Sequence and Disposal Guidelines	I-19
3.5	Regional Administrative Decisions	I-21
4.	DREDGING IN THE PHASE I AREA	I-24
4.1	Major Dredging Areas	I-24
4.2	Historic Dredging	I-24
4.3	Dredging Forecasts	I-24
5.	ALTERNATIVE APPROACHES TO DREDGED MATERIAL MANAGEMENT	I-29
5.1	Technology-Based Approach	I-29
5.2	Material Release Approach	I-29
5.3	Human Health Effects Approach	I-31
5.4	Reference Site Approach	I-31
5.5	Biological Effects-Based Approach	I-32
5.6	Selected Approach	I-32

TABLE OF CONTENTS (con.)

Paragraph		Page
6.	ASSUMPTIONS	I-33
	PART II. UNCONFINED, OPEN-WATER DISPOSAL	
1.	EXISTING DISPOSAL GUIDELINES	II-1
1.1	Background	II-1
1.2	Federal Guidelines Governing Dredged Material Disposal in Water	II-4
1.2.1	Subpart A, General Information	II-4
1.2.2	Subpart B, Criteria for Compliance with Guidelines	II-4
1.2.3	Subparts C to F	II-5
1.2.4	Subpart G, Evaluation and Testing	II-6
1.2.5	Subpart H, Actions to Minimize Adverse Effects	II-7
1.2.6	Federal Guidelines for Permitting Discharges of Dredged Material	II-7
1.3	Decision Basis in Puget Sound	II-8
1.3.1	Historical Disposal Guidelines for Puget Sound	II-8
1.3.2	Fourmile rock Interim Criteria	II-12
1.3.3	Puget Sound Interim Criteria	II-17
1.3.4	Relationship Between the 1980 Proposed Section 404 Testing Guidelines and PSDDA Dredged Material Evaluation Procedures	II-19
2.	DECISIONMAKING FOR UNCONFINED, OPEN-WATER DISPOSAL	II-21
2.1	Dredging and Dredged Material Disposal Processes	II-21
2.2	Key Chemical Pathways	II-24
2.3	Additional Issues	II-26
2.3.1	Paralytic Shellfish Poisioning (PSP) Cysts	II-26
2.3.2	State Dangerous Waste Testing	II-26
2.3.3	Sea-Surface Microlayer	II-26
2.3.4	Material Release	II-27
2.4	Test Sequence and Disposal Guidelines	II-28
2.5	Dredger Option to Conduct Biological Testing Rather Than Accept Chemical Test Indications	II-33
3.	PRELIMINARY RANKING AND REVIEW OF THE DREDGING SITE	II-35
3.1	Location of Dredging and Area Ranking	II-35
3.1.1	Introduction	II-35
3.1.2	Description of Ranks	II-36
3.1.3	Relation to Disposal Guideline	II-38
3.1.4	Reranking of Areas/Projects	II-38
3.1.5	General Rankings	II-39
3.1.6	Specific Rankings	II-39
3.2	Project Size	II-39

TABLE OF CONTENTS (con.)

Paragraph		Page
3.3	Assessment of Existing Information	II-42
3.3.1	"Safety Net" Concept	II-42
3.3.2	Recency and Frequency Guidelines	II-44
3.3.3	Quality Assurance of Existing Data	II-45
4.	SAMPLING ISSUES AND CONCERNS	II-46
4.1	Dredged Material Management Units	II-46
4.2	Patchiness of Sediment Chemical Distributions	II-47
4.3	Sampling Method and Depths	II-48
4.3.1	Overview	II-48
4.3.2	Number of Samples and Analyses for Full Characterization	II-48
4.4.3	Positioning Methods for Station Location	II-50
4.4.4	Full Characterization Sampling and Analysis Guidelines Case Study	II-50
4.5	Sample Storage, Archiving, and Management	II-58
4.5.1	Storage and Archiving of Sediment for Chemical Tests	II-58
4.5.2	Storage and Archiving of Sediment for Biological Tests	II-58
4.6	Other Issues	II-59
5.	SAMPLING AND TESTING SEQUENCE	II-60
5.1	Sampling Sequence	II-60
5.2	Testing Sequence	II-61
5.2.1	Chemical and Biological Testing of Marine Sediments	II-61
5.2.2	Protocols	II-61
5.2.3	Data Verification	II-62
5.2.4	Partial Characterization	II-63
5.2.5	Partial Characterization Guidelines	II-63
6.	BIOLOGICAL TESTING	II-65
6.1	Biological Testing Issues	II-65
6.2	Biological Testing Reference Areas	II-66
6.3	Acute Testing Protocols	II-67
6.4	Chronic Testing Protocols	II-72
6.4.1	Recommended Tests	II-72
6.4.2	Other Chronic/Sublethal Tests	II-74
6.5	Alternative Tests Considered	II-75
6.5.1	Geoduck Acute Bioassay	II-75
6.5.2	Geoduch Growth Test	II-75
6.5.3	Intrinsic Rate of Population Growth	II-75
6.6	Biological Testing of Freshwater Sediments and Soils	II-77
6.7	Additional Issues	II-78
6.7.1	Reduced Testing Requirements for Small Projects	II-78
6.7.2	Biological Testing of "Anomalous" Samples	II-80
7.	CHEMICAL TESTING	II-80
7.1	Chemicals of Concern	II-80
7.1.1	Chemicals of Concern in Limited Areas	II-83

TABLE OF CONTENTS (con.)

Paragraph		Page
7.1.2	Comparison with Alternative Lists of Chemicals of Concern	II-86
7.1.3	Other Chemicals to be Measured	II-87
7.2	Development of Sediment Quality Values	II-87
7.2.1	Use of the Puget Sound Sediment Quality Data Base	II-88
7.2.2	Use of the Apparent Effects Threshold	II-91
7.2.3	Key Issues in Development of Chemical Disposal Guidelines	II-95
7.2.3.1	Reliability of Chemical Disposal Guidelines	II-95
7.2.3.2	Scientific Peer Review of Chemical Disposal Guidelines	II-97
7.2.3.3	Possible Consequences of Sediment Chemicals Not Measured	II-97
7.3	Screening Levels	II-98
7.3.1	Procedure for Setting Screening Levels	II-98
7.3.2	Procedure for Setting Screening Levels for Special Cases	II-100
7.4	Maximum Levels	II-100
7.4.1	Rationale for Maximum Level Concept	II-101
7.4.2	Single Chemical vs. Chemical Groups Maximum Levels	II-102
7.5	Toxic Chemical Testing Protocols	II-103
7.5.1	Metals and Metalloids	II-103
7.5.2	Organics	II-104
7.5.3	Conventional Parameter Testing Protocols	II-105
7.6	Detection Limits	II-105
7.6.1	Metals and Metalloids	II-105
7.6.2	Organics	II-106
7.7	Conventional Chemical Tests	II-106
8.	TEST INTERPRETATION: ALTERNATIVE BIOLOGICAL EFFECTS CONDITIONS FOR SITE MANAGEMENT	II-109 II-109
8.1	Overview	II-109
8.2	Options for Biological Effects Condition for Site Management	II-112
8.3	Options for Setting Maximum Chemical Concentrations for Site Management Conditions	II-117
8.3.1	Maximum Chemical Level for Site Condition I	II-117
8.3.2	Maximum Chemical Level for Site Condition II	II-118
8.3.3	Maximum Chemical Level for Site Condition III	II-118
8.4	Procedure for Defining Human Health Bioaccumulation Levels	II-123
8.4.1	Assumptions Made in Calculating Adjusted Health Indicators	II-123
8.4.2	Target Tissue Concentration Calculation Models	II-124
8.4.3	Seafood Ingestion Rate Estimate	II-125
8.4.4	Analysis of Adjusted Human Health Indicator Values	II-127
9.	EFFECTS ANALYSIS OF ALTERNATIVES	II-129
9.1	Introduction	II-129
9.2	Dredging Site Environmental Analyses	II-130

TABLE OF CONTENTS (con.)

Paragraph		Page
9.3	Disposal Site Environmental Analysis	II-131
9.3.1	Factors Affecting the Fate of Dredged Material Contaminants	II-131
9.3.2	Review of Available Information on Disposal Impacts	II-132
9.3.3	Unconfined, Open-Water Disposal	II-134
9.3.4	Confined Aquatic Disposal	II-135
9.3.5	Upland Disposal (Conventional and/or Confined)	II-136
9.3.6	Nearshore Disposal (Conventional and/or Confined)	II-136
9.4	Availability of Alternative Disposal Options	II-137
9.5	Comparison of the Preferred Phase I Disposal Sites	II-138
9.6	Adverse Effects of Alternative Site Management Conditions	II-139
9.6.1	Assumptions Used in Alternative Site Condition Analysis	II-139
9.6.2	Tradeoffs Between Alternative Site Management Conditions	II-140
9.6.3	Adverse Effects of Alternative Site Management Conditions	II-141
9.6.3.1	Site Condition I Effects	II-141
9.6.3.2	Site Condition II Effects	II-143
9.6.3.3	Site Condition III Effects	II-144
10.	COST ANALYSIS	II-146
10.1	Overview and Calculation of Dredged Material Volumes	II-146
10.1.1	Sources of Data	II-148
10.1.2	Cost Assumptions	II-148
10.1.3	Dredged Material Volume Estimates	II-150
10.2	Cost of Testing	II-160
10.2.1	Testing Requirements	II-164
10.2.2	Costs	II-167
10.3	Cost of Disposal	II-168
10.3.1	Assumptions	II-168
10.3.2	Dredging Costs	II-176
10.3.3	Transport Costs	II-178
	a. Marine Transport	II-178
	b. Overland Transport	II-178
10.3.4	Disposal Costs	II-182
10.3.4.1	Unconfined Disposal	II-182
10.3.4.2	Confined Disposal	II-182
10.3.5	Costs of Alternative Disposal Management Options	II-189
10.4	Cost of Ocean Disposal	II-189
10.4.1	Hauling Costs	II-189
10.4.2	Comparison to Costs for Confined Disposal	II-197
10.5	Conclusions	II-197
10.5.1	Costs of Testing	II-197
10.5.2	Sediment Management Costs	II-201

TABLE OF CONTENTS (con.)

Paragraph		Page
11.	PROPOSED DISPOSAL GUIDELINES FOR SITE MANAGEMENT	II-202
11.1	Basis for Selection	II-202
11.2	Selected Disposal Guidelines	II-202
11.3	Dredger Option to Conduct Biological Testing	II-203
12.	REVISIONS TO THE EVALUATION PROCEDURES	II-216
12.1	Annual Review of the Evaluation Procedures	II-216
12.2	General Considerations for Revising the Evaluation Procedures	II-217
13.	WORK GROUP CONCLUSIONS	II-218
13.1	Proposed, Allowable Site Condition	II-218
13.2	Additional Effort	II-218
13.3	Policy on Research and Development	II-219
	PART III. OTHER DISPOSAL OPTIONS	
1.	INTRODUCTION	III-1
2.	CONVENTIONAL UPLAND AND NEARSHORE DISPOSAL	III-3
2.1	Existing Guidelines for Conventional Upland and Nearshore Disposal	III-3
2.2	Upland and Nearshore Disposal Chemical Pathways	III-4
3.	CONFINED DISPOSAL	III-7
3.1	Confined Disposal Assessment Issues	III-8
3.2	Confined Disposal Testing Requirements	III-8
3.3	Comparison of Disposal Options	III-10
3.4	Alternatives to Confined Disposal	III-11
3.4.1	Contaminant Separation	III-12
3.4.2	Physical Separation	III-12
3.4.3	Contaminant Extraction	III-13
3.4.4	Chemical Immobilization	III-13
3.4.5	Contaminant Destruction	III-14
3.4.6	Summary	III-14
	PART IV. REFERENCES	IV-1
	PART V. GLOSSARY OF TERMS AND ABBREVIATIONS	V-1

TABLE OF CONTENTS (con.)

		Page
	EXHIBITS	
A.	EPWG Plan of Study	A-1
B.	Regional Administrative Decisions	B-1
C.	Section 404 Testing Guidelines	C-1
D.	Cost Analysis Case Studies	D-1
E.	Summary of Reports Prepared for or Relevant to the Evaluation Procedures Work Group	E-1
E.1	Puget Sound Dredged Disposal Analysis Plan of Study	E-3
E.2	Description of Evaluation Procedures Work Group Tasks Conducted in Phase I	E-6
E.3	Regional Administrative Decision Paper	E-9
E.4	Preliminary Findings Report	E-11
E.5	Dredged Material Inventory System	E-13
E.6	Decisionmaking Framework Developed With Commencement Bay Data	E-15
E.7	Illustrated Guide to Dredged Material Disposal	E-17
E.8	Pattern Recognition Report	E-18
E.9	Sediment Quality Values Report	E-21
E.10	Microlayer Reports	E-26
E.11	Protocols for Bioassays	E-28
E.12	Protocols for Navigation and Siting	E-30
E.13	Protocols for Analysis of Metals	E-35
E.14	Protocols for Analysis of Organic Compounds	E-37
E.15	Report on Guidelines for Confined Disposal	E-39
E.16	Comparative Risk Analysis and Report on Workshop	E-41
E.17	Chemical and Biological Monitoring of Disposal Sites	E-44
E.18	Cost Analysis for Testing and Dredged Material Management	E-46
E.19	Review of Canadian Regulations for Disposal of Dredged Material in Open Water	E-48
E.20	Waterways Experiment Station Draft Pretreatment Report	E-50
E.21	Dredged Material Alternative Selection Strategy (DMASS) Report	E-51
E.22	NOAA Sublethal Bioassay Report	E-53
F.	Engler, R. 1980. Prediction of Pollution Potential Through Geochemical and Biological Procedures: Development of Regulation Guidelines and Criteria for the Discharge of Dredged and Fill Material	F-1

Number	FIGURES	
1	PSDDA Testing Sequence	ES-7
I.1-1	PSDDA Study Areas	I-4
I.1-2	PSDDA Phase I Study Area	I-5

TABLE OF CONTENTS (con.)

Number		Page
I.1-3	Basic Decision Process and Organization of Technical Appendix	I-7
I.2-1	Cross Section of a Dredging Prism	I-13
I.3-1	Disposal Testing Strategy for Unconfined, Open-Water Disposal	I-20
I.3-2	Factors in Regional Administrative Decisions	I-22
II.1-1	Decision Flow Chart for Fourmile Rock Interim Dredged Material Disposal Criteria	II-16
II.2-1	Dredging and Disposal Processes	II-23
II.2-2	Environmental Pathways for Unconfined Open-Water Disposal	II-25
II.2-3	PSDDA Testing Sequence	II-29
II.2-4	PSDDA Disposal Guidelines	II-30
II.2-5	Section 404 and Section 401 Disposal Guidelines	II-31
II.3-1	Sources of Existing Information	II-43
II.4-1	Plan View and Cross Section of Example Dredging Project	II-52
II.4-2	Dimensions of Example Dredging Prism Used to Estimate Dredging Volumes	II-54
II.4-3	Examples of (A) Vertical Lifts in Dredging Prism, and (B) Allocations of Samples Among Lifts	II-55
II.4-4	Plan View of Sampling Stations in Dredging Prism	II-57
II.7-1	Location of Chemical and Biological Samples Included in Puget Sound Data Base	II-90
II.7-2	The Apparent Effects Threshold (AET) Approach Applied for a Single Chemical (Lead)	II-92
II.7-3	The Apparent Effects Threshold (AET) Approach Applied for a Single Chemical (4-methyl phenol)	II-93
II.8-1	Relationship of Control, Reference, and Test Treatment Bioassay Results in Determining Significant Toxicity	II-113
II.9-1	Alternative Biological Effects Conditions	II-122
II.10-1	Relationship of Testing and Dredged Material Management Analyses to the Overall Cost Analysis for Dredging Areas	II-149
II.10-2	Methods for Quantifying Dredged Material Volumes According to Each EPWG Level	II-151
II.10-3	Locations of the Three Phase I Dredging Areas in Central Puget Sound	II-152
II.10-4	Total Sediment Allocation for Each Site Condition	II-162
II.10-5	Comparison of Sampling and Testing Costs for Each Dredging Area	II-174
II.10-6	Structure of the Cost Model for Dredged Material Management, Including Costs of Dredging, Transport, and Disposal	II-175
II.10-7	Dredging, Hauling, and Disposal Costs for Each Area	II-192
II.10-8	General Location of Puget Sound Area Dredged Material Sources and the Material Transport Routes and Distances to the Strait of Juan de Fuca and the Pacific Ocean	II-193

Number		Page
II.10-9	Comparison of Total Costs for PSDDA and PSIC Program Alternatives	II-200
II.11-1	PSDDA Testing Sequence	II-204
II.11-2	Section 404 and Section 401 Disposal Guidelines	II-210
II.11-3	PSDDA Disposal Guidelines	II-211
II.11-4	Relationship of Control, Reference, and Test Treatment Bioassay Results in Determining Significant Acute Toxicity in Sediment Toxicity Tests for Dredged Material	II-212
II.11-5	Illustrated Example of the Differences Between Interim Criteria and the Proposed PSDDA Sediment Quality Values	II-213
II.11-6	Illustrated Example of the Differences Between Interim Criteria and Proposed PSDDA Sediment Quality Values	II-214
II.11-7	Illustrated Example of the Differences Between Interim Criteria and Proposed PSDDA Sediment Quality Values	II-215
III.1-1	Environmental Pathways for Conventional Upland Disposal	III-5
III.1-2	Environmental Pathways for Conventional Nearshore Disposal	III-6
III.3-1	Environmental Pathways for Confined Aquatic Disposal	III-9

TABLES

1	Biological and Chemical Disposal Guidelines for Alternative Allowable Site Conditions	ES-14
I.1-1	List of EPWG Participants	I-10
I.4-1	Major Dredging Areas in the Phase I Area, Central Puget Sound	I-25
I.4-2	Puget Sound Dredged Material Inventory for the Phase I Area (Seattle, Tacoma, Everett) 1970-1985	I-26
I.4-3	15-Year Projections (1985-1999) of Total Dredging Volumes (c.y.) By Specific Dredging Areas Within Phase I	I-28
I.5-1	Alternative Approaches for Managing Dredged Material	I-30
II.1-1	Fourmile Rock Chemical Sediment Criteria	II-15
II.1-2	PSIC (Port Gardner) Chemical Sediment Criteria	II-17
II.1-3	Chronology of Interim Sediment Criteria Developed Prior To the PSDDA Program	II-18
II.3-1	Definition of Area Ranks for Dredging Projects	II-37
II.3-2	Initial Area Rankings in the Phase I Study Area (Relative to Potential for Containing Chemicals of Concern)	II-40
II.3-3	"No Test" Volumes for Small Projects	II-41
II.4-1	Dredged Material Management Units	II-47
II.4-2	Sampling and Analysis Guidelines for Full Characterization	II-49

TABLE OF CONTENTS (con.)

Number		Page
II.4-3	Summary of Steps Used in Applying Sampling and Analysis Guidelines	II-51
II.6-1	Suggested Reference Sites for Collection of Reference Sediments for Biological Testing	II-68
II.6-2	Sediment Bulk Chemistry Trigger Values for Bioaccumulation	II-73
II.6-3	Reduced Biological Testing Requirements for Small Projects Above "No Test" Volume	II-79
II.7-1	Chemicals of Concern	II-83
II.7-2	Recommended Metals Limits of Detection for Water, Sediment, and Tissue Matrices	II-107
II.7-3	Recommended Organics Limits of Detection for Sediment and Tissue Matrices	II-108
II.8-1	Alternative Definitions of Alternative Biological Effects Conditions for Management of the Unconfined, Open-Water Disposal Sites in the Phase I Area	II-111
II.8-2	Biological Disposal Guidelines for Alternative Site Management Conditions	II-114
II.8-3	Chemical Disposal Guidelines for Alternative Site Management Conditions	II-119
II.8-4	Screening and Maximum Level Chemistry Values	II-120
II.8-5	Resulting Target Tissue Concentration Values (HI) for Chemicals of Concern to Human Health	II-126
II.9-1	Alternative Allowable Site Conditions for Unconfined, Open-Water Disposal Sites	II-139
II.9-2	Comparison of Physicel and Biological Parameters of the Preferred Open-Water Disposal Sites in the Phase I Study Area	II-142
II.10-1	Forecast Dredging Volumes (C.Y. x 1000) for Phase I Area, 1985-2000	II-154
II.10-2	Fifteen-Year Projections (1985-1999) of Total Dredging Volumes (C.Y. x 1000) by Specific Dredging Subareas Within Each Dredging Area	II-156
II.10-3	Sediment Chemistry Guidelines	II-157
II.10-4	Disposal Volume Allocations (1985-2000) (C.Y. x 1,000)	II-161
II.10-5	Mean Dredged Material Volumes (C.Y. x 1,000) Expected to Be Allowed at Multiuser Public Unconfined, Open-Water Disposal Sites	II-163
II.10-6	Area Rankings, Number of Cores, and Number of Analyses Estimated for Each Subarea	II-165
II.10-7	Costs for Present (Interim) Sediment Testing Requirements	II-169
II.10-8	Costs for Projected Sediment Testing Requirements	II-170
II.10-9	Projected Costs of Sediment Sampling and Testing Over The Next 15 Years (1985-2000)	II-172
II.10-10	Descriptions of Sediment Disposal Technology Assumptions	II-177

TABLE OF CONTENTS (con.)

Number		Page
II.10-11	Subarea Locations and Their Transport Distances to Dredged Material Disposal Areas	II-179
II.10-12	Locations Chosen for Disposal Sites in the Three Phase I Dredging Areas	II-181
II.10-13	Sediment Transport Costs by Specific Dredging Areas Within Phase I Dredging Areas	II-183
II.10-14	Disposal Technology Cost Model: Open-Water Capped	II-185
II.10-15	Nearshore Disposal Dike and Weir Costs	II-186
II.10-16	Disposal Technology Cost Model: Nearshore	II-188
II.10-17	Summary of Costs for Confined Disposal	II-190
II.10-18	Costs of Dredging Material from the Phase I Areas, Hauling to the Appropriate Site, and Disposal	II-191
II.10-19	Dredged Material Haul Distances From the Three Phase I Dredging Areas to Locations in the Strait and Ocean	II-194
II.10-20	Dredged Material Disposal Costs: Disposal in the Strait/Ocean	II-195
II.10-21	Comparison of Disposal in the Strait/Ocean to Transport and Disposal Unit Costs for Other Technologies	II-196
II.10-22	Total Costs for the Management Options Presented in the PSDDA Draft EIS ($ x 1,000)	II-198
II.11-1	Biological and Chemical Disposal Guidelines for the Selected Site Condition	II-205
II.11-2	Screening and Maximum Level Chemistry Values for the Recommended Site Condition	II-206

PART I. INTRODUCTION

1. STUDY GOALS, DESCRIPTION, AND ORGANIZATION

This technical appendix addresses the development of evaluation procedures (testing and disposal guidelines) for determining when dredged material is acceptable for unconfined, open-water disposal pursuant to the Clean Water Act in central Puget Sound, the Phase I area of the Puget Sound Dredged Disposal Analysis (PSDDA) Study. A review and synthesis of studies conducted, information gathered, and analysis performed during development of the evaluation procedures are provided.

Since the 1970's, elevated concentrations of chemicals of concern as a result of multiple discharge sources have been found in sediments of urban bays in Puget Sound. Some of these chemicals of concern have also been identified in fish, shellfish, and other organisms. While research is continuing on the pathways by which exposure to sediment chemicals affect marine life or human health, recent field studies have noted adverse biological effects in areas of high sediment chemical concentrations. Because open-water disposal of dredged material from harbors and navigation channels can result in transfer of sediment chemicals from shallow to deep water, both State and local governments have invoked procedures of the State of Washington's Shoreline Management Act to impose stringent conditions on renewals of open-water disposal site shoreline permits. Dredging is necessary to keep shipping channels and harbors open, to construct new ports, and *sometimes* to cleanup containing material containing high chemical concentrations. Consequently, dredging in Puget Sound has been a commonplace activity historically and is an ongoing necessity for the forseeable future.

Five basic disposal options are possible. These include unconfined, open-water, "conventional" (unconfined, without chemical restrictions) upland/nearshore, confined aquatic, confined nearshore, and confined upland. The three confined options result from the need to address sediment chemical levels that are unacceptable for unconfined or conventional disposal. Open-water sites are located offshore in deep water areas. Unconfined, open-water disposal occurs through releasing material to freefall to the bottom with no subsequent handling. Confined aquatic disposal involves capping material that is unacceptable for unconfined disposal with material that is acceptable for unconfined, open-water disposal. Nearshore disposal sites are typically diked aquatic areas, but the final surface of the site is at or above the waterline. Upland disposal sites are on land entirely above the waterline, are typically removed some distance from the shoreline, and are often diked. Of these options, PSDDA is addressing unconfined, open-water disposal in detail (i.e., siting, dredged material evaluation procedures, and site management). PSDDA developed some information on other disposal options; however, further efforts with confined disposal are planned by other, separate State programs.

Cost effective disposal of dredged material is essential to the economic interests of the Puget Sound region, which serves as a major port for the

Nation. More than 200 small boat harbors meet the needs of commercial fishing vessels and pleasure craft in the Puget Sound region. Periodic dredging is necessary in most of these small boat harbors, as well as for the major deep-water ports. For dredged material without significant levels of chemicals of concern, which constitutes the majority of dredged material, disposal at unconfined, open-water sites has been the least costly alternative. As upland and nearshore areas become more difficult to secure, use of unconfined, open-water disposal will increase.

1.1 Puget Sound Dredged Disposal Analysis. PSDDA is an interagency program which includes the Seattle District, U.S. Army Corps of Engineers (Corps) as lead agency, supported by the Region 10, U.S. Environmental Protection Agency (EPA), and the Washington Departments of Ecology (Ecology) and Natural Resources (DNR). The goal of PSDDA is to provide the basis for publicly acceptable guidelines governing environmentally safe unconfined, open-water disposal of dredged material, and to provide Puget Sound-wide consistency and predictability in decisions concerning dredged material disposal. The objectives of PSDDA are as follows:

- o Identify acceptable unconfined, open-water disposal sites.
- o Define consistent and objective evaluation procedures for the dredged material to be discharged at those sites.
- o Develop site use management plans.

Three work groups have been formed to address the PSDDA objectives, with staff from the four PSDDA agencies serving on each work group. Many other interest groups including representatives from Puget Sound ports, Indian tribes, environmental groups, the dredging industry, local governments, and other State and Federal agencies are also participating in the work group activities. The work groups, under the general guidance of the PSDDA Study Director, have conducted studies and analyses needed to meet the stated objectives. These work groups are:

- o Disposal Site Work Group (DSWG)
- o Evaluation Procedures Work Group (EPWG)
- o Management Plan Work Group (MPWG).

DSWG was assigned the responsibility for identifying and selecting the locations of the unconfined, open-water disposal sites in central Puget Sound.

EPWG was assigned the responsibility for development of procedures and guidelines for assessing the quality of dredged material and delineating which materials are acceptable for unconfined, open-water disposal.

MPWG was assigned the responsibility for development of a management plan for use of each of the unconfined, open-water disposal sites.

The work of PSDDA is divided into two phases that differ geographically and temporally (figure I.1-1). Phase I of the study began in April, 1985. The Phase I study area covers a smaller geographic area than Phase II and includes Puget Sound from Everett south to Tacoma, and all of Port Susan to the north of Everett (figure I.1-2). The bulk of dredging in Puget Sound derives from this area, which also contains some of the dredged material with higher levels of chemicals of concern. All findings contained in this technical appendix are pertinent soley to the Phase I area of PSDDA.

Phase II of the PSDDA study overlaps the Phase I schedule and includes the rest of Puget Sound up to the Canadian border (figure I.1-1). The Phase II study began in April, 1986 and is scheduled to end 1 year later than Phase I. Though the focus of this technical appendix is the Phase I area, public scoping meetings were held by PSDDA in the Phase II communities of Olympia, Port Townsend, and Bellingham to ensure that the public in the Phase II area would have an opportunity to influence the Phase I process and results. Phase II decisions are separate from those of the Phase I area, but many of the Phase I results are expected to be applicable to the Phase II area. This is especially true for the dredged material evaluation procedures, where Puget Sound-wide consistency is a stated goal.

The regulatory context for the PSDDA study is Section 404 of the Clean Water Act of 1977 (Public Law 92-500), which establishes a Federal permit system for the disposal of dredged and fill material, and Section 401, which requires a water quality certification from the State prior to issuance of a Federal permit. The Coastal Zone Management Act (Public Law 92-583) requires Federal projects in the particular State be consistent with the State's coastal zone management program to the "maximum extent practicable." Full consistency is required for non-Federal projects. Although its current thrust is associated with the dredging site, Section 10 of the 1899 River and Harbor Act also applies to disposal activities in navigable waters. A more detailed description of the legal requirements relevant to disposal of dredged material is presented in part II.1 of this technical appendix.

PSDDA is only one of several ongoing environmental programs in Puget Sound. The work of PSDDA requires detailed coordination with the efforts of the Puget Sound Estuary Program (PSEP) and the Puget Sound Water Quality Authority (PSWQA). PSDDA originated in the PSEP program as a discrete, and now separate, component of the overall estuary program. Because the charter of PSWQA also includes dredging issues, components of the Authority's Puget Sound Water Quality Plan were developed in close coordination with PSDDA.

1.2 Evaluation Procedures Work Group (EPWG). The goal of EPWG is to establish chemical and biological evaluation procedures for dredged material that

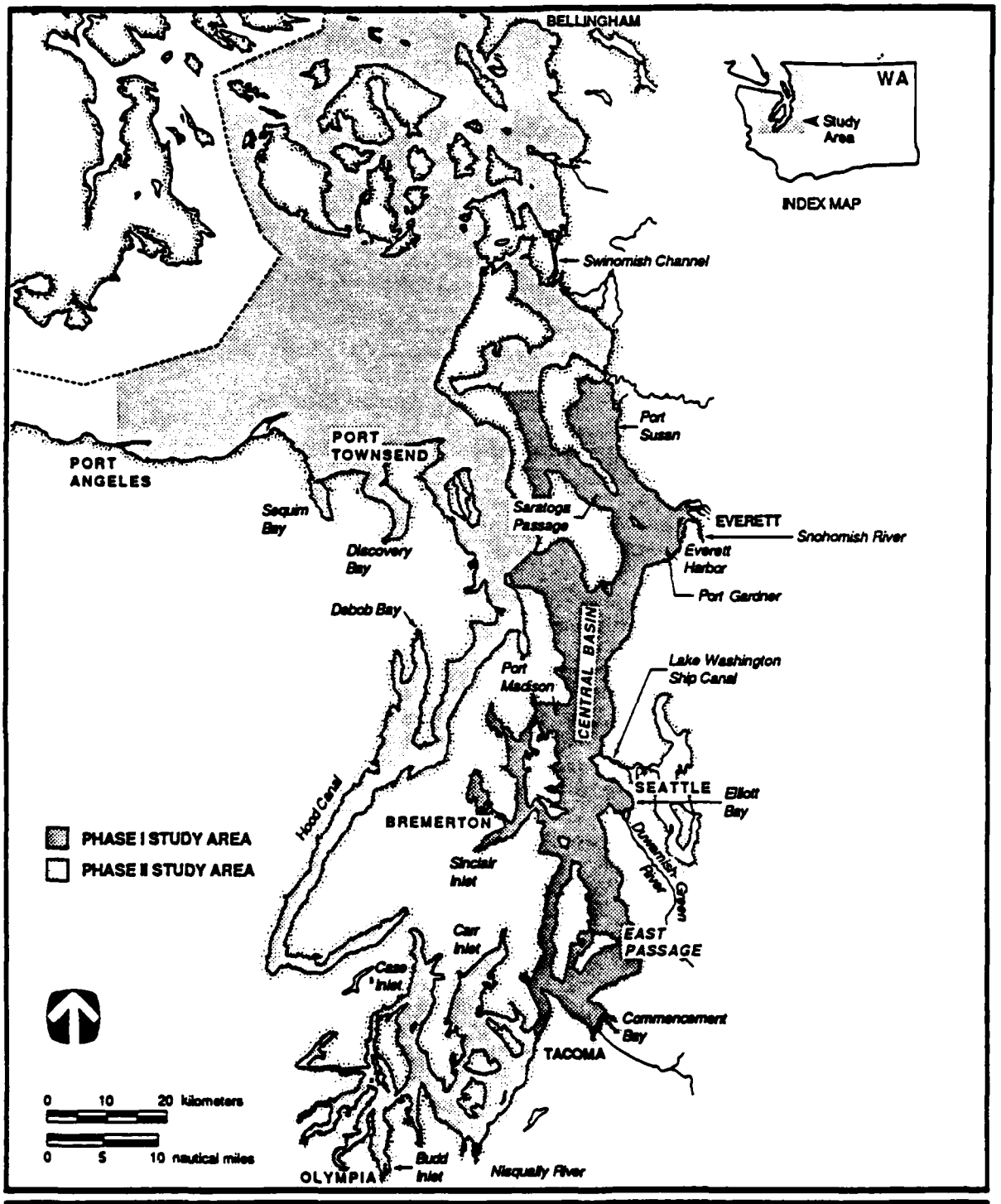


Figure I.1-1. PSDDA study areas.

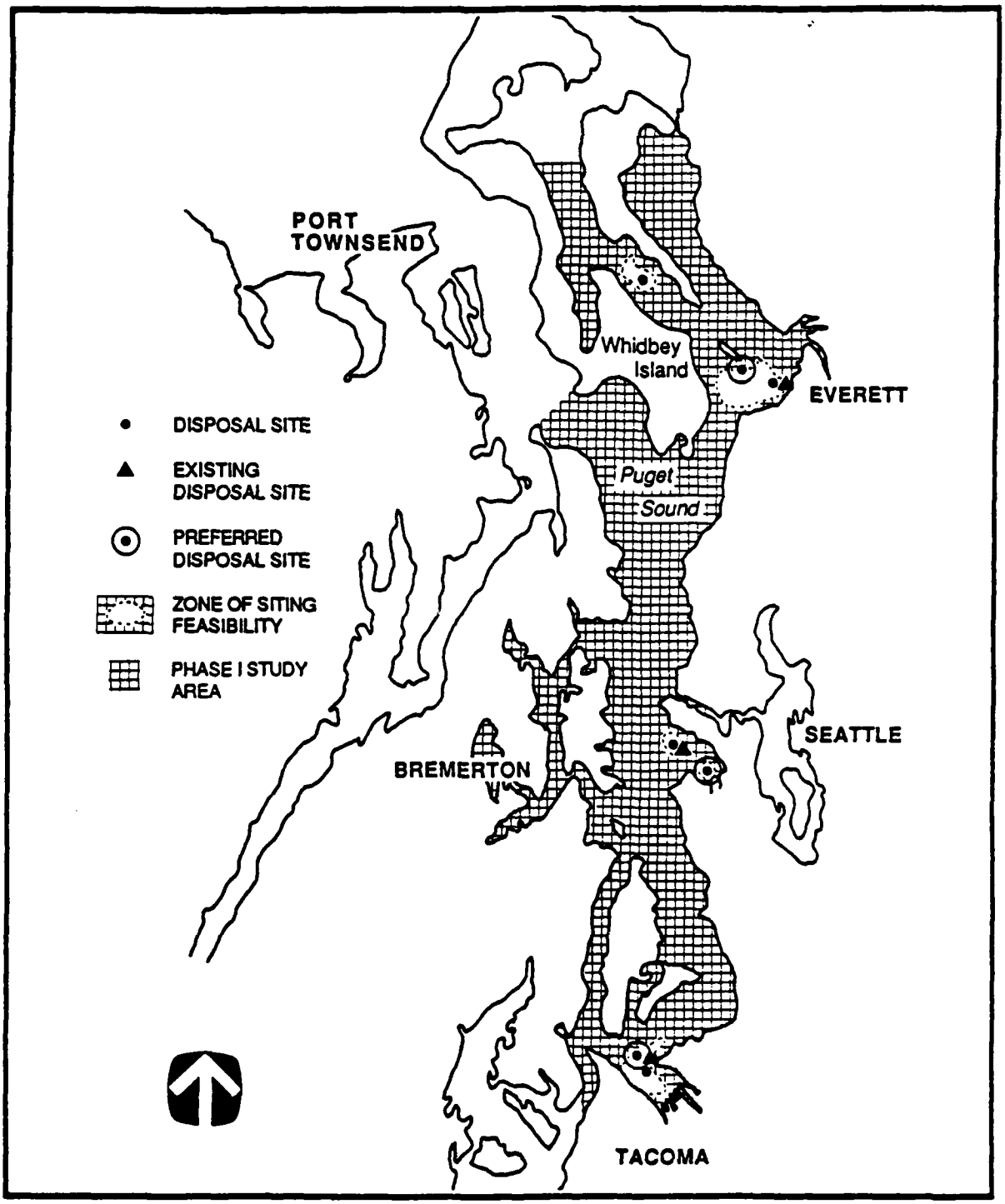


Figure I.I-2 PSDDA Phase I study area.

allow unconfined, open-water disposal in an environmentally safe manner by avoiding unacceptable adverse effects to human and environmental health. In achieving this goal, several important issues had to be addressed:

1. What chemical and/or biological tests should be used on sediments?

2. How should these tests be interpreted?

3 What level of sediment chemical effects on biological resources should be considered acceptable?

EPWG attempted to identify the most cost effective sampling and analysis procedures for appropriately characterizing dredged material, and to incorporate these procedures into comprehensive guidelines. Chemical and biological tests and interpretation guidelines were developed for assessing the acceptability of dredged material for unconfined, open-water disposal. Application of these tests and guidelines allow preliminary decisions to be made on the need for confined disposal (i.e., confined aquatic, nearshore, or upland). Though the focus of PSDDA is unconfined, open-water disposal, this total approach was required to consider overall environmental consequences of disposal in all environments and the cost implications associated with deciding what material is acceptable for unconfined, open-water disposal.

Much of this work was accomplished in close coordination with other programs. PSEP and PSDDA jointly participated in the work to identify chemicals of concern and to develop sediment quality values. PSDDA participated in the development of several of the PSEP protocols for sampling and analysis methods. In addition, the original work of the Commencement Bay Nearshore/ Tideflats Superfund Remedial Investigation in developing a decisionmaking framework for evaluation of contaminated sediments, and in defining chemical-specific sediment quality values, were important contributions (see exhibits E.6 and E.9).

1.3 Concepts. Evaluation procedures comprise the sampling requirements, tests, and guidelines for test interpretation (i.e., "disposal guidelines") that are to be used in assessing the quality of dredged material and deciding on the acceptability of dredged material for a proposed disposal option. Evaluation procedures have been developed for chemical and biological tests that serve to identify whether unacceptable adverse effects on biological resources might result from dredged material disposal. A decision for disposal (i.e., unconfined or confined disposal) of this material is determined from the test results. The general flow of decisions in determining an acceptable disposal option is shown in figure I.1-3.

Not all dredged material is acceptable for unconfined, open-water disposal or for conventional upland/nearshore disposal. Dredged material that has high enough chemical concentrations to result in unacceptable adverse effects must

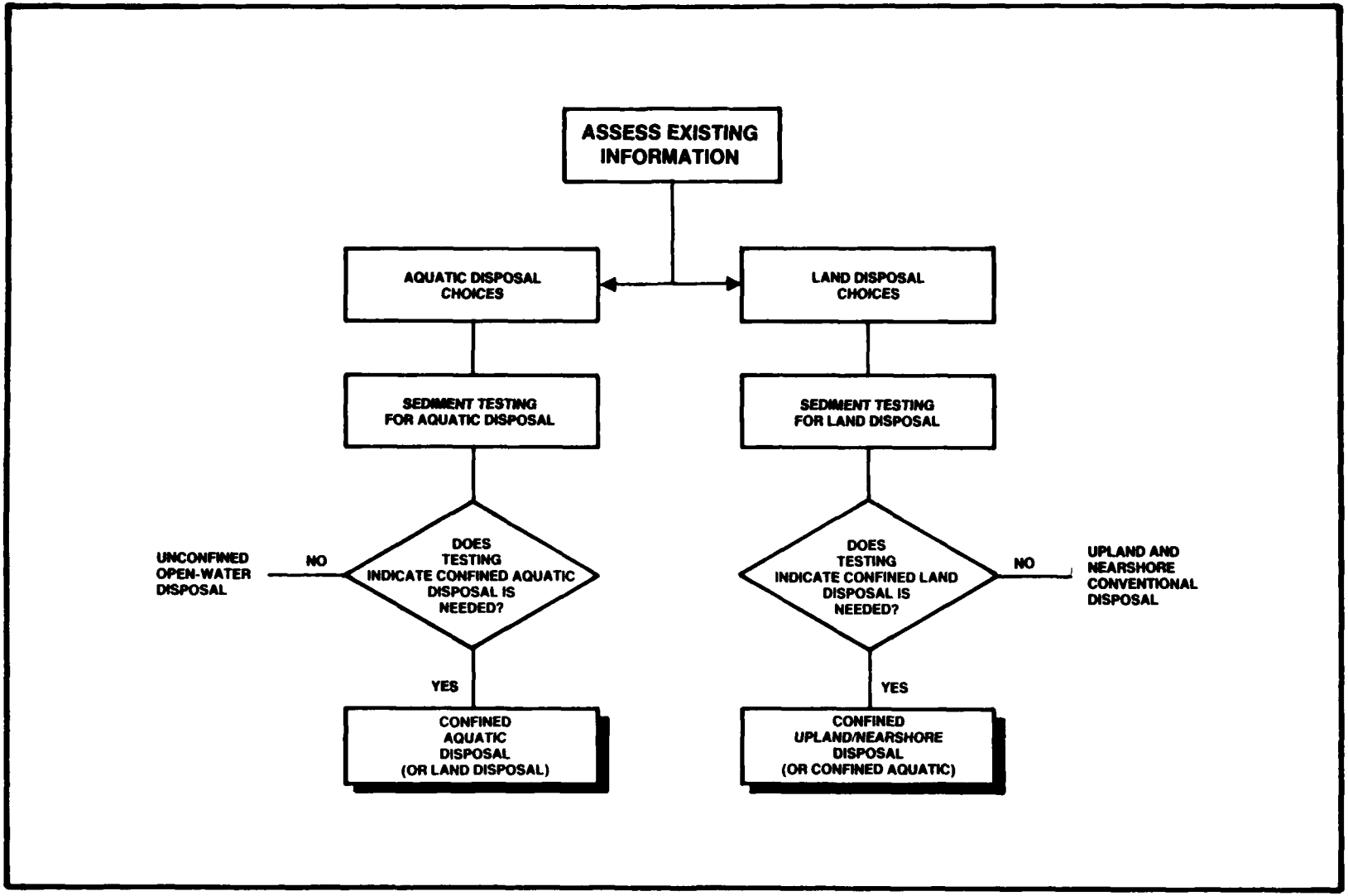


Figure I.1-3. Basic decision process for dredged material disposal.

be placed in a confined disposal site (i.e., aquatic, land, or nearshore). Chemical effects are estimated by conducting chemical and biological tasts on the sediment prior to dredging. Material that is found to be unacceptable for unconfined, open-water disposal may or may not be acceptable for conventional upland/nearshore disposal, because of differing behavior of chemicals in land and nearshore disposal environments. As a result, testing for disposal at upland and nearshore sites would differ from that for disposal in water, and test results for one environment are not directly transferable to the other.

There is no single best option when confined disposal is required. Although all options may be feasible, not all confined disposal options are available to every dredging project. Additionally, confined disposal decisions will often revolve around the advantages and disadvantages of specific sites (e.g., proximity to resources). Besides availability and siting, the issues of cost and of the necessary degree of chemical confinement and control also must be considered.

1.4 Implementation of the PSDDA Evaluation Procedures. Responsibilities of each of the PSDDA regulatory agencies under Section 404 or Section 401 of the Clean Water Act (CWA) will be accomplished in accordance with each agency's authorities and policies. The PSDDA dredged material evaluation procedures will be applied by each regulatory agency consistent with these authorities and policies. This appendix provides the basis for an overall approach which can meet the case-by-case requirements of both Section 404 and Section 401. Most elements of the PSDDA procedures are common to both authorities. However, some elements are unique to either Section 404 of Section 401 requirements. Those seeking approval for unconfined, open-water disposal will need to meet both requirements, i.e., undertake the full suite of PSDDA tests, as each agency determines is applicable.

The Corps requirements for the evaluation of dredged material proposed for unconfined disposal in Puget Sound waters, as specified in Subpart G of the Section 404(b)(1) Guidelines, will be met primarily by the Section 404 components of the PSDDA evaluation procedures. The Section 404 component of the PSDDA procedures are, and will be, applied consistent with the national Corps process described in the PMP. The Corps will address other aspects of the Section 404(b)(1) compliance, such as impacts on navigation and national commerce and avoidance and minimization of impacts, including mitigation of unavoidable impacts and alternatives analysis on a case-by-case basis. Required national Corps procedures for implementation are reflected in 51 FR 19694, dated May 30, 1986 for Corps projects and 33 CFR 320-330 for the Corps regulatory program.

EPA will rely on the PSDDA evaluation procedures as the basis for preventing significant degradation of the aquatic environment as required by the Section 404(b)(1) Guidelines. These procedures represent the testing approaches and procedures, allowed under the guidelines, which EPA would require during the evaluation of dredged material. Other aspects of the Section 404(b)(1)

compliance, such as avoidance and minimization of impacts, including mitigation of unavoidable impacts, will also be addressed by EPA, during comprehensive reviews, on a case-by-case basis.

Ecology will apply the appropriate PSDDA evaluation procedures in assessing applications for Section 401 Water Quality Certification. Initially, the procedures will be treated as guidelines. However, depending on actions that might be taken by the Puget Sound Water Quality Authority in their adoption of the proposed PSDDA management plan as a feature of the PSWQA Water Quality Management Plan, the PSDDA evaluation procedures may later be adopted as State regulation.

1.5 Management of the Evaluation Procedures Work Group

1.5.1 Participants and Coordination of Work. Representatives of the Corps, EPA, Ecology, and DNR met as necessary to coordinate the work group activities. Active participation by affected users was also obtained at the meetings via representatives of the port districts. In addition to these principal groups, a number of other city, county, State, and Federal agencies have participated in the work of EPWG (table I.1-1). This participation has helped to ensure that resulting recommendations would reflect a balance of all appropriate views.

Over 50 EPWG meetings were held from 1985 to 1987. For most meetings detailed minutes were recorded, summarizing the conclusions of the work group discussion. Meetings were frequent enough to enable thorough discussion of all issues that needed to be addressed. The ultimate resolution of such issues appears in the minutes or in special reports, and in this appendix. Additionally, the EPWG meetings allowed general monitoring of the work as it proceeded. This monitoring included contract oversight and review of technical documents submitted by agencies or contractors.

1.5.2 Public Involvement. With the exception of budgeting meetings, all EPWG meetings were open to the public. The public was also involved in the EPWG decisionmaking process through a series of evening meetings held at several locations during the summers of 1985 and 1986. These public meetings were publicized through news media coverage, information brochures, newsletters, and by encouraging involvement of various organizations.

TABLE I.1-1. LIST OF EPWG PARTICIPANTS

Agency	Representative		
U.S. Army Corps of Engineers	Keith Phillips	EPWG member	*(a)
"	John Malek	EPWG member	*
"	Frank Urabeck		*
U.S. Environmental Protection Agency	Brian Ross	EPWG member	*
"	Carl Kassebaum		*
"	Catherine Krueger	PSEP/EPWG member	*
"	John Malek	EPWG member	*
Washington Dept. of Ecology	Jim Krull	EPWG member	*
"	Jim Thornton	EPWG member	*
Washington Dept. of Natural Resources	David Jamison	EPWG member	*
Washington Public Ports Assn.	Don Moos		*
Port of Anacortes	Don Moos		*
Port of Bellingham	Don Moos		*
Port of Edmonds	Don Moos		*
Port of Everett	Don Moos		*
Port of Olympia	Don Moos		*
Port of Port Angeles	Don Moos		*
Port of Skagit	Don Moos		*
Port of Tacoma	Don Moos		*
Port of Tacoma	Gary Kucinski		*
Port of Seattle	Doug Hotchkiss		*
Port of Seattle	Don Moos		*
Puget Sound Alliance	Jim Heil		*
Northwest Indian Fisheries Comm.	Dennis McDonald		*
Washington Dept. of Fisheries	Curtis Dahlgren		*
"	Mary Lou Mills		*
U.S. Fish & Wildlife Service	Chuck Dunn		*
"	John Cooper		*
Dept. of Social and Health Services	Carl Sagerser Steve Norsted		*
National Marine & Fisheries Service	Mike Schiewe		
Puget Sound Water Quality Authority	John Dohrmann		

TABLE I.1-1 (con.)

Agency	Representative	
Tetra Tech, Inc.	Robert Barrick	*
"	D. Mike Johns	*
"	Chuck Lytle	*
"	Nancy Musgrove	*
Hart-Crowser, Inc.	Phil Spadaro	*
Ogden-Beamen Assoc., Inc.	John Vlastelicia	
City of Everett	Gerry Ervine	
Metro	Pat Romberg	
JRB/SAIC	Don Weston	
National Oceanic & Atmospheric Administration	Ed Long	
Waterways Experiment Station, WES	Dick Lee	*
"	Dick Peddicord	*
"	Stratford Kay	*
"	John Cullinane	*
"	Tom Dillon	
University of Washington	Paul Dinnel	
University of Massachusetts	Jim Male	
New York University	Joe O'Connor	
Invert-Aid	Dianne Robbins	
consulting engineer	Jay Spearman	
citizen	Bonnie Orme	
OTHERS CONTACTED/CONSULTED		
City of Seattle	Elsie Hulsizer	
"	Julia Gibbs	
"	Fran Solomon	
National Marine Fisheries Service	Ed Murrell	
Battelle	Jack Anderson	
"	Jack Word	
"	Jack Hardy	

(a) * Indicates active participant. Attended several meetings and/or made frequent phone contact on the proceedings.

2. BACKGROUND AND OVERVIEW

2.1 Introduction. A number of conceptual terms and assumptions were used in a specific context within the PSDDA program. These terms (and assumptions) and their interrelationships are defined in this section.

2.2 Definition of Dredged Material. The PSDDA study focused on the disposal of dredged material (e.g., relocation of construction material, waste, or debris, and habitat improvement were not within the scope of PSDDA). In open-water areas, dredged material comprises sediment, rocks, and other bottom material that is removed during dredging operations. The definition of dredged material is more complex when dredging operations occur along the shoreline. Strictly speaking, only material to the left of the vertical line in figure I.2-1 is dredged material (per Section 404 of the Clean Water Act). Material to the right of the vertical line in figure I.2-1 is classed as "excavation material" and is officially not considered for disposal in marine waters (per permitting regulations). When such a vertical cut is made, slumping of bank material in the areas labeled 1b and 1c in figure I.2-1 occurs because it lies above a reasonable angle of repose and is unstable. Historically in Puget Sound, such excavation material has been informally considered dredged material. However, bank material excavated below the angle of repose (i.e., areas labeled 2 and 3 in figure I.2-1), or other land excavation material, has been permitted, and will continue to be included, as dredged material only if there would be an ecological benefit (e.g., habitat improvement) at the disposal site.

EPWG agreed that the bank material in areas 1b and 1c of figure I.2-1 should continue to be defined as dredged material. In addition, bank material in areas 2 and 3 of figure I.2-1 also should be considered dredged material for possible open-water disposal if an ecological benefit can be shown at the dredging site. For example, a fill project may remove shallow water habitat that can be replaced with new shallow water habitat if some of the material in areas 2 and 3 of figure I.2-1 is allowed for open-water disposal.

Finally, dredging contracts routinely include "overdepth" material that is often 2 feet below the required dredging depth (except for very small projects which may decide to minimize overdepth volume for cost control). In the past, the volume of overdepth material has not been shown in permit applications. This volume of dredged material now would be included in permit applications, at least for moderate and large size projects. Additionally, the overdepth volume would be included in the calculation of the requirements for sampling and analysis (see section II-4 below) and monitoring fees. Small projects will not necessarily be required to include a full 2-foot overdepth in calculating volumes unless such volumes are likely to be dredged.

2.3 New Sediment Surface Exposed by Dredging. Dredging operations can alter the condition of the surface sediments in the dredging area by exposing new sediments to direct contact with biota and the water column. Because the exposed surfaces may result in greater surface sediment chemical concentrations than existed before dredging, this aspect of dredging must be considered in project planning, review and decisionmaking.

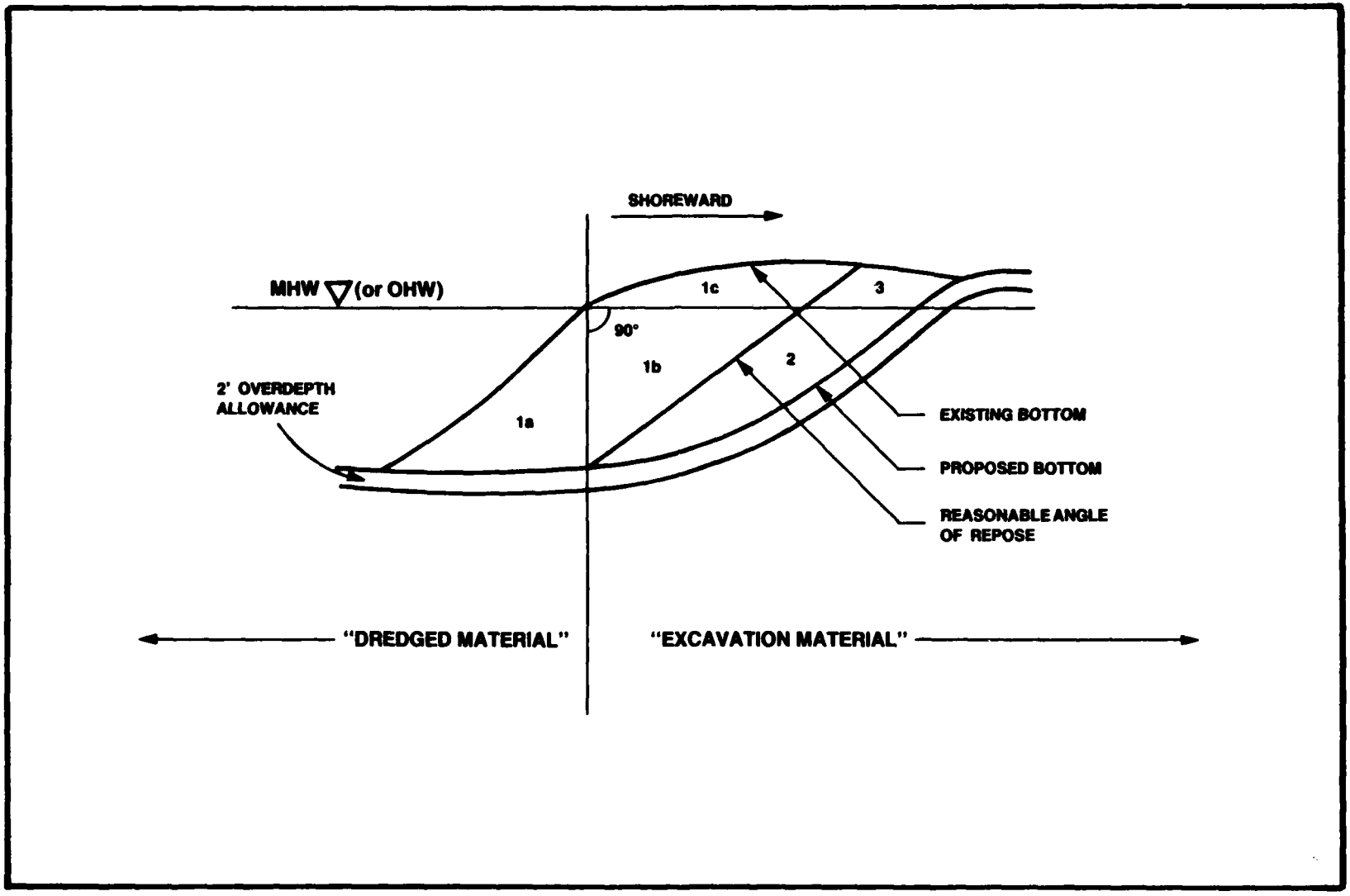


Figure I.2-1. Cross section of a dredging prism.

A variety of options were considered for the sampling of material that might be left following a dredging operation. EPWG specified that the new exposed surfaces be sampled to a depth of 1 ft below overdepth, and that the composited sample be archived. Chemical analyses of this material would only be required of the dredger if the sediment above the proposed exposed surface indicated potentially elevated chemical concentrations.

Several options for disposition of, and responsibility for, material that might be left following a dredging operation were discussed. Resolution of this issue was as follows, with three separate cases considered:

1. Material with unacceptable chemical concentrations may be present adjacent to a dredging area, but in an area that is not proposed to be dredged. In such cases, the dredger has no requirement under the PSDDA program to address the fate of the sediment in the adjacent area.

2. The dredging operation may result in exposure of sediment that has higher chemical concentrations than the material that was dredged. The concentration of chemicals in the exposed sediment could:

   a. be less than the chemical ML for unconfined, open-water disposal;

   b. exceed the chemical ML for unconfined, open-water disposal, but not the in situ sediment standard for chemical concentrations (i.e., a chemical guideline requiring evaluation of potential remedial action; such a guideline has not yet been established); or

   c. exceed the in situ sediment standard for chemical contamination as well as the chemical ML for unconfined, open-water disposal.

   The dredger must overdredge or cap the exposed sediment if chemical concentrations in the sediment exceed the ML for unconfined, open-water disposal (see section II-8.2 and table II.11-1). Dredging that causes surface chemical concentrations to exceed this level is unacceptable.

3. The dredging operation may leave material that contains lower chemical concentrations than was initially present. In this case, the dredger has no requirement under the dredging program concerning the fate of the exposed sediments. However, there may be other regulatory programs that request or require additional dredging in this, and the other cases. For example, the dredger may be determined to be responsible for discharge of the chemicals of concern and be required under a State or Federal regulation to conduct additional dredging as a remedial measure.

2.4 The Need for Consistency in Dredged Material Evaluation. Consistent evaluation procedures are important to the regulated community, demanded by local government agencies, and are needed to obtain public acceptance. Though consistent and "objective" evaluation procedures may somewhat reduce flexibility and reliance on best professional judgment, they achieve agreement among the various regulatory agencies and allow the transfer of knowledge as staffs change. The approach used was to compile the consensus "best judgment" of professionals currently involved in dredged material management and build this judgment into the procedures and guidelines.

2.5 The Need for Flexibility in Application of Evaluation Procedures. Although consistency is an important objective, EPWG recognized that flexibility must be maintained in the way the evaluation procedures and disposal guidelines are applied. When technical indications warrant, decisions different from those indicated by the guidelines will be allowed, and properly documented. The evaluation procedures will be applied and considered on a project-specific basis. In developing procedures for use everywhere in Puget Sound, it was not possible to consider all individual project technical factors, or assess all the possible outcomes that might arise from the test results. Consequently, professional judgment is essential in reaching project-specific decisions. The evaluation procedures (including the disposal guidelines) require full consideration of all pertinent project factors. Flexibility will be provided "by exception." The guidelines are expected to apply in the majority of cases. Rather than integrating flexibility into the guideline statements (by showing ranges of values, or by using terms such as "may do"), "exceptions" to the guidelines are allowed with appropriate technical rationale and documentation, when such rationale warrants a different conclusion. A consensus of all appropriate agencies would likely be required for use of this exception approach.

A good example of how flexibility enters into the decisionmaking process using evaluation procedures is the use of statistics and professional judgment in data interpretation. Statistics are primarily applied in the initial data analysis stage of the PSDDA disposal guidelines. Statistical significance is used to determine if observed differences are "potentially real" when natural variability of the parameters being measured is considered. Ultimate data interpretation requires judgment on the part of a professional who is intimately familiar with the testing procedures, the project specifics, and the initial data analysis conclusions.

Analysis of data consists of a comparison to guideline values that are developed using statistical significance as a clear indicator of toxicity. However, ecological significance cannot be determined by this process. Determination of ecological significance requires both an understanding of the data and evaluation procedures, and evaluation of those test results based on best professional judgment. In addition to data analysis and interpretation,

decisions on the acceptability of material for unconfined, open-water disposal may be further influenced by administrative considerations of factors such as magnitude of the proposed discharge, the degree of environmental risk that the discharge may present, and other project-specific features.

The full meaning of "statistical significance" was purposely not detailed in the proposed PSDDA guidelines. This provides some of the necessary flexibility to consider statistical confidence and magnitude of the apparent toxic response in interpreting whether test results indicate potential ecological significance.

2.6 Critical Characteristics of Evaluation Procedures. Evaluation procedures comprise the complete process of dredged material assessment and incorporate a range of scientific and administrative factors. Beyond the decision to base dredged material evaluation on avoiding unacceptable adverse biological effects, effective evaluation procedures should also be:

- o Accountable — Any required tests as part of the permitting process must be justifiable to the individual permittee and to the public.
- o Adaptable — The requirements must be flexible enough to allow for project and site-specific concerns and be adaptable to projects of any size.
- o Consistent — Within the different regions of Puget Sound there will be multiple projects of various sizes, kinds, scope, and chemical concentrations. Nevertheless, the permitting procedures must be applied consistently.
- o Cost effective — The most cost-effective means of achieving the required technical adequacy must be applied.
- o Objective — The requirements must be clearly stated and logical. Even if the criteria are subjective, they must be able to be applied in an objective manner.
- o Revisable — Because scientific uncertainties exist, the procedures must be able to be updated to incorporate best current information and judgment.
- o Understandable — The requirements must not be unnecessarily cumbersome or convoluted.

- Technically adequate -- Characterization of the dredged material must be adequate to make appropriate decisions concerning project dredging and disposal, and should address the behavior of chemicals of concern after the dredged material is placed at the disposal site.

- Time efficient -- Because major dredged disposal projects are a continual necessity in Puget Sound, evaluation procedures must not result in unnecessary delays.

- Verifiable -- To be enforceable, the implementation of the requirements must be verifiable by means of monitoring.

These 10 characteristics were used as standards for the final development of the evaluation procedures.

3.1 Overview of Evaluation Procedures Work Group Strategy. An overall strategy was formulated based on the need for evaluation procedures, their critical characteristics, the issues that required resolution (see exhibit A), and underlying assumptions. The critical elements of this strategy are summarized below:

- o Comprehensive approach -- A comprehensive approach (considering all dredged material and disposal options) is required to make proper decisions on guidelines for unconfined, open-water disposal.

- o Quality-based standards -- Selection of appropriate dredging and disposal technology will be based on the quality of the dredged material and the level of protection desired.

- o Chemical and biological tests -- Both chemical and biological testing are needed. Chemical testing for all harmful chemicals of concern is not possible, nor is it possible to reliably predict biological effects of single or multiple chemicals. Biological testing directly measures such effects, although all biological effects cannot be assessed by available testing procedures. Current protocols for biological testing are not a panacea, but are the best available.

- o Available guidelines -- Biological and chemical tests will be interpreted by applying available guidelines, standards, and effects data to the test results (e.g., human health standards, water quality criteria, and "sediment quality values"). Where possible, additional interpretive guidelines have been developed from existing information.

- o Biological testing reference areas -- Where there is no available or applicable guidance for interpreting biological test results, acceptable reference areas have been identified and tests must be run on sediments from these reference areas to compare to dredged material results.

For Phase I, the biological and chemical testing strategy described in the following sections was applied by EPWG to unconfined, open-water disposal. Further investigation by others will be needed to determine if this approach is applicable for assessment of conventional upland/nearshore disposal.

3.2 Chemical Characterization of Dredged Material. Sediments in urban waterways often contain chemicals from industrial, urban, or agricultural wastes. Such sediments raise concerns about the release of chemicals of concern into the environment during and after dredging and discharge, the movement of those chemicals along environmental pathways, and their effects on organisms. Because the nature and magnitude of chemical concentrations in dredged material are site-specific, sediment-specific information from the project area is needed to assess potential chemical effects.

Based on existing data and knowledge on apparent biological effects of chemical of concern, chemical characterization of a sediment may enable recognition of the potential for adverse effects from dredging and disposal of that sediment. Hence, for unconfined, open-water disposal, evaluation procedures were developed to relate the chemical concentrations in dredged material to potential biological effects. Chemical-specific "sediment quality values" were developed using sediment chemistry and biological effects information from over 190 stations in Puget Sound. The sediment quality values are useful tools in identifying potentially harmful levels of chemicals in sediments and, as part of PSDDA, will be used as chemical guidelines for determining when biological testing of dredged material should be required before a final decision concerning disposal can be made. The EPWG strategy was to set a low chemical concentration (i.e., a SL; see section II) below which unacceptable adverse biological effects are not anticipated, and dredged material would not require biological testing to determine if unconfined, open-water disposal is appropriate. At a much higher chemical concentration (i.e., ML; see section II), the dredged material is expected to be unacceptable for unconfined, open-water disposal. At intermediate chemical concentrations, biological testing would always determine whether the proposed disposal method was acceptable (see figure I.3-1). The dredger is also given the option to conduct biological testing on material that exceeds the ML. Appropriate testing under this option is discussed in section II-2.5.

3.3 Biological Characterization of Dredged Material. Dredged material is a complex mixture of soils minerals, water, and inorganic and organic chemicals. Complex and unpredictable, as well as predictable, interactions can occur among these components of dredged material and with organisms exposed to the dredged material. Frequently, chemical characterization of dredged material is inadequate by itself to predict the potential effects on aquatic organisms. Biological characterization of dredged material has been incorporated as an additional means of ensuring that potential effects to both water column and benthic organisms are not overlooked. The biological tests typically include direct exposure of the dredged material to sensitive organisms (e.g., sediment bioassay and bioaccumulation tests), or indirect tests using extracts from the dredged material. The reasons for not relying entirely on biological testing include the high costs of the testing (especially when very low or high chemical concentrations suggest the likely testing outcomes), and the inability of current bioassessment protocols to adequately address all adverse biological effects of concern.

3.4 Development of a Test Sequence and Disposal Guidelines. Selection of appropriate alternatives for the disposal of dredged material requires a strategy for the orderly assessment of chemical and biological test results. Though substantially refined for application to Puget Sound, the testing sequence and guidelines are based on the framework developed by the Corps Waterways Experiment Station (WES) for PSDDA and the Commencement Bay Nearshore/Tideflats Superfund Remedial Investigation. The WES framework is based on the Corps' management strategy for overall dredged material management that provides:

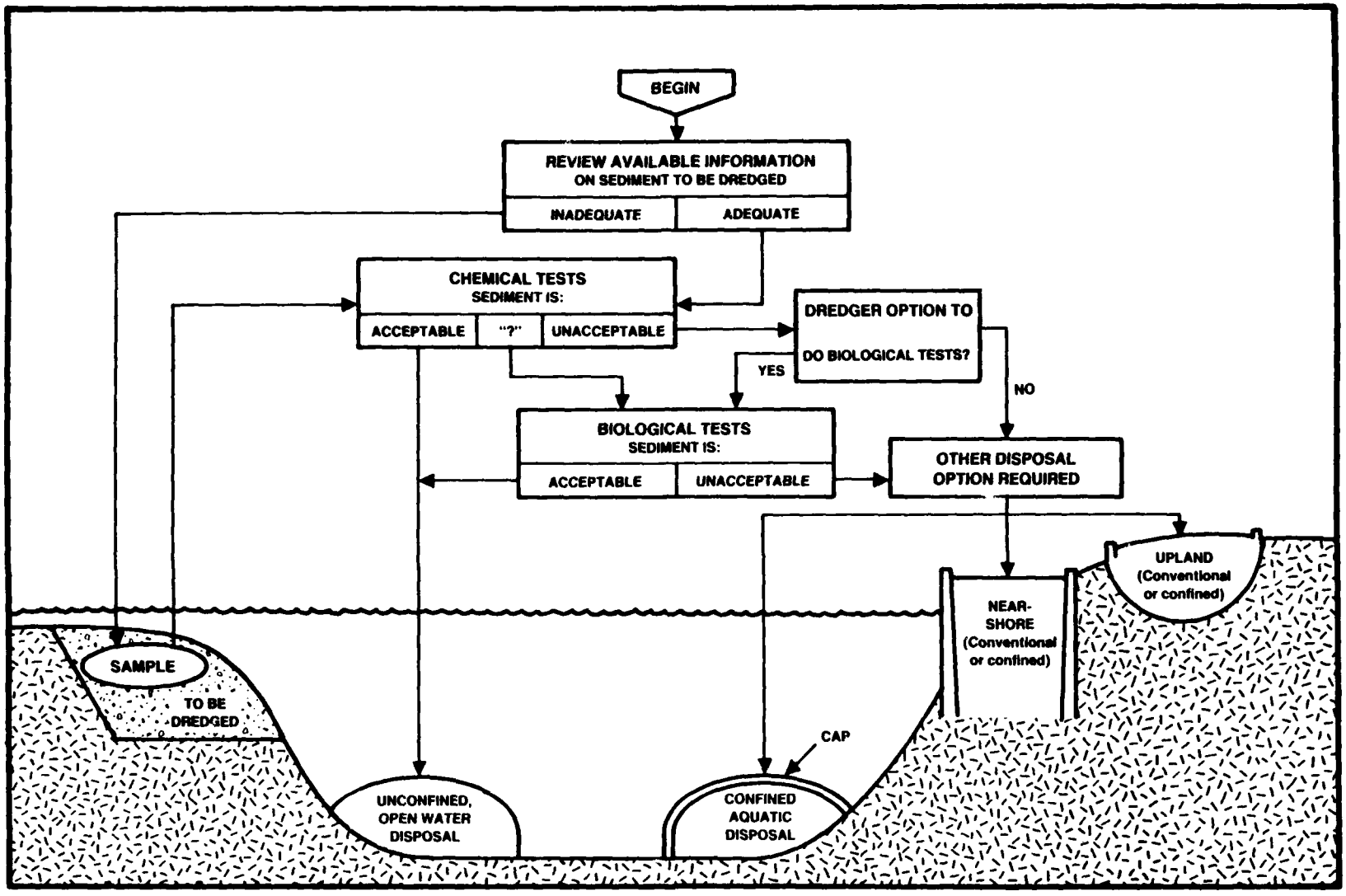


Figure I.3-1. Disposal testing strategy for unconfined, open water disposal.

- o An explanation of environmental concerns for different dredging and disposal alternatives, and the corresponding management strategies (the WES framework perspective was adopted by PSDDA without changes).

- o Testing strategies and protocols for determining the need for restrictions or controls during and after dredging and disposal (many of the WES report recommendations were used, but regional protocols for Puget Sound were also developed).

- o Guidelines for interpreting test results, implementing design strategies, and applying management plans. (WES interpretation guidelines were adapted and expanded to address regional needs, issues, and data.)

For application to unconfined or conventional disposal, many of the decisions are of a regulatory nature, relatively straightforward, and as a result, the decisionmaking framework is simplified. For confined disposal, iterative steps in the framework and complexities in project design will require the development of detailed site management plans.

3.5 Regional Administrative Decisions. Technical knowledge and understanding of scientific issues are only part of the decisionmaking process. When few data are available to support a particular decision, when data are inconclusive, or even when substantial data are available, the priorities for choosing among alternatives will be established by regional administrative decisionmakers. These Regional Administrative Decisions (RAD) are based on both scientific evidence and administrative judgment (figure I.3-2).

The term "RAD" is a general term used to describe a wide variety of issues where administrative judgment must be added to insufficient scientific information in order to make a decision. RAD's in the Phase I study concern the acceptability of the material to be disposed in unconfined, open water. In Puget Sound, administrative judgment is shared by the State and the Federal governments. Ecology certifies that the material meets applicable requirements of Section 401 of the Clean Water Act. The Corps determines if disposal of the material complies with Section 404 of the Act with review and comment by EPA.

RAD's include selecting among multiple options that are similarly defensible in a scientific sense; in a policy sense, such as inclusion of a dilution (mixing) zone as an allowable technique for accounting for the impact of disposal and achieving acceptable disposal conditions; or in an overall social and regulatory sense. In the past, these judgments were generally made on a case-by-case basis. EPWG has identified these decisions (listed in exhibit B), and prepared the recommended evaluation procedures in large part by developing a consensus on how each RAD should be handled. RAD is made during PSDDA are program-level decisions that affect dredging in the entire

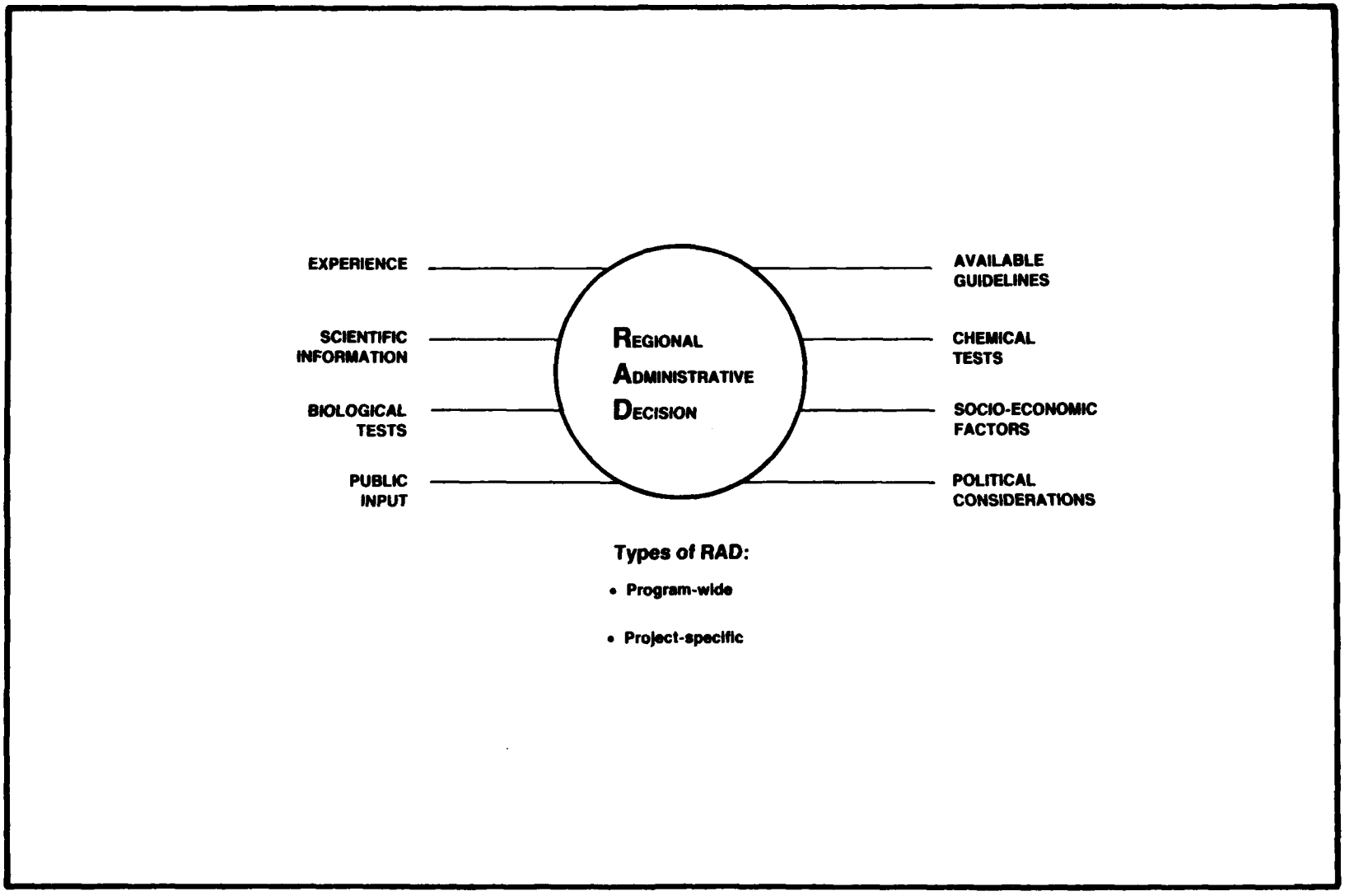


Figure I.3-2. Factors in Regional Administrative Decisions.

Phase I area. For clarity within PSDDA, remaining issues that were necessarily left for case-by-case, project-specific resolution by best professional judgment are not referred to as RAD's.

Project-specific decisions will be guided by these PSDDA RAD's. For example, one RAD in the Phase I study was to establish an upper chemical level for each chemical of concern, based on evaluation of numerous factors discussed in part II of this technical appendix. This one-time programmatic decision was part of the comprehensive planning process, with the RAD being accepted collectively by the PSDDA regulatory agencies (see section I.1.1). Additional RAD's may arise and be resolved during specific projects and studies and then be applied to all subsequent activities as part of implementation of the PSDDA plan. Also, future changes to the PSDDA RAD's would be accomplished through a similar consensus process.

The list of RAD's considered by EPWG covered a wide range of issues, including:

- Selection of reference conditions against which to compare biological test results.
- Selection of test species and bioassay techniques for dredged material testing.
- Sampling requirements when collecting sediment for analysis.
- Environmental pathways requiring testing for different disposal methods.
- Interpretation of bioaccumulation test results relative to human health effects.
- Selection of acceptable upper levels of adverse biological effects at disposal sites.

The last category is of particular importance. All dredged material containing chemicals of concern entail some level of risk, regardless of the disposal option selected. Federal and State regulatory agencies, in consultation with the public and others, must determine what level of effects is acceptable for different concerns, and how those effects are to be managed (i.e., what tradeoffs and comparisons need to be made). Details of the RAD's considered by EPWG are given in exhibit B (with emphasis on the alternative decisions considered). A summary of RAD issues is provided in exhibit E.3.

Application of the evaluation procedures will require continued direct involvement by experienced professionals. The procedures set forth in this appendix were developed by experienced managers and regulators. However, additional discussions are anticipated as the procedures are implemented with clarifications and modifications to the procedures expected.

4. DREDGING IN THE PHASE I AREA

Phase I of PSDDA is focused on dredging activities in the central area of Puget Sound, including maintenance navigation dredging, and dredging for new port facilities. There are five Federal and numerous port and private navigation projects in the Phase I area of Puget Sound that require maintenance dredging, many of which assume use of unconfined, open-water disposal. Most dredging activity is highly dependent on the availability of nearby disposal sites because of economic considerations. Alternative disposal sites (e.g., upland sites) are generally not available without considerable increases in costs. Disposal at confined aquatic or upland/nearshore sites, while dependent on the specific project, is estimated to cost from 3 to 10 times more per cubic yard than the cost of present open-water disposal. These cost differences affect the feasibility of many dredging projects.

4.1 Major Dredging Areas. Most dredging activities in central Puget Sound occur in a small number of subareas associated with the three major urban embayments (table I.4-1). Dredging activities in central Puget Sound have been reviewed and summarized in the Puget Sound Dredged Material Inventory System (Envirosphere 1986). The Dredged Material Inventory was developed from Corps permit applications, EPA summary records, data from Ecology, and other sources. Its purpose was to inventory the sources of dredged material and to characterize these dredged sediments with regard to location, volume, chemical composition, and known biological effects. The computerized data base has been used to summarize historic and current dredging activities, and to forecast the volume and nature of sediments that may be dredged in the future.

4.2 Historic Dredging. Dredging operations in Puget Sound involve removal and disposal of very large volumes of material. From the Dredged Material Inventory it has been estimated that a total of 16,850,000 c.y. was dredged during the 15-year period from 1970 to 1985 (table I.4-2). Approximately 40 percent of this total was deposited at unconfined, open-water disposal sites. Thus, an average of approximately 450,000 c.y. of dredged material was deposited into central Puget Sound each year during this period. The remainder of dredged material was deposited at nearshore or upland disposal sites. However, nearshore and upland sites have become scarce in recent years, and use of unconfined, open-water disposal has increased. While 24 percent of the material dredged by the Corps during the 1970's went to open-water sites, over 50 percent of the material dredged in the 1980's has been sent to open-water sites.

4.3 Dredging Forecasts. The Dredged Material Inventory data base was used in conjunction with information on currently planned projects to project the total volume of sediment to be dredged in the Phase I area during the 15-year period from 1985 through 2000. A 15-year planning horizon was used, as it encompasses all known major navigation projects and is a forecasting period that could be established with reasonable certainty. The projected total volume to be dredged is 22,697,000 cy, a volume 35 percent higher than the

TABLE I.4-1. MAJOR DREDGING AREAS
IN THE PHASE I AREA, CENTRAL PUGET SOUND

Phase I Area	Major Subareas
Port Gardner	East Waterway
	Lower Snohomish (below I-5 bridge)
	Upper Snohomish (above I-5 bridge)
Elliott Bay	Lower Duwamish (below 1st Avenue)
	Upper Duwamish (above 1st Avenue to turning basin)
	Duwamish Upper Turning Basin
	Lakes: Kenmore/Sammamish River
	Lakes: Lake Washington
	Lakes: Lake Union
	Lakes: Lake Washington Canal
	Sinclair Inlet
	Eagle Harbor
Commencement Bay	Hylebos Waterway
	Blair Waterway
	Sitcum Waterway

TABLE I.4-2 PUGET SOUND DREDGED MATERIAL INVENTORY FOR THE PHASE I AREA (SEATTLE, TACOMA, EVERETT) 1970-1985

Total volume dredged	16,850,000 c.y.
Total volume disposed to open water	6,758,000 c.y.
Total volume disposed at:	
Port Gardner	692,000 c.y.
Elliott Bay	4,598,000 c.y.
Commencement Bay	782,000 c.y.
Other locations	686,000 c.y.

	Dredger		
	Corps of Engineers	Ports	Others
Total volume dredged (c.y.)	5,755,000	4,635,000	6,460,000
Total volume disposed to open water (c.y.)	2,167,000	1,389,000	3,202,000
Total volume disposed upland or nearshore (c.y.)	3,588,000	3,246,000	3,258,000

	Disposal Methods for Corps of Engineers Projects			
	1970-1980		1980-1985	
	Volume	Percent	Volume	Percent
Water	961,000	26	1,206,000	56
Upland/nearshore	2,661,000	74	927,000	44

Reference: Envirosphere (1986).

1/Not all dredged material was discharged at designated DNR sites.

total dredged during the previous 15-year period. Of this total, approximately 90 percent of projected dredging activities will occur in five areas: Duwamish River (32 percent), Snohomish River (20 percent), East Waterway in Port Gardner (17 percent), Blair Waterway in Commencement Bay (13 percent), and Lake Washington (7 percent) (table I.4-3). Approximately 3.3 million c.y. for Port Gardner vicinity is associated with the Navy Homeport project. This project was included to present a total future dredging volume for comparison with historical statistics. As a decision has been made not to use the PSDDA Port Gardner preferred site for any of the Navy project material, its volume has been excluded from the Port Gardner PSDDA site impact analysis. Much of the future dredging will be done by the Corps for navigation channel maintenance, and most such projects have used unconfined, open-water disposal sites in the recent past. Permit applications also indicate that there will be a continuing demand for open-water disposal sites for other navigation projects. Without the availability of the open-water sites, some of these projects may not be economically feasible.

TABLE I.4-3. 15-YEAR PROJECTIONS (1985-2000) OF TOTAL DREDGING VOLUMES (C.Y.) BY SPECIFIC DREDGING AREAS WITHIN PHASE I

Phase I Area	Dredging Area (Subarea)	Projected Volume (c.y.)
Port Gardner	East Waterway	3,552,000 1/
	Lower Snohomish	2,321,000
	Upper Snohomish	2,175,000
	All other areas	195,000
	Total	8,243,000
Elliott Bay	Lower Duwamish	4,812,000 2/
	Upper Duwamish	2,021,000
	Duwamish Turning Basin	612,000
	Lakes: Kenmore/Sam. R.	114,000
	Lakes: Lake Washington	1,368,000
	Lakes: Lake Union	5,000
	Lakes: Lake Wash. Canal	80,000
	Sinclair Inlet	200,000
	Eagle Harbor	115,000
	All other areas	1,198,000
	Total	10,525,000
Commencement Bay	Hylebos Waterway	216,000
	Blair Waterway	2,936,000 3/
	Sitcum Waterway	56,000
	Other waterways	166,000
	All other areas	555,000
	Total	3,929,000
	Grand Total	22,697,000

Reference: Projections made by U.S. Army Corps of Engineers, Seattle District.

1/Includes U.S. Navy Homeport project (3.3 million c.y.)
2/Includes Duwamish widening and deepening project.
3/Includes Blair/Sitcum navigation improvement project.

5. ALTERNATIVE APPROACHES TO DREDGED MATERIAL MANAGEMENT

Dredged material may be managed to control potential environmental risks using a number of different approaches. Each approach has advantages and limitations. EPWG considered a number of alternative approaches to developing evaluation procedures for managing dredged material. These alternative approaches differed in the degree of reliance on (1) dredged material evaluation, or (2) technological control of dredging and disposal to minimize environmental risk.

The five major alternative approaches considered by EPWG are described in sections 5.1 through 5.5 and are summarized in table I.5-1. The rationale for the final choice of approach, which draws from several of the approaches described, is given in section 5.6.

5.1 Technology-Based Approach. A dredged material management system could rely exclusively on dredging and disposal technology to control environmental risks. This approach could involve disposing of all sediments with a single design "best available technology" (BAT), matching disposal technology to major kinds of dredging areas, separating the chemicals of concern from the dredged material, destroying the chemicals of concern in the dredged material, and relying upon monitoring of effects and subsequent control technologies at the disposal site.

Without extensive sediment testing, a technology-based approach would have no provisions for determining whether biological or human health effects might occur, and considerable environmental harm could occur if the technologies were not sufficient to control release of chemical from sediment with high chemical concentrations. Furthermore, this system would be expensive if costly technologies were used for sediments that did not contain chemicals of concern or contained concentrations where no adverse effects would occur.

5.2 Material Release Approach. The assumption underlying the material release approach is that limiting material release will limit the transfer of individual chemicals to the surrounding environment. Chemicals may still be transferred at a rate that is far from proportional to the rate of sediment transfer. Chemicals typically adsorb to the fine-grained component of sediments, and, because these sediments are easily transported in water currents, this is the component most likely to be lost during dredging and disposal operations. Relying on material release limits might result in the transfer of particular chemicals to the environment at unacceptable levels, or may unnecessarily regulate particle losses relative to potential effects. This approach also does not provide for an evaluation of potential biological effects from the particular mix of chemicals in any given sediment. Relying solely on the material release approach would also be expensive and may not provide any additional protection.

TABLE I.5-1. ALTERNATIVE APPROACHES
FOR MANAGING DREDGED MATERIAL

APPROACH	CONCEPTS
1. Technology based	Use single design/best available technology Extract and/or destroy chemicals in sediment Monitor chemicals at site Classify sediment
2. Material release	Performance standards to limit sediment release Use silt curtains Avoid disposal in areas of high current flow Avoid open-water disposal of sediments with large portion of fine material
3. Human health based	Analyze sediment for carcinogens Assess bioaccumulation Use existing FDA regulations for food
4. Reference site	Match physical characteristics of dredge site with those of a reference site Do bulk chemistry sediment comparisons
5. Biological effects based	Determine environmental risks by testing effect of sediment on biological species Assess potential effects by predicting from chemical analyses of sediment

The advantage of this approach is that technology and operating procedures can be used to minimize loss of dredged material and associated chemicals to the surrounding environment. Limits could be placed on the maximum amount of sediment allowed to be released to the environment during dredging and disposal, (i.e., "performance standards") and these limits could be met by employing appropriate technology (e.g., use of silt curtains) and disposal procedures (e.g., limiting disposal to certain depths and current conditions).

5.3 Human Health Effects Approach. A sediment evaluation system could be based solely upon risks to human health associated with each of the disposal options used. Such a system could, for example, require the analysis of sediments for potential chemical carcinogens. The decision regarding which disposal technology would be appropriate for a given volume of sediment could then be based on limits to chemical concentrations related to cancer risk (or other health risks). These limits could be based on existing regulations regarding allowable concentrations of chemicals in food. The limits could be related to environmental measurements by analysis of chemical pathways into human food (e.g., bottom fish caught in recreational or commercial fisheries). Studies might focus on bioaccumulation, for example, and chemicals in edible fish and shellfish could be monitored.

The major disadvantage of this approach is that it includes no provision for protecting important species or biological communities not related to human health risk through food or other exposure pathways.

5.4 Reference Site Approach. A comparison of material to be dredged with sediments from a preselected reference site can be used to make the decision of whether or not to allow dredged material to be disposed of in unconfined, open-water sites. Management systems based on reference sites typically rely on bulk chemistry analyses to make these comparisons. The management of dredged sediments under the existing Puget Sound Interim Criteria (PSIC) is basically a reference site approach (see part II, section 1.3.4) with the addition of bioassay testing. Reference sites can be selected to match the physical characteristics of the site to be dredged (e.g., with respect to sediment grain size and total organic carbon), and often must be demonstrably uninfluenced by pollution. One advantage of this approach is the relative ease of regulatory administration, in that there are fewer decisions points when compared to other approaches.

The reference site approach may be appropriate when adequate criteria for evaluating the sediments to be dredged are not available. One disadvantage of the reference site approach is that it may not provide a Puget Sound-wide standard for evaluating sediment, and determining the most appropriate reference sites may be difficult. Reference sites may also represent protection standards that are unnecessarily protective (e.g., a pristine site) or overly adverse (e.g., a previously containing chemicals of concern site). However, the major disadvantage of reliance on the reference area approach is the inability to consider the effects potential of chemicals of concern.

5.5 Biological Effects-Based Approach. The choice of disposal options could be keyed to a biological evaluation of the sediment to be dredged. The potential environmental risks associated with sediment can be evaluated either by directly determining its biological effects on test organisms, or by characterizing the sediment chemistry with respect to biological effects known to be associated with the concentrations of chemicals present. Decisions on how to dispose of particular sediments could then be made on the basis of selected critical levels of adverse biological effects that are the maximum acceptable for each disposal option.

One difficulty with this approach is understanding the complexity of cause-effect relationships between sediment chemistry and adverse biological effects. Also, this approach does not necessarily include a method for ensuring that human health risks are minimized, although such a method could be incorporated.

5.6 Selected Approach. From the standpoint of protecting the environment, there are disadvantages and advantages with each of the approaches reviewed above. As a result, the proposed PSDDA evaluation procedure are combination of the best features of each of these approaches. Disposal decisions are based primarily on a biological effects approach, using chemical and biological tests on the dredged material. Hence, the selected approach most closely implements the intent and letter of the Clean Water Act and related regulations, particularly Section 404(b)(1) Guidelines that require avoidance of "unacceptable" adverse effects. While these guidelines are often related to biological effects (because of direct effects on biological systems as the result of dredged material disposal), they are equally applicable to avoidance of unacceptable adverse effects on human health. Given the diversity of dredged material types, it may not be feasible to define a single Best Available Technology (BAT) for dredged material management. Therefore, technology should be applied as needed to avoid unacceptable adverse effects.

The selected approach also incorporates elements of the reference site approach. Use of reference sediments to interpret bioassay tests is a necessary limitation of the interpretation of bioassay results. The known variability in test animal response when exposed to sediments does not allow an "absolute" interpretation of test responses. Reference exposure responses must also be considered. Finally, an assessment of chemicals of concern released during disposal operations is also incorporated into the selected approach. While not directly linked to onsite effects, this assessment does provide some consideration of the potential exposure of animals off site.

6. ASSUMPTIONS

Major assumptions made in developing the evaluation procedures for dredged material are identified in this section. These assumptions include:

- The major pathways by which chemicals of concern move, and effects are transmitted, can be identified.
- Confined disposal sites can be located and made available as needed, such that disposal decisions can be based primarily on a biological effects approach that avoids unacceptable adverse effects at unconfined, open-water sites.
- Technology is available to minimize effects of, and to appropriately manage, sediments with unacceptable chemical concentrations in all disposal environments.
- Mixing, dilution, and dispersion of chemical concentrations are not relied upon in defining dredged material management units.

To describe dredged material sampling and analysis requirements, EPWG defined the concept of a dredged material "management unit." The management unit is the minimum volume of material on which a decision can be made regarding acceptability for unconfined or conventional disposal (see section II-3 for further explanation). As an artifact of sampling and compositing of samples prior to analysis, mixing of sediments with differing chemical concentrations within a management unit is an acceptable practice. Mixing of a unit of unacceptable sediment with an acceptable unit, in order to render the former acceptable by dilution, is not an acceptable practice.

PART II. UNCONFINED, OPEN-WATER DISPOSAL

1. EXISTING DISPOSAL GUIDELINES

1.1 Background. The body of law regulating the disposal of dredged material has its roots in the Rivers and Harbors Act of 1899 that required a U.S. Army Corps of Engineers (Corps) permit for any discharge to navigable waters. The purpose of this act was primarily to restrict the dumping of refuse, a practice that was innibiting navigation in some east coast harbors.

In 1967, the Departments of the Army and Interior signed a Memorandum of Understanding establishing a review procedure for proposed dredging projects. This memorandum required Federal and State agencies to consider pollution in both dredging and disposal operations. In 1970, the Water Quality Office of the newly established U.S. Environmental Protection Agency (EPA) adopted criteria for determining the acceptablility of dredged material for disposal in the Nation's waters. The criteria, based on freshwater sediment concentrations in the Great Lakes, included maximum concentrations of three metals (mercury, lead, and zinc), oil and grease, and several chemical (conventional) variables (volatile solids, chemical oxygen demand, and total Kjeldahl nitrogen).

The Federal Water Pollution Control Act amendments that were passed in 1972 gave rise to the Section 404 permit program, as well as launched a renewed EPA water quality criteria effort. However, it was 3 years before National guidance documents on water quality criteria and Section 404 were promulgated. Also in 1972, Congress passed the Marine Protection, Research, and Sanctuaries Act, known as the Ocean Dumping Act.

Much of the current knowledge concerning the impacts of dredged material disposal in open water is derived from a series of studies conducted by the Corps of Engineers Waterways Experiment Station (WES). Since 1970, when the Dredged Material Research Program (DMRP) (Saucier et al., 1980) was authorized under the Rivers and Harbor Act, several research and applied programs have been instituted by WES. These include the DMRP, the Long-Term Effects of Dredging Operations Program (LEDO), and the Field Verification Program (FVP). Together these programs have addressed a wide array of topics concerning the dredging and disposal of dredged material including the effects of dredging operations on water column and benthic environments, description of dredged material behavior during and following disposal, design and operation of confined disposal sites, and field investigations of the effects of disposal operations. This work has also addressed beneficial uses of dredged material, including use of dredged material for habitat development. Subsequently, many of the conclusions from the research program have been incorporated into national regulations and procedures. In addition to the work developed under the direction

of WES, other sources of information on the impacts of dredged material disposal are available from the open literature. Information on dredging can be found in symposium proceedings such as the International Ocean Disposal Symposium, Symposium on Coastal and Ocean Management, and Dredging and Dredged Material Disposal Symposium (sponsored by American Society of Civil Engineers). In addition, major dredging studies have been undertaken in the Northwest and Puget Sound region which have provided a further understanding of dredging and dredged material disposal in this area. The studies included the Anacortes Dredging Study (1970), Northwest Dredging Effects Study (1974), the Budd Inlet, Olympia Study (1975), the Grays Harbor Dredging Effects Study (1976-1977), and the Duwamish River Sediment Study (1976-1980).

In 1977, the Corps and EPA jointly published a guidance manual (known as the "green book") on implementation of Section 103 of the Ocean Dumping Act. It includes fairly detailed guidelines and requirements for conducting testing on dredged material headed for disposal in ocean waters. Testing procedures are described for liquid, suspended, and solid phases of the dredged material. Biological testing and statistically significant effects relative to reference was the basis for assessing the acceptability of the dredged material for ocean disposal. A basis for exclusion from testing is also provided.

In 1976, the Corps published an interim guidance manual for implementing the evaluation and testing required by Section 404 of the Clean Water Act (CWA; previously known as the Federal Water Pollution Control Act of 1972, Public Law 92-500) (U.S. Corps of Engineers 1976). Though the interim guidance manual was widely available, the usual approach in Section 404 marine waters has been to adapt and use the Corps/EPA ocean disposal manual (the green book). Many districts adopted or promulgated regional interim guidelines, often jointly with EPA.

Present day regulation of dredged material is based on the CWA that establishes a permit process (Section 404) for dredged material disposal. Section 401 of the CWA provides for State water quality certification of discharges to navigable waters, including dredged material disposal. Thus, the CWA is the primary Federal and State authority for regulation of dredging activities. Other Federal laws that affect dredged material disposal are:

- National Environmental Policy Act (NEPA) - requires the preparation of an Environmental Impact Statement (EIS) for Federal activities ("major Federal actions") judged to cause significant adverse environmental effects, and establishes procedures for environmental review by relevant agencies.

- Coastal Zone Management Act (CZMA) - establishes mechanisms for states to develop Management Programs for land uses in the coastal zone (including, for example, dredged material disposal sites).

- o Fish and Wildlife Coordination Act, Migratory Marine Game/Fish Act, and Fish and Wildlife Act of 1956 - require that agencies modifying a body of water (e.g., dredged material disposal) consult with the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and State departments of fisheries and game (where appropriate).

- o Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA or "Ocean Dumping Act") - Sets criteria for evaluating permit applications and managing disposal sites. Only applicable to open ocean territorial waters, thus excluding Puget Sound.

In the State of Washington, the following laws serve to further regulate dredged material disposal:

- o Water Pollution Control Act (RCW 90.48) - The State WPCA establishes the policies, authorities, management, and enforcement water quality programs for the State. The RCW provides for the control of discharges, including sediment, and grants authority to promulgate rules and regulations for substances discharged to State waters.

- o State Environmental Policy Act (SEPA) - requires the preparation of an EIS for all projects suspected to cause a significant adverse environmental impact, and establishes procedures for environmental review

- o Shoreline Management Act (SMA) - provides for the preparation of Shoreline Master Programs by counties and cities for regulation of land uses in the coastal zone

- o Dangerous Waste Regulations of the State of Washington are designed to protect the public from dangers associated with the generation, transport, treatment, storage, and disposal of hazardous wastes. Only contaminated dredged material would be affected by these regulations, and only if it is classified either as "Dangerous Waste" or "Extremely Dangerous Waste."

- o Hydraulic Project Appprovals (HPA) by the Washington Departments of Fisheries and Wildlife are considered by the State to be a major regulatory tool for dredging operations; HPA are required for all non-Federal dredging [the Federal agencies (by policy) accept the applicable conditions of the HPA through the Section 401 certification process].

Federal guidelines for establishing disposal sites, and reviewing disposal permits are contained in the Code of Federal Regulations (CFR), and State guidelines are contained in the Washington Administrative Code (WAC). Other guidelines also exist at local levels of government (i.e., counties and cities). The remainder of this section describes guidelines for dredged material disposal and the site selection/permitting process in Puget Sound.

1.2 Federal Guidelines Governing Dredged Material Disposal in Water. Federal guidelines for specifying disposal sites and testing dredged or fill material are in 40 CFR 230 (U.S. Environmental Protection Agency 1985a). These guidelines provide guidance for evaluating and testing the impact of discharges of dredged or fill material.

1.2.1 Subpart A General Information. The guidelines are applicable to the regulatory and civil works programs of the Corps, approved programs of states, and Federal construction projects that meet the specified criteria. The guidelines apply to all waters of the United States. General permits may be granted for a category of activities if the activities have similar impacts and their separate and cumulative environmental impacts are minimal. The guidelines describe an evaluation process for general permits.

1.2.2 Subpart B Criteria for Compliance with Guidelines. There are four categories of restrictions on discharges. In summary, no discharge of dredged or fill material shall be permitted if:

1. There is a "practicable alternative to the proposed discharge." "An alternative is practicable if it is available and capable of being done" after considering "cost, existing technology, and logistics...." The guidelines take into account alternatives considered under a Coastal Zone Management Program (CZMP), Section 208 program (areawide planning), or an EIS process under NEPA.

2. After consideration of dilution and dispersion, the action contributes to a violation of a State water quality standard, toxic effluent standard, or toxic effluent prohibition; threatens the existence of an endangered species; or threatens a marine sanctuary.

3. The discharge will cause or contribute to significant adverse effects on human health, or cause or contribute to significant degradation of the waters of the U.S. Adverse effects considered include:

    - Human health or welfare by affecting plankton, fish, shellfish, wildlife.
    - Life stages of aquatic life and other wildlife dependent on aquatic ecosystems.
    - Loss of fish and wildlife habitat or loss of the capacity of a wetland.

4. All appropriate and practicable steps have not been taken to minimize potential adverse effects to the aquatic environment.

The guidelines also specify the following kinds of required effects determinations:

- o Physical substrate determinations include consideration of particle size and shape, degree of compaction, elevation, and bottom contours.

- o Water circulation, fluctuation, and salinity determinations include consideration of downstream flows and normal fluctuation, water chemistry, salinity, color, odor, taste, dissolved gas, temperature, nutrients, and eutrophication.

- o Suspended particulate/turbidity determinations include consideration of grain size, plume characteristics, and physical transport factors.

- o Contaminant determinations are required to describe if and how the onsite contaminant regime will be modified.

- o Aquatic ecosystem and organism determinations include consideration of bottom topography, water or substrate chemistry, nutrients, currents, circulation, fluctuation, and salinity as these may affect recolonization, or indigenous communities.

- o Proposed disposal site determinations include consideration of currents, stratification, vessel speed and rate of discharge, types and amounts of discharged material, type of substrate, and other factors needed to define the areal extent of the site.

- o Cumulative effects determinations are required to describe if and how an aquatic ecosystem will be changed by the collective effect of a number of individual discharges of dredged material.

- o Secondary effects determination involves consideration of effects on an aquatic ecosystem that are associated with a discharge of dredged materials, but do not result from the actual placement of the dredged material.

Compliance or noncompliance is determined by comparing the information compiled during the effects determinations to the four categories of restrictions described above.

1.2.3 Subparts C to F. These subparts consist primarily of descriptions of potential impacts that should be considered in making the factual determinations and findings of compliance or noncompliance. Examples are given of environmental impacts for discharge-related changes in:

- o substrate,

- o particulates/turbidity,

- o water characteristics,
- o current patterns and circulation,
- o normal water fluctuations, and
- o salinity gradients.

Types of impacts are described for the following biological resources and human uses:

- o Threatened and endangered species
- o Fish, crustaceans, molluscs, and other aquatic organisms in the food web
- o Other wildlife
- o Sanctuaries and refuges
- o Wetlands, including mudflats and vegetated shallows
- o Coral reefs
- o Riffle and pool communities
- o Municipal and private water supplies
- o Recreational and commercial fisheries
- o Water-related recreation
- o Esthetics
- o Nature preserves.

1.2.4 Subpart G, Evaluation and Testing. This subpart provides guidance on the evaluation and testing of dredged or fill material. The guidelines state that material shall be examined for the potential presence of chemicals of concern based on potential sources and routes of chemical concentrations from adjacent contaminated material; upland sites; spills; industrial, municipal, or other point sources; or natural mineral deposits. Testing is not necessary if the material is determined to be sufficiently removed from sources of pollution to provide "reasonable assurance" that the material is not containing chemicals of concern. Disposal may be authorized even if the

material is believed to be containing chemicals of concern, or found to be containing chemicals of con- cern if steps can be taken to reduce chemical concentrations to acceptable levels within the disposal site and prevent offsite migration of chemicals of concern. Testing is described for the following variables:

- Chemical-biological interactive effects - Evaluations may be required on a case-by-case basis by the Regional Administrator of EPA. Bioassays may be indicated in lieu of extensive chemical testing.

- Water column effects - The permitting authority (e.g., Corps, Seattle District, is the Section 404 permitting authority for dredged material disposal in Puget Sound) determines what constituents to analyze (elutriate test for sediment; leachate test for material originating on land) and may specify the need to perform bioassays. General guidelines are given for data evaluation.

- Effects on benthos - The permitting authority may require the use of benthic bioassays, sediment chemical analyses, community structure (abundance, diversity, and distribution), and physical tests and evaluations (sieve tests, settleability, compaction, etc.).

1.2.5 Subpart H, Actions to Minimize Adverse Effects. This subsection provides guidelines for performing actions to minimize adverse effects. Actions are described concerning discharge location; actual discharge of the material; control of the material after discharge; methods of dispersion; available technology; the effect of actions on plant and animal populations, and human use; and other actions.

1.2.6 Federal Guidelines for Permitting Discharges of Dredged Material. Guidelines for issuing permits for discharges of dredged or fill material are specified in Parts 320 to 330 of Title 33 of the Code of Federal Regulations, dated 13 November 1986 (Regulatory Program for the Corps of Engineers 1986). In Puget Sound, all dredged material discharge permits (also known as 404 permits) are processed by the Corps. Because Puget Sound waters are subject to the ebb and flow of the tide, and used for interstate and international commerce, permit processing authority cannot be delegated to the State of Washington (U.S. Corps of Engineers 1985b). A summary of the Corps national disposal guidelines is presented in exhibit C.

Under Section 404(c) of the CWA, 40 CFR Part 231 (U.S. Environmental Protection Agency 1985c) the Administrator of EPA can prohibit or withdraw a permit upon determination that the discharge would have unacceptable adverse effects on municipal water supplies, shellfish beds and fishery areas, wildlife, or recreational areas. EPA staff review 404 permits during the comment period after Public Notice.

Under Section 401 of the CWA, a water quality certification is necessary for any project that may cause the violation of a State water quality standard. This certification is granted or denied by a State authority or EPA (when more than one state may be affected). Chapter 173-201 of the Washington Administrative Code (WAC) details water quality standards for waters of the State. Certification is primarily a statement on whether or not a discharge will meet State water quality standards and other applicable State laws. The WAC allows for dilution zones in order to meet water quality standards. Other requirements specified by the Federal guidelines include review of the application for:

- o consistency with the State Coastal Zone Management Act,
- o consistency with the provisions of the National Historical Preservation Act (NHPA),
- o coordination with any relevant Federal navigation project, and
- o consistency with the Endangered Species Act (ESA).

In general, district engineers must decide on permits within 60 days after receipt of a complete application. However, there are provisions for extending this period should delays occur due to legal matters, an extension of the comment period, time constraints of gathering important information, or procedural requirements of certain laws (e.g., CWA, CZMA, NEPA, ESA, MPRSA).

1.3 Decision Basis for Puget Sound.

1.3.1 Historical Disposal Guidelines for Puget Sound. The approach to dredged material assessment in the Puget Sound region has changed substantially since the 1970's. In 1970, the Water Quality Office of the newly established EPA adopted criteria for determining the acceptability of dredged material for disposal in the Nation's waters. Commonly known as the "Jensen criteria," the criteria, based on freshwater sediment concentrations in the Great Lakes, included maximum concentrations of three metals (mercury, lead, and zinc), oil and grease, and several chemical variables (volatile solids, chemical oxygen demand, and total Kjeldahl nitrogen). In 1971, Region X of EPA published its "blue book," describing the effects of dredging and dredged material disposal in the Pacific Northwest. The blue book recognized the bulk criteria established by the EPA Water Quality Office, noting that these determined the acceptability of dredged material for in-water disposal. The publication summarized bulk chemistry data and field effects information for many of the major dredging areas in Puget Sound and parts of Oregon.

Until the mid-1970's, the Water Quality Office bulk criteria plus information compiled in the 1971 blue book, and results of other sediment testing often served as the sole basis for decisionmaking on a project. For those projects

where dredged material was subjected to engineering tests for dredgeability (gradation, plasticity, solids, void ratio), other tests were also conducted pursuant to requirements of the EPA Water Quality Office. Cost of analysis was a key factor in deciding whether to require additional testing. This emphasis resulted in the generation of substantial amounts of data by large projects (especially Federal projects) and subsequent application of the data interpretations to small projects where extensive testing was not conducted. A variety of variables were investigated on a case-by-case basis depending on the site and the investigator. For example, chemical oxygen demand (COD) was often compared to total organic carbon (TOC), and occasionally inorganic dissolved oxygen demand (IDOD) and biological oxygen demand (BOD) in attempts to find useful correlations between chemical concentrations and biological effects. Other metals, and extractable oil and grease (through freon extraction) were also frequently analyzed.

With the advent of the Federal Water Pollution Control Act Amendments and Marine Protection, Research, and Sanctuaries Act (Ocean Dumping Act) in 1972, and guidance provided by Section 404(b)(1), decisionmaking in Puget Sound shifted to water quality issues and focused on water column effects using elutriate assessment. The cost of analyzing additional chemicals in the elutriate required a "best professional judgment" consideration of which projects actually warranted bulk sediment testing. The primary tools used for disposal decisionmaking in Puget Sound during the mid- to late 1970's were the bulk conventional variables (e.g., COD, TOC), the elutriate test for heavy metals (and sometimes specific organics), and several methods for determining when to exclude materials from testing requirements. Testing programs were developed to address a project-specific concern rather than to comprehensively characterize dredged material, and were still designed to assess dredged material relative to water quality criteria. For example, when a chemical was analyzed in the elutriate, it was typically not analyzed in the bulk sediments.

In 1976, the Corps published an interim guidance manual for implementing the evaluation and testing required by Section 404 under the auspices of the DMRP program. In 1977, the Corps and EPA jointly published a guidance manual (the "green book") on implementing Section 103 of the Ocean Dumping Act, which provided detailed guidelines and requirements for testing dredged material as well as a basis for excluding dredged material from testing. The green book described bioassay testing procedures for liquid, suspended, and solid phases of the dredged material. Though the 404 interim guidance manual was available, the usual approach taken in managing dredged material disposal into Section 404 marine waters was to adapt and use the Corps/EPA green book. The cost associated with implementing such comprehensive testing programs was substantial and difficult to justify based on the large cost of "test development" typically needed at the time. By 1979, the Corps' Seattle District had begun implementing testing protocols for planning of large navigation projects consistent with these publications; although this was not the case for Corps maintenance dredging. For most permit applicants and small Corps projects, bioassay testing was not required.

Many of the water quality "criteria" in this period were not numerical standards, but required professional interpretation of water column bioassay results. During this time, the Corps sponsored the Washington Department of Fisheries in conducting oyster larvae bioassays, water analyses, and limited bulk sediment analyses. These elutriate tests and bioassay studies were used to help identify areas where the dredged material appeared to present chemical concerns, however, the studies' emphasis on dissolved chemical analyses as opposed to bulk sediment analyses obscured any definitive correlations between sediment chemicals and biological effects. Additionally, the provision for mixing zones in the Section 404 evaluation process made it possible to meet EPA water quality criteria, larval response standards, and the typically more stringent water quality criteria recommended by the American Fisheries Society, in all but a few cases because of rapid dilution in the water column. Generally, field measurements of impacts to water column organisms resulting from dredged material disposal did not indicate serious water quality problems.

Based on consistent elutriate results that indicated low concern for most areas, exclusions from testing were common in Puget Sound. In 1978, staff from EPA Region X and the Corps Seattle District met to informally review the Section 404 testing process. The results of those meetings were to develop a testing program in which significant responses at a first level of evaluation would trigger further detailed analysis. First level testing included elutriate testing. This testing scheme was applied to several large navigation improvement projects throughout the sound as described following. The results of the testing program indicated that the dredged material was acceptable for in-water disposal and further analyses were not triggered. Five areas warranting detailed testing were identified: Bellingham Bay, East Waterway of Everett Harbor, Duwamish River, Commencement Bay, and Grays Harbor.

The District's Navigation Improvements study for Grays Harbor (Widening and Deepening) involved a substantial volume of dredged material, some of which was targeted for ocean disposal (Section 103). Because of the chemical concerns and the testing requirements of Section 103, a detailed biological testing program was developed in 1979. The program was based on application of the green book and included water column and benthic bioassays. The design of this testing program sparked serious discussion of a number of issues regarding dredging and disposal practices, and decisionmaking in Puget Sound.

During the Grays Harbor projects, attempts were made to standardize biological testing methods and their use for all Seattle District projects. Because of work done through the DMRP program of the Corps of Engineers (Saucier et al., 1980) including national experiences with water column testing, there was an attempt to shift testing emphasis away from water quality concerns and toward sediment chemical concentrations. However, substantial costs to develop multispecies bioassays and the debates over methods and data interpretation,

as well as the then-current interpretation of specific requirements of Section 103, hampered this attempt. Only elutriates, including weak acid elutriates, were chemically analyzed. Using the concept of "tiering," the program was designed so that significant adverse responses would trigger further detailed analyses. The results of the testing program indicated that the dredged material was acceptable for in-water disposal and additional analyses were not required.

Also during development of the Grays Harbor biological testing program, the issue of sediment chemical concentrations heterogeneity surfaced. Because the project would involve deep cuts by the dredge, a decision was made to use a mechanical coring device for assessing sediment chemical profiles. In addition, because of the known horizontal diversity of the sediments throughout the navigation channel, it was decided to make separate decisions on different reaches of the area to be dredged. This was the first time in Seattle District that decisionmaking was to be made on a smaller geographical scale than projectwide.

In 1980, the biological testing program developed for Grays Harbor was adapted to another District Navigation Improvements project: Blair and Sitcum Waterways in Commencement Bay. Once again, because of high costs for multispecies testing and the then-current interpretation of Section 404 testing requirements, it was decided to pursue water quality and water column testing, though some benthic bioassays were conducted. The program included a tiered approach with increased testing triggered by adverse biological responses. Because it was generally believed that Commencement Bay sediments were "highly contaminated," there was a high expectation that additional testing would be triggered. However, as in the Grays Harbor project, the test results did not trigger additional testing. The focus on water column testing in Commencement Bay drew criticism from some local researchers because of increasing evidence that chemical effects were associated with the sediment and not the water column.

Ongoing research in Commencement Bay by EPA and the National Oceanic and Atmospheric Administration using a bulk sediment bioassays was demonstrating significant toxicities. Amphipods exposed to marine sediments from Commencement Bay evidenced substantial acute toxicity. Bottomfish studies (Malins, et al., 1980) in Commencement Bay and elsewhere in Puget Sound also indicated a relationship between adverse biological effects and concentrations of chemicals in marine sediments. Research programs that sampled the Puget Sound open-water dredged material disposal sites (particularly the Fourmile Rock site) found elevated chemical concentrations. For these reasons, it became obvious that reliance on water column tests was incomplete as a basis for decisionmaking.

Studies were being conducted almost concurrently with the Blair-Sitcum studies at a Navigation Improvements project in the Duwamish River at Seattle. Sediment chemicals of concern were known to exist in the project area. The Grays Harbor testing program was applied to Duwamish River sediments revealing that chemicals found in bulk sediment samples was not evident in the elutriate. This consistent discrepancy in results between elutriate testing and bulk sediment testing, combined with reports from other researchers that documented adverse biological effects through sediment bioassays, raised concern with Seattle District planners. As a result, benthic bioassays were deemed necessary. Because of budgetary considerations, these tests were scheduled for the next planning stage of the Duwamish project.

Based primarily on results of the District's studies and the work of NOAA and other researchers in Puget Sound, increased emphasis was placed on testing programs that addressed both water column effects and potential effects of dredged material disposal on bottom-dwelling organisms. Water quality criteria, however, were not entirely abandoned. Initiated in 1981 and completed in 1983, the State of Washington developed guidelines for Section 401 (water quality) certification of dredging projects. These guidelines provided testing exclusions for coarse material with low organic content and detailed testing requirements for all other sediments to be dredged. The guidelines included requirements for analyzing several heavy metals in the elutriate, and added PCB's and sulfides to be routinely analyzed in the bulk fraction. All of the interpretive standards, however, were for the dissolved phase, using EPA water quality criteria.

Accordingly, decisions about whether to use bulk analyses or water column testing, what variables to analyze for, whether to collect sediment using a core or a grab, whether to exclude a project entirely or in part from testing, and (most importantly) whether to accept or reject a specific material for unconfined, open-water disposal, varied significantly from case-to-case in the late 1970's and early 1980's. Consistency in testing requirements and in decisionmaking depended primarily on the agency reviewers assigned to individual projects. Because of the ongoing dredging program managed by the Corps Seattle District, a greater degree of consistency in testing and evaluation of dredged material was achieved for Federal navigation projects than for individual permit actions. As reviews became centralized in EPA and Ecology during the 1980's, and as Corps research and project data aided in understanding sediment problems, consistency improved overall.

1.3.2 Fourmile Rock Interim Criteria. During the mid-1980's, the city of Seattle was asked by DNR to issue a shoreline permit for continued use of the Fourmile Rock unconfined, open-water disposal site. In response to the increasing concerns about potential environmental and human health impacts associated with open-water disposal of unconfined dredged material, EPA and Ecology, at the request of the City of Seattle and DNR, formulated disposal criteria for the Fourmile Rock unconfined, open-water disposal site in Elliott

Bay. The Fourmile Rock Interim Criteria (FRIC) are based on reference conditions found at or near the site (a "nondegradation" policy), not a determination of what might constitute an adverse environmental effect. Chemical criteria were based upon average chemical concentrations found at the Fourmile Rock site (i.e., a decision was made not to permit further chemical degradation of the site). Reference conditions for sediment toxicity from stations near the disposal site were used to set the biological criteria. Both chemical and acute biological tests were required of all dredged material planned for disposal at the Fourmile Rock site. This management approach enabled dredging activities to continue and was protective of existing conditions at the site, until more acceptable evaluation procedures could be developed through the PSDDA study.

On June 29, 1984, the Seattle Department of Construction and Land Use approved a shoreline permit (No. 8401530) to DNR for continued use of the Fourmile Rock open-water disposal site. The Notice of Decision for the permit includes special terms and conditions; an analysis of the decision in terms of technical background, the SMA, and SEPA; and the FRIC. Use of the Fourmile Rock site, which closed on June 7, 1987, was contingent upon EPA using nondegradation criteria for assessing dredged materials proposed for disposal at the site.

The FRIC (contained in the Notice of Decision) specifies a comparison process to be used to determine whether dredged material would be permitted at Fourmile Rock.

For chemical variables, the FRIC state:

" 1. If any pollutant, or group of pollutants, listed in table II.1-1 is found in concentrations greater than 125 percent of the ambient concentrations of that pollutant at the Fourmile Rock site (table II.1-1, column 2), in-water disposal will not be allowed.

2. If three or more pollutants listed in table II.1-1 are found in concentrations greater than 110 percent of the ambient concentrations for those same pollutants at the Fourmile Rock site (table II.1-1, column 3), in-water disposal will not be allowed.

3. Of one or two pollutants listed in table II.1-1 are found in concentrations within the range of 110 to 125 percent of the ambient concentrations for those same pollutants at the Fourmile Rock site (table II.1-1, columns 3 and 2), in-water disposal will be allowed, provided that bioassay criteria are not exceeded.

4. If all pollutants listed in table II.1-1 are found at concentrations of 110 percent or less than the ambient concentrations for the same pollutants at the Fourmile Rock site (table II.1-1, column 3), in-water disposal will be allowed provided that bioassay criteria are not exceeded.

5. If, in the best professional judgment of EPA and Ecology decisionmakers, additional chemical data not listed in table II.1-1 indicate unacceptable sediment chemical concentrations, in-water disposal will not be allowed."

For biological variables, the FRIC state:

" 1. If the mean amphipod survival for the five replicates from an individual core or core section is significantly (P less than 0.05) greater than or equal to 16.0 individuals (out of 20), the mean survival at the sites near the Fourmile Rock site, in-water disposal will be allowed provided that chemical criteria are not exceeded.

2. If the mean amphipod survival for the five replicates from an individual core or core section is significantly (P less than 0.05) less than 16.0 individuals (out of 20), the mean survival at the sites near the Fourmile Rock site, in-water disposal will not be allowed.

3. If the mean oyster larvae mortality/abnormality for the three replicates from an individual core or core section is significantly (P less than 0.05) less than or equal to the mean mortality/abnormality at the sites near the Fourmile Rock site, in-water disposal will be allowed, provided that chemical analyses criteria are not exceeded. (Note: Since the mortality/abnormality level in the Fourmile Rock site sediments is not well documented, the oyster larvae tests are often not required).

4. If the mean oyster larvae mortality/abnormality for the three replicates from an individual core or core section is significantly (P less than 0.05) greater than the mean mortality/abnormality at the sites near the Fourmile Rock site, in-water disposal will not be allowed."

For conventional variables, physical tests and chemical bulk tests are required for grain size, total solids, total volatile solids, total organic carbon, sulfides, and oil and grease. The decisionmaking process for evaluating dredged material under these guidelines is depicted in figure II.1-1. As noted in the figure, testing variables are fewer in areas of lower concern regarding chemical concentrations. EPA (1984) provides detailed guidance (in the form of protocols and references for protocols) for conducting the requisite sampling and analysis.

TABLE 11.1-1. FOURMILE ROCK CHEMICAL SEDIMENT CRITERIA

Pollutant	Fourmile Rock Concentration	Percent of Fourmile Rock Ambient Concentration 125%	110%
Metals (ppm)			
Arsenic	15	19	16.5
Cadmium	0.7	0.9	0.75
Copper	92	115	100
Lead	126	158	140
Mercury	1.1	1.4	1.2
Zinc	359	450	395
Organics (ppb)			
Polychlorinated biphenyls(a)	610	760	670
High molecular weight polynuclear aromatic hydrocarbons(b)	11,200	14,000	12,300
Low molecular weight polynuclear aromatic hydrocarbons(c)	683	855	750
DDT(d)	7	9	8

(a) Summation of PCB 1016, 1232, 1242, 1248, 1254, 1260.

(b) Summation of dibenzo(a-h)anthracene, benzo(a)anthracene, benzo(a) pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, fluoranthene, indeno(1-2-3-c-d)pyrene, pyrene, benzo(g-h-i)perylene.

(c) Summation of acenaphthene, naphthalene, acenaphthylene, anthracene, phenanthrene, fluorene.

(d) Summation of 4-4 DDD, 4-4 DDE, and 4-4 DDT.

Reference: U.S. Environmental Protection Agency (1984).

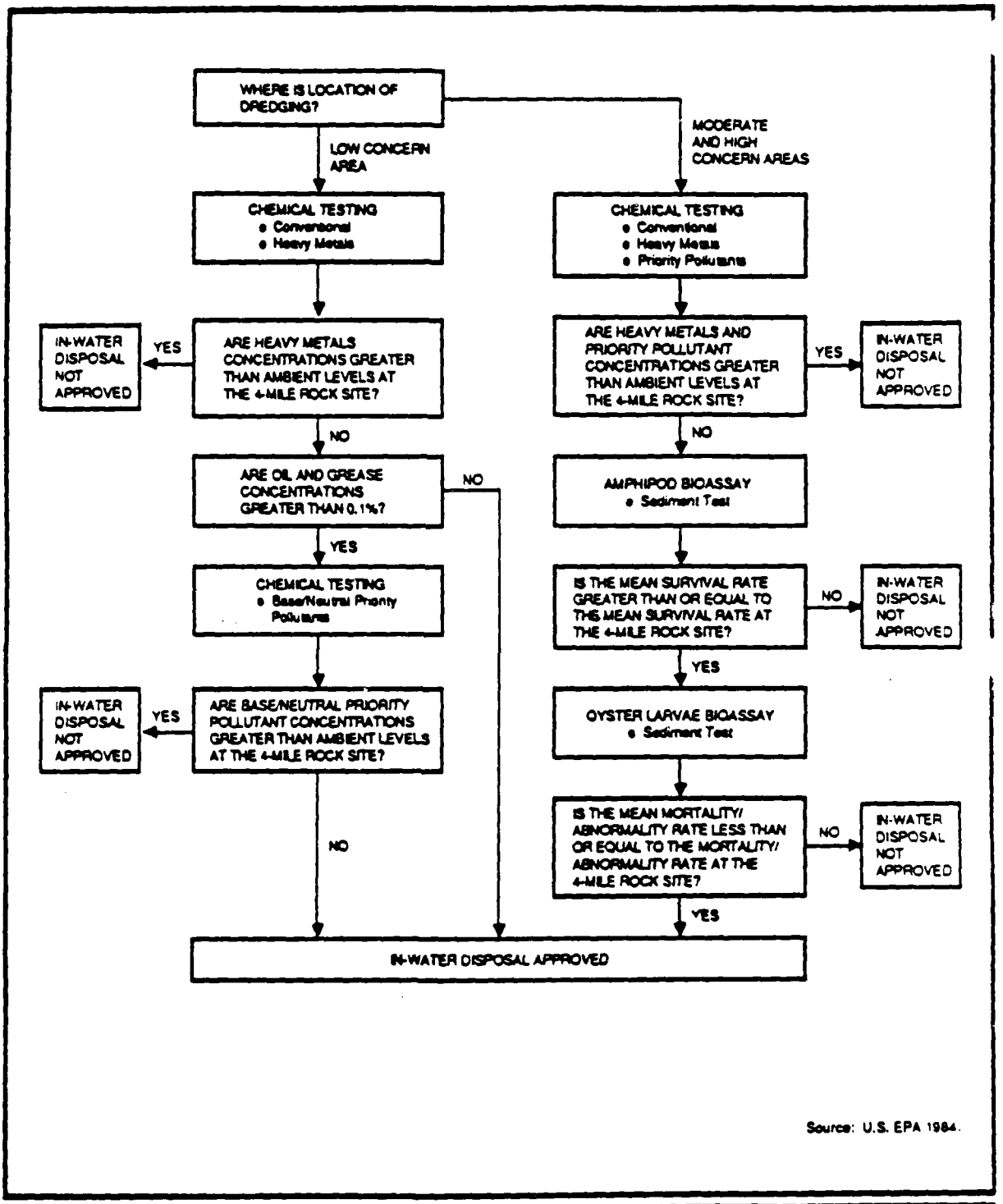


Figure II.1-1. Decision flow chart for Fourmile Rock interim dredged material disposal criteria.

1.3.3 Puget Sound Interim Criteria. A similar decisionmaking process and interim criteria also developed for the rest of Puget Sound in much the same way as they were developed for Fourmile Rock, with both bulk chemical and bioassay tests required. However, the Puget Sound Interim Criteria (table II.1-2) are based on the premise that dredged material should not have higher chemical levels than central Puget Sound sediments, and must not exhibit a statistically significant increase in toxic biological effects. (Note: the Puget Sound Interim Criteria are essentially the same as those promulgated in draft form in May, 1985 for the Port Gardner "Interim Criteria," in response to a shoreline permit condition required by the city of Everett for continued use of the Port Gardner dredged material disposal site. The Port Gardner Interim Criteria were released in final form by the EPA in February, 1986 and adopted by the local jurisdiction in June 1987.)

TABLE II.1-2. PUGET SOUND (AND PORT GARDNER) INTERIM CHEMICAL SEDIMENT CRITERIA

Pollutant	Allowable Concentration Level
Metals (ppm)	
Arsenic	12.5
Cadmium	0.7
Copper	68
Lead	33
Mercury	0.15
Zinc	105
Organics (ppb)	
Polychlorinated biphenyls (PCB)(a)	380
High molecular weight aromatic hydrocarbons(b)	2,690
Low molecular weight aromatic hydrocarbons(c)	680
DDT(d)	5.0

(a) Summation of PCB 1016, 1221, 1232, 1242, 1248, 1254, 1260.
(b) Summation of dibenzo(a,h)anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, fluoranthene, indeno(1,2,3-c,d)-pyrene, pyrene, benzo(g,h,i)perylene.
(c) Summation of acenaphthene, naphthalene, acenaphthylene, anthracene, phenanthrene, fluorene.
(d) Summation of 4-4 DDD, 4-4 DDE, and 4-4 DDT.
Reference: U.S. Environmental Protection Agency (1986)

Although not formally promulgated, the Puget Sound Interim Criteria are used throughout Puget Sound, except in Elliott Bay where the Fourmile Rock criteria are still in effect, although the disposal site closed in June 1987. In Port Gardner, the Port Gardner criteria are presently in effect. The chronology of the interim criteria developed prior to PSDDA is summarized in table II.1-3.

TABLE II.1-3. CHRONOLOGY OF INTERIM SEDIMENT CRITERIA DEVELOPED PRIOR TO THE PSDDA PROGRAM

Interim Criteria	Area of Application	Date
Fourmile Rock	Elliott Bay	June 13, 1984
Port Gardner	Port Gardner	May 16, 1985 (draft) February 1986 (final)
Puget Sound	Puget Sound(a) (except Elliott Bay and Port Gardner)	July 26, 1985

(a) The Puget Sound Interim Criteria are nearly identical to the Port Gardner Criteria, but have not been formally promulgated.

The Puget Sound Interim Criteria for biological variables are:

1. If the mean amphipod survival for the five replicates from an individual core, core section, or composite sample is equal to or greater than 16.0 individuals (out of 20), unconfined in-water disposal will be allowed provided that chemical criteria are not exceeded.

2. If the mean amphipod survival for the five replicates from an individual core, core section, or composite sample is equal to or less than 10.0 individuals (out of 20), unconfined in-water disposal will not be allowed.

3. If the mean amphipod survival for the five replicates from an individual core, core section, or composite sample is greater than 10.0 individuals (out of 20) and less than 16.0 (out of 20), additional bioassay and/or bioaccumulation analyses, as determined on a case-by-case basis by EPA and Ecology decisionmakers, will be required prior to granting of approval for unconfined in-water disposal (U.S. Environmental Protection Agency 1985d)."

1.3.4 Relationship Between the 1980 Proposed Section 404 Testing Guidelines and PSDDA Dredged Material Evaluation Procedures. The existing Section 404(b)(1) Guidelines were promulgated as interim final on 24 December 1980. These provided the initial starting point for PSDDA evaluation procedures. The PSDDA implementation approach for the guidelines was based on the aquatic disposal portion of the dredged material management strategy (decision framework) developed by the Corps of Engineers Waterways Experiment Station (WES). The strategy of PSDDA was to adapt and supplement the decision framework to develop a regionally (i.e., Puget Sound) appropriate Federal program which also met State objectives. this is consistent with Corps policy guidance which states that the decision framework "should be used to supplement the review procedures and requirements outlined in the Section 404(b)(1) Guidelines."

Review of the proposed 1980 testing package indicated five major areas that EPWG felt should be further addressed. These area are summarized below.

1. The proposed regulations emphasize the assessment and consideration of potential water column effects of dredging and dredged material disposal, e.g., the use of elutriates for "sediment assessment," requirement for water column bioassays, reliance on mixing zones, and a strong tie to "water quality standards" [230.60(b)]. Although water column concerns can be important under special circumstances, reliance on such tests as the primary decision tool is not reflective of the body of data that indicate dredging-related effects to the water column are typically minimal. The PSDDA evaluation procedures call for water column testing if warranted on a case-by-case basis; however, the emphasis of the program is on sediment toxicity analysis.

2. The proposed testing approach provides no details on how to conduct the benthic bioassay or the bioaccumulation test. For example, sampling requirements, test species, and exposure periods are left to the permitting authorities to determine. The nature of the "organic extract" to be used to conduct the sediment assessment of organic contaminants is not specified, although the kind Of extract is a key factor in determining which chemicals are "bioavailable" (see additional discussion of organic vs. saline extracts in section II-6.3).

3. The proposed testing package uses the disposal site condition as a reference for potential effects of a dredged material discharge. This procedure is allowable under the proposed regulations to distinguish Section 404 "Category 2" from "Category 4" material. This "nondegradation" approach is also reflected in the current Puget Sound interim criteria for dredged material disposal. However, if the sediments at the disposal site are already acutely toxic, there are concerns that use of such a reference approach may perpetuate a "known problem" by discharging more of the same material.

4. The proposed testing package requires (with a possible "out") the use of a bioaccumulation test, with the interpretation based on statistically significant bioaccumulation in test tissues relative to reference tissues. The presence of chemicals of concern in the test tissues is not considered by EPWG to be indicative of potential biological effects to that organism, or to the environment. EPWG does consider bioaccumulation as an important indicator for the health of human seafood consumers.

5. The proposed testing package provides no guidance on test interpretation. In response to significant test results, the regulations provide only that the permitting authority is to "assess the substantive effects of the containing chemicals of concern discharge in making the factual determinations [required by the 404(b)(1) Guidelines." Additional guidance is considered necessary by EPWG to provide the needed consistent and objective test interpretation.

Despite the issues outlined above, there are many similarities between the PSDDA procedures and the 1980 testing proposals. However, in general, additional development was recommended before the proposed package could be applied to Puget Sound. EPWG members consider the Corps' management strategy, decisionmaking framework (exhibit E.4) and disposal guidelines as subsequent refinements of the 1980 approach, with many of the technical issues more fully addressed.

2. DECISIONMAKING FOR UNCONFINED, OPEN-WATER DISPOSAL

Decisionmaking for unconfined, open-water disposal must consider potential relationships among sediment chemical concentrations, dredging and disposal processes, and possible biological effects. The major environmental processes that require consideration for unconfined, open-water disposal are summarized in the following two sections.

2.1 Dredging and Dredged Material Disposal Processes. A number of pathways could lead to release and possible loss of dredged material during dredging and disposal operations (figure II.2-1). For unconfined, open-water disposal, these potential losses include:

- o Dredging losses -- resuspension of material at the dredged site occurs during dredging because of disturbance of the bottom sediments and losses of material from the dredging process.

- o Transport losses -- leaking of material can occur from barges that transport dredged material to the disposal site, and releases of chemicals to the atmosphere can occur by volatilization.

- o Water column and bottom impact losses during disposal -- when released from a barge, a small fraction of the dredged material may float to the surface of the water (the sea-surface microlayer), exposing sensitive juvenile organisms that are found near the surface of the water column to chemicals of concern. Water column shearing and stripping can also occur as the dredged material settles to the disposal site, resulting in a plume of material that may be transported away from the disposal site by currents. Impact of the material with the bottom can also cause material resuspension and loss.

- o Losses from the disposal site -- a number of physical, chemical, and biological processes acting at the dredged disposal mound could result in losses of dredged material (discussed in section 2.2).

Several of these pathways represent minor losses of material. For example, little material (1-2 percent) is resuspended at the dredged site and potentially lost. Because the pathway is minor, the choice of dredging options (e.g., mechanical or hydraulic dredging) for material that is acceptable for unconfined, open-water disposal is not expected to have environmental consequences. Therefore the choice of a dredging option will generally depend upon which option is the most cost-effective (or available).

Where concern warrants (e.g., poor flushing, low flows), monitoring at the dredging area may be needed to ensure that State water quality standards (e.g., DO, turbidity) are not exceeded. Such a decision is made case-by-case, in accordance with current State requirements. Mixing zones are also established case-by-case. These procedures are appropriate and adequate for the

dredging of material that is acceptable for unconfined, open-water disposal. However, the proposed State guideline that discourages mixing zones from occupying the upper and lower foot of the water column is considered by EPWG as infeasible and not generally applicable to dredging projects.

In general, all water column pathways are expected to account for only minor losses of material during dredging and disposal operations. Elutriate testing and bioassays for potential water column effects are recommended by EPWG only as needed to determine potential effects resulting from disposal of material with higher chemical concentrations. Thus, tests for water column effects will be required only as appropriate on a case-by-case basis. Of greater importance than the water column are the many pathways at or near the site bottom, by which chemicals can be dispersed during and after disposal. These pathways are discussed in the following section.

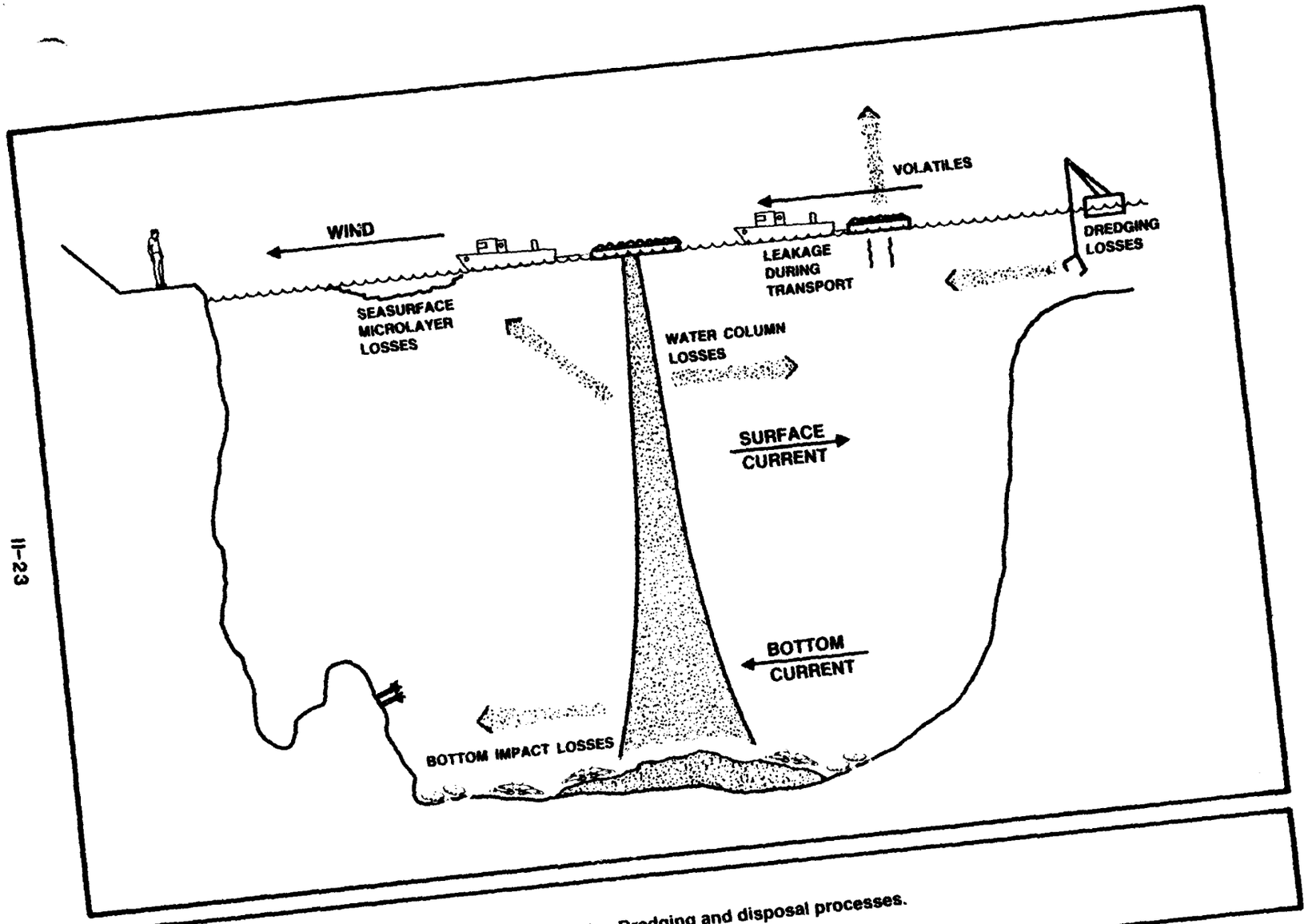


Figure II.2-1. Dredging and disposal processes.

Potential concerns for open-water discharge of dredged material also include direct physical effects caused by the burial of bottom-dwelling organisms at the open-water site and loss of habitat for organisms that feed on the existing bottom. These concerns are addressed in the DSS TA and were not considered by EPWG.

2.2 Key Contaminant Pathways. Key pathways for the dispersal of chemicals at unconfined, open-water disposal sites are shown in figure II.2-2. These pathways concern the fate of sediment deposited on the mound and flanks of the disposal site, and in a mobile layer of unconsolidated "fluff" overlying the bottom sediments (i.e., the nepheloid layer; Curl 1981; Bates et al. 1984). Lateral transport of suspended matter in this bottom nepheloid layer (net southward transport and extending up to 50 m from the bottom) in central Puget Sound has been estimated to be 1,000 times as great as the vertical transport in the water column (Curl 1981). Unconfined, open-water disposal sites are selected in part because of a low current regime that favors deposition rather than dispersion. Hence, dispersal of dredged material in the nepheloid layer is expected to be an important pathway only for a short time during and after disposal. The long-term fate of dredged material at these sites is primarily controlled by processes that affect deposited sediment.

Mechanisms of chemical release from deposited sediment at unconfined, open-water disposal sites include convection, diffusion, and bioturbation. Convection involves the transport of chemicals by water moving over and through the site. Diffusion involves movement of dissolved chemicals within the sediments of the disposal site, and between the sediments and the overlying water. Bioturbation, or disturbance of the sediments by organisms, can move sediment chemicals around or off the site, and from deeper sediments into surface sediments.

The basic problem posed by pathways shown in figure II.2-2 are biological effects or processes at the site and the release of chemicals into the environment, resulting in subsequent biological effects. For a given dredged material, some or all of the pathways indicated in figure II.2-2 may be of importance, because of sediment characteristics and chemical behavior in the disposal environment. However, because most chemicals of concern have a high affinity for particles, processes that primarily affect dissolved substances (e.g., diffusion) are less important than those that also affect chemicals associated with particles (e.g., convection).

Accumulation of chemicals in the tissues of organisms (bioaccumulation) leads to movement of the chemical through the food web. Toxic effects may still result from direct contact of organisms with the dredged material even when there is little physical or biological transfer of chemicals of concern from the site.

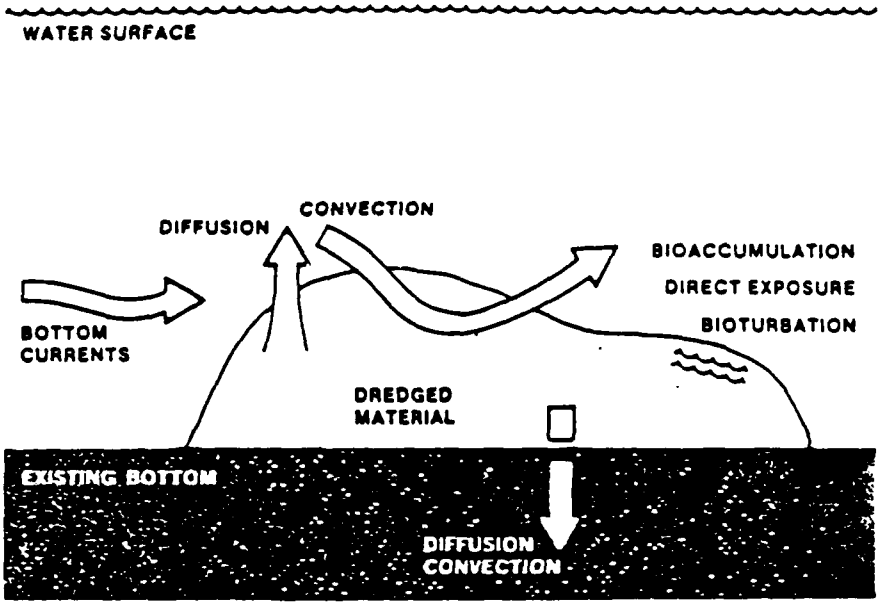


Figure II.2-2. Environmental pathways for unconfined open-water disposal.

2.3 Additional Issues.

2.3.1 Paralytic Shellfish Poisoning (PSP) Cysts. The dinoflagellate (Gonyaulax catenella) forms annual blooms in Puget Sound and produces toxins that can be accumulated in bivalve molluscs (e.g., clams, mussels, cockles, oysters, scallops) while feeding (Kozoloff 1983). These accumulations can pose a danger to humans because of "paralytic shellfish poisoning" (PSP). Finfish, unlike shellfish, are also sensitive to these toxins. During intense blooms, fish kills could result from transfer of the toxin through the food web. The dinoflagellate reproduces from one bloom season to the next by forming resting cysts, which are deposited in the sediment for overwintering. EPWG debated the issue of dredging resuspension and relocation of cysts resulting in blooms. EPWG concluded that the cysts were not found in most dredging areas in the Phase I study area, and that introduction of the cysts to areas in which favorable bloom conditions might exist was unlikely.

2.3.2 State Dangerous Waste Testing. EPWG concluded that the Extraction Procedure (EP) toxicity testing is not technically appropriate and should not be used for testing of material proposed for unconfined, open-water disposal sites. This conclusion was based on EPA Region X, policy that RCRA testing (i.e., testing required by the Resource Conservation and Recovery Act) would not be required for open-water disposal of dredged material, *provided that* testing and disposal criteria established under the Clean Water Act Dredge and Fill Permit Program (Section 404) were followed (Feigner, K., 14 August 1986, personal communication). These testing procedures, which include an elutriate test, bulk sediment analyses, and/or bioassays, are the basis for EPA evaluation of aquatic disposal of dredged material.

The Washington State dangerous waste book review procedure represents values for sediments that would be clearly unacceptable for unconfined, open-water disposal (see section II-8) and which do not apply to most dredged materials. EPWG concluded that there was no need to conduct the corrosivity or ignitability tests required in this procedure on dredged material, and that the reactivity tests should only be considered when the concentration of sulfide and cyanide in the dredged material becomes unusally high (a very rare circumstance resulting in the need for measurement of the release of sulfides and cyanides over a pH range of 2.0 to 12.2). EPWG also concluded that bioassay tests using marine species better address aquatic disposal concerns than optional bioassays in the book review procedures (using trout, rabbit, or rat species).

2.3.3 Sea-Surface Microlayer. The sea-surface microlayer (SSM) consists of the top 100 microns (0.004 in) of the sea surface, and contains increased numbers of bacteria, phytoplankton, and animal eggs and larvae relative to subsurface waters The SSM may concentrate a number of chemicals from natural and human sources that could adversely affect these life forms. In response to public concerns about sea-surface microlayer chemical concentrations derived from dredging and disposal activities, PSDDA sponsored two studies (see exhibit E.10):

- o A literature search - to document known information on atmospheric input, urban runoff, sewage effluent, industrial point sources, aquatic disposal, and sediment disturbances as possible sources of SSM chemicals of concern (Word et al. 1986).

- o A mathematical modeling effort - to predict possible releases of chemicals from dredged material and theoretical flatfish egg survival in various concentrations of particular chemicals found in the sea-surface microlayer (Hardy et al., 1986).

Neither study (nor more recent publications e.g., Hardy and Word, 1986, and Hardy, et al., 1987) provided direct or conclusive evidence about the relative contributions of dredging and disposal to the sea-surface microlayer. The following items are still unknown: (1) the areal extent of chemical concentrations in the sea-surface microlayer, (2) the percent of the total fish population that is exposed to the sea-surface microlayer, (3) the relative importance of different natural and human sources to the sea-surface microlayer (including the floatable fraction of dredged material), and (4) the nature and magnitude of any impacts of the chemicals.

A lack of evidence of sea-surface microlayer chemical concentrations derived from dredging and disposal does not mean that the sea-surface microlayer is not an important issue for EPWG. However, the basic research required to establish the impact of dredging on the sea-surface microlayer and the consequences to the environment is beyond the scope and financial resources of PSDDA. When any additional studies sponsored by other agencies and programs (e.g., PSEP and NOAA) are completed, the information will be incorporated as appropriate into the PSDDA program.

2.3.4 Material Release. The potential adverse effects of chemicals released or resuspended during dredging and disposal operations has long been an issue of concern with dredged material management. Consideration of the mass of dredged material potentially released during and after disposal is important because many chemicals tend to concentrate on fine-grained particles that are subject to dispersal (e.g., in the water column or in the nepheloid layer overlying the bottom sediments; see section II-2.2). A definitive assessment of long-term effects of material release is obscured by the complexities of the release process and difficulties in predicting the fate of the released material. Consequently, the approaches to evaluating this concern have relied on assessment of intermediary pathways and resulting possible effects.

The historical approach for material release relies on predicting and assessing the release of chemicals to the water column, typically in the dissolved state. After mixing and dilution are considered, water quality criteria developed from laboratory testing of chemical effects are applied to determine the acceptability of the predicted release. These assessments have typically indicated that water column releases of dissolved chemicals pose little risk for most dredged materials, although water column toxicity testing may be warranted under some circumstances. Hence, the focus of the assessment

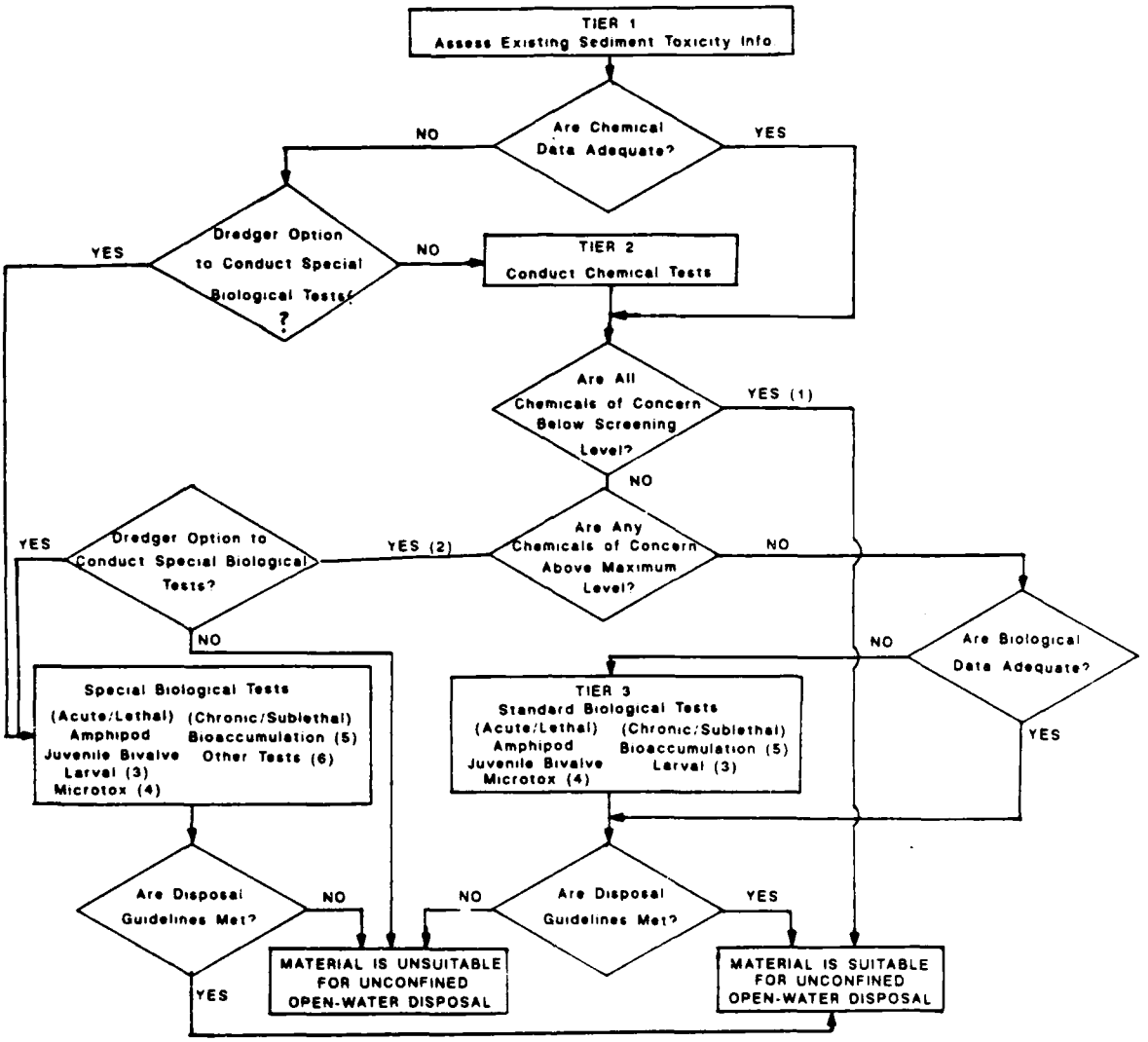
of chemical effects has shifted to sediment particles. Disposal models (dump models) are used to predict where discharges will land on the bottom and the amount of material that might be left in suspension after various time periods. In most cases, the models (and supporting field data) indicate that the discharged material descends rapidly to the bottom and settles at or near the impact point. However, the models are unable to address the long-term fate of fine-grained particles that do not settle within a reasonable distance. The models are also unable to assess the potential for a disproportionately high chemical load on these fine-grained particles.

Suspended phase bioassays (like the water column larval test) can be used to assess the possible effects on animals that encounter the suspended sediment plume from a disposal operation. These tests focus on the possible adverse effects resulting from the release of suspended particulates and chemicals into the water column. For most projects, offsite transport of suspended sediments should result in no adverse effects because the material has already been found acceptable by laboratory testing. Further, disposal site environmental monitoring (including offsite chemical and biological measurements, as well as use of a sediment vertical profiler to verify the absence of offsite transport) will verify and document any offsite effects.

Disposal of dredged material that contains relatively high chemical concentrations, lacks cohesiveness and has a small proportion of fine-grained material represents a potential exception that may result in additional adverse effects. EPWG debated numerous approaches to addressing these exceptions, and concluded that additional assessment may be warranted for certain projects. In these cases, chemical elutriate testing, additional suspended phase bioassays, and/or project-specific dump model analysis may be useful tools of use in the assessment. The need for such an assessment, and the specific assessment techiques, would be determined on a case-by-case basis.

2.4 Test Sequence and Disposal Guidelines. The test sequence and disposal guidelines recommended by EPWG for unconfined, open-water disposal separate sediments into two classes: 1) acceptable for unconfined, open-water disposal and 2) unacceptable for unconfined, open-water disposal. A diagram of the basic approach is given in figure II.2-3. Figures II.2-4 and II.2-5 summarize the disposal guidelines to be used in interpreting test results.

Because the following proposed procedures contain several features that have not received full implementation in a regulatory program prior to PSDDA, an annual reviews of evaluation procedures will be undertaken once PSDDA is initiated. Based on this annual review, evaluation procedures will be modified



(1) Biological testing may still be required if there is reason to believe that the sediment is highly anomalous and may represent a significant environmental risk even though all chemicals of concern are below screening levels for unconfined open-water disposal.

(2) Standard tier 3 biological testing can still be conducted when only a singl- chemical of concern exceeds the maximum level by < 100% Biological testing of material with chemical levels above maximum level is allowed as an option of the dredger(see footnote 6)

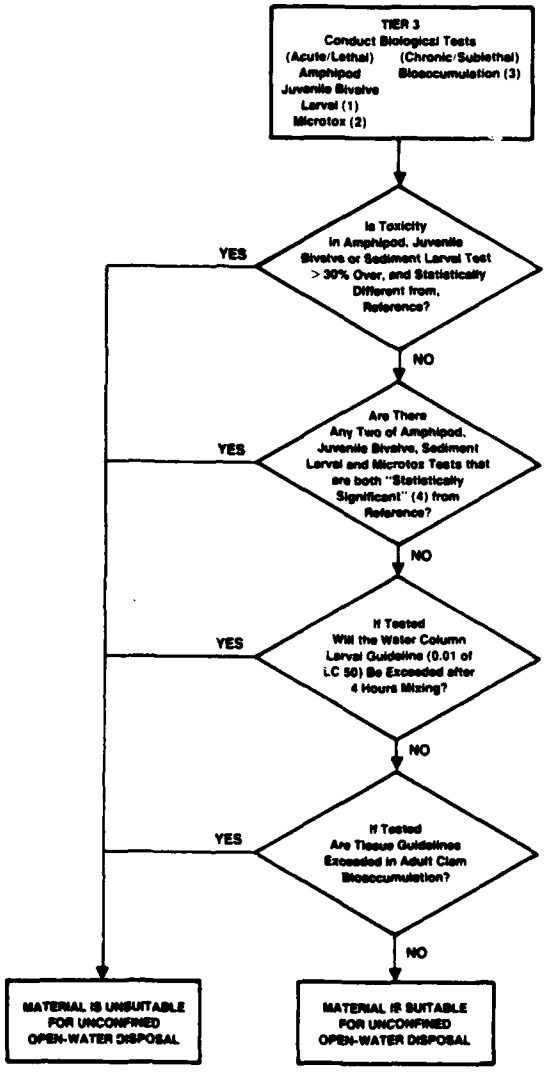
(3) The larval species can be used in either a sediment toxicity bioassy (for Section 401) and/or in a water column bioassy (for Section 404) The sediment larval test is required whenever biological testing is necessary, the water column larval test is only required when water column effects are of concern

(4) Microtox testing is required only for Section 401 reviews; it is not required for Section 404 evaluations.

(5) The chemical screening level that determines when bioaccumulaton testing is required is higher than for other biological testing.

(6) Special biological testing under the "Dredger Option" will include additional, more sensitive sublethal biological tests (see EPTA).

Figure II.2-3 PSDDA testing sequence.



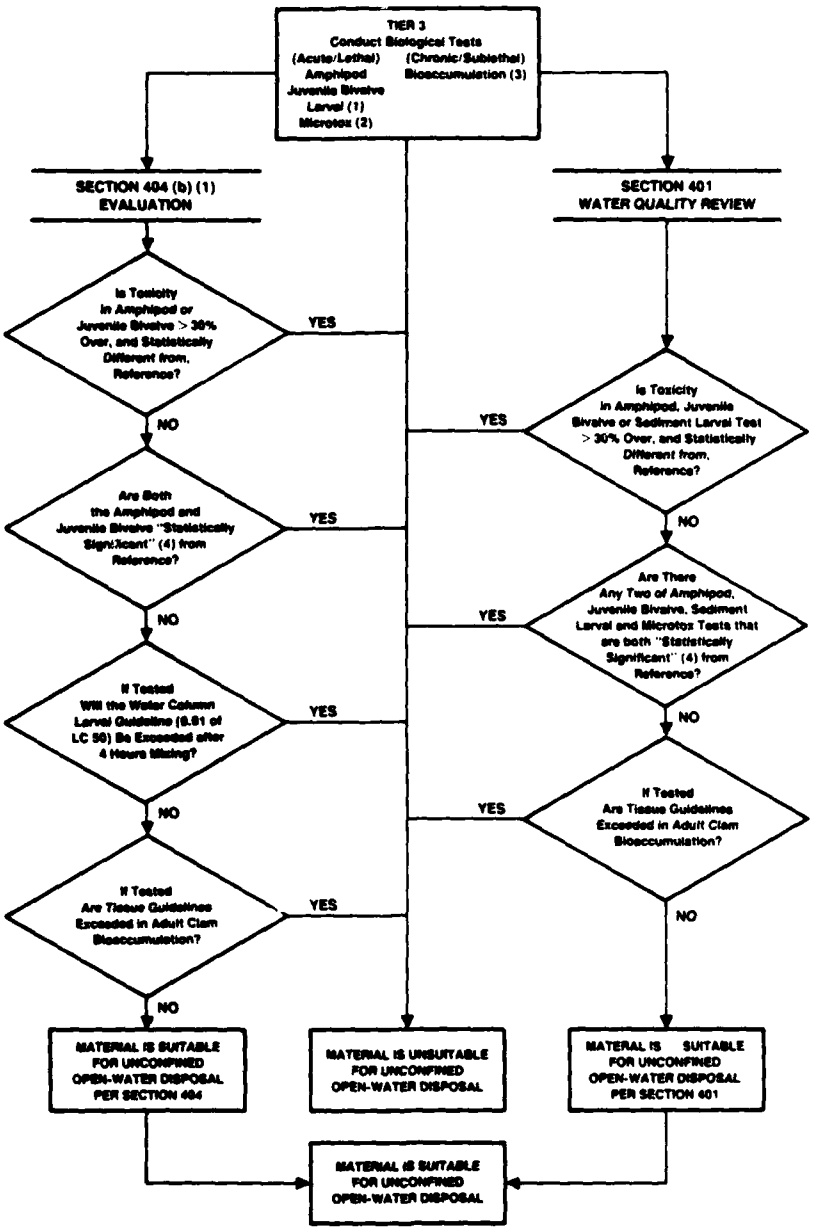
(1) The sediment larval test (for Section 401 reviews) is conducted whenever biological testing is required. The water column larval test (for Section 404 evaluations) is done only when water column effects are of concern.

(2) Microtox testing is required only for Section 401 reviews; it is not required for Section 404 evaluations.

(3) The chemical screening level that determines when bioaccumulation testing is required is higher than for other biological testing.

(4) "Statistically Significant" requires both a statistical difference from reference and total mortality response that is greater than 20 percent (absolute) over control.

Figure II.2-4. PSDDA disposal guidelines.



(1) The sediment larval test (for Section 401 reviews) is conducted whenever biological testing is required. The water column larval test (for Section 404 evaluations) is done only when water column effects are of concern.

(2) Microtox testing is required only for Section 401 reviews; it is not required for Section 404 evaluations.

(3) The chemical screening level that determines when bioaccumulation testing is required is higher than for other biological testing.

(4) "Statistically Significant" requires both a statistical difference from reference and total mortality response that is greater than 20 percent (absolute) over control.

Figure II.2-5. Section 404 and Section 401 disposal guidelines.

as appropriate. It is likely that future improvements in agency ability to characterize the distribution of chemicals of concern in sediment in different parts of the sound and to better understand the relationship between specific chemical concentrations and associated biological effects at the disposal site could result in an eventual reduction in sampling and analysis requirements.

Tier 1. Assess Existing Sediment Information. The first step of the test sequence and disposal guidelines is to examine available information about the dredging site and the composition of the sediment to be dredged, including the potential for sediment chemicals of concern. As a cost-saving strategy, all available information on the dredged material should be collected and assessed (if time restrictions permit such a review). The first decisions in this review include the ranking of the project area relative to their potential for chemicals of concern, and assessing the adequacy of the assembled data to characterize the composition of the material to be dredged. Adequacy implies that the presence and concentration of the chemicals of concern (or proof of their absence) be known. Where records are complete or available data can be used to reach a decision, additional testing is not required. If the data are inadequate (see section II-3.1), additional testing is required.

Because no single test or evaluation procedure can address all potential concerns, a sequence of chemical, biological, and physical tests may have to be conducted. These tests are used as independent indicators that provide complementary information. To control costs, a tiering strategy is recommended that enables testing to proceed only to the extent necessary to confirm the appropriate disposal decision. Currently, two tiers of testing are specified: (1) chemical testing, and (2) biological testing.

Tier 2. Conduct Chemical Tests if Necessary. The first step in the testing program is to conduct bulk chemical analysis of the sediments to be dredged. If all chemicals of concern are below a certain concentration (i.e., the screening level; see section II-7.3), there is no reason to believe that the chemical levels pose a biological risk and the sediment is acceptable for unconfined, open-water disposal without further biological testing. If any two chemicals are above a much higher concentration (i.e., the maximum level; see section II-7.3), or a single chemical of concern exceeds the maximum level by more than 100 percent (i.e., is 2 times the maximum level), there is reason to believe that the sediment is unacceptable for unconfined, open-water disposal. However, the dredger does have the option to conduct biological testing and, depending on the results of these tests, unconfined, open-water disposal may be allowed. For sediments with chemical levels between these lower and upper concentrations, biological testing is required for a decision. If the single chemical exceeds the maximum level by less than 100 percent, standard, tier 3 biological testing is the basis for a decision on disposal acceptability.

Tier 3. Conduct Biological Testing if Necessary. Biological testing is the third tier of testing. If any chemical of concern is present in sediment at levels above the established screening level, and no one chemical exceeds the established maximum level by more than 100 percent, biological testing is needed to determine material acceptability for unconfined, open-water disposal. Required biological testing over this intermediate range of chemical concentrations (see figures II.2-3 and II.2-4) to determine its acceptability for disposal at unconfined, open-water sites acknowledges scientific uncertainty over the predictability of biological effects from intermediate chemical concentrations. If the biological test results do not meet the guidelines summarized in figure II.2-4, the sediment would require some other disposal option. Hence, the results of the biological tests, rather than chemical concentrations, determine if the sediment is acceptable for unconfined, open-water disposal. The sequence of sampling and testing procedures is further discussed in section II-5.

2.5 Dredger Option to Conduct Biological Testing Rather Than Accept Chemical Test Indications. For dredged material with chemical concentrations exceeding the maximum level (ML) values, there is reason to believe that the material is unacceptable for unconfined, open-water disposal. For material exceeding ML values, the dredger will have two options at this point. First, he may elect to accept the indication of the ML that the material is unacceptable for unconfined, open-water disposal. Biological testing is not required for this decision. However, it is recognized that chemical levels in dredged material provide a relatively indirect measurement of possible adverse biological effects, as several factors can influence the bioavailability of these chemicals (e.g., sediment grain size, presence of organic carbon, etc.). This is why the dredger will have a second option to conduct biological testing rather than rely on the indications of the chemical maximum level. For this option, the dredger would conduct both the standard bioassays (five acute bioassays and bivalve bioaccumulation) and other additional, more sensitive sublethal tests in order to determine final biological acceptability of the material for unconfined, open-water disposal. Appropriate biological tests and test interpretation would be determined by the PSDDA agencies on a project-by-project basis. If the project material meets the test requirements, the dredged material will be considered acceptable for unconfined, open-water disposal.

For dredging projects involving dredged material with high chemical concentrations, the dredger may opt to proceed directly to biological testing rather than conduct chemical tests. If adequate chemical test data were not available for the project it would be assumed that the material contained chemical levels exceeding the ML values, and that it warraranted complete biological testing (both standard and other, sublethal biological tests; i.e., the "dredger option" in figure II.2-3), analyzing for all human health chemicals of concern in the bioaccumulation test.

For any dredged material exceeding the ML values that is found to be acceptable for unconfined, open-water disposal based on biological test results, the use of the PSDDA disposal sites may not be appropriate or allowable. For these projects, locating an appropriate site, and determining site use requirements and disposal site monitoring needs will be addressed on a case-by-case basis. Any needed identification and designation of special unconfined, open-water disposal sites would be the responsibility of the dredger.

In summary, unconfined, open-water disposal of dredged material with chemicals exceeding the ML values is generally considered to be outside of the scope of the PSDDA study and sites, and will necessarily be considered on a project-by-project basis (as required by the Clean Water Act). Overall, unconfined, open-water disposal of sediments containing high chemical concentrations into Puget Sound waters is not very likely to occur.

An additional benefit of the optional biological testing can occur when the test data are added to the chemical/biological effects data base. The standard biological tests (five acute bioassays and bivalve bioaccumulation) may provide information which could result in changes to the maximum level guidelines during the annual reviews of the evaluation procedures. This information will be considered along with other dredged material test results, field monitoring data, and pertinent research results, during the annual review of the PSDDA management plan. These reviews will include an assessment of possible changes to the ML guidelines.

3. PRELIMINARY RANKING AND REVIEW OF THE DREDGING SITE June 1988 rev.

The steps outlined in the following sections are concerned with actions to be taken by a dredger and regulatory agencies in advance of any decision to conduct additional chemical or biological sampling and analysis for a proposed dredging project. Information reviewed at this stage of the project enable the following questions to be answered:

- o Where is the project located relative to potential sources of chemicals of concern? What is the rank of the site based on this information and available historical chemical data?
- o What is the proposed volume of sediment to be dredged?
- o Is existing information adequate to fully characterize the sediment to be dredged?

After these questions have been answered, a decision can be made concerning the need for additional tests.

Information supplied by the dredger during the review of available data includes the following:

a. Area map identifying dredging project location and surrounding area.

b. Plan view drawing of area to be dredged. Storm drains and all known potential sources of chemicals of concern are identified.

c. Sufficient number of cross section view drawings to adequately describe the dredging prism showing dredging depths to scale. If greater than a 4-foot dredging cut is proposed, the 4-foot cut depth is marked on the cross section drawings.

d. Estimate of the quantity of material to be dredged both above and below the 4-foot cut (including project "overdepth" material).

e. Brief history of project site. What past activities may have contributed to chemicals in the sediments? What existing activities and discharges could result in the presence of chemicals of concern?

f. Existing chemical and biological sediment sampling data from on site and nearby sites.

3.1 Location of Dredging and Area Ranking.

3.1.1 Introduction. Sampling and analysis requirements for full characterization[1/] of project dredged material vary by dredge cut depth and potential degree of chemical concentrations of the dredging area. While the first factor is always project-specific, the latter factor has been embodied

1/See Section II-5.2.4 for partial characterization guidelines.

in a ranking system for the various dredging areas in central Puget Sound. Ranking can also be performed within a project. The rank of a dredging area is used to determine the degree of concern regarding possible material chemical concentrations and the intensity of sampling and analysis that a proposed dredging project warrants. This section describes the initial area rankings for the Phase I area of PSDDA.

3.1.2 Description of Ranks. A dredging area may be assigned to one of four possible ranks: high, moderate, low-moderate, and low (table II.3-1). In that order, these ranks represent a scale of decreasing concern for potential chemical concentrations, and concomittant reduction in the information, sampling, and analysis requirements.

The ranking system is based on two factors:

1. The number and kinds of chemical sources (existing or historic).

TABLE II.3-1. DEFINITION OF AREA RANKS FOR DREDGING PROJECTS

Area Rank	Characteristics
Low (a)	Few or no sources of chemicals of concern, data are available to verify low chemical concentrations (typically below a level predicted to result in significant biological effects; see section II-7.4), and no significant response in biological tests.
Low-Moderate	Available data indicate a low rank, but there are insufficient data to confirm the ranking.
Moderate	Chemical and biological data are not available or are incomplete, and some sources of chemicals of concern exist nearby.
High (a)	Many known chemical sources, high concentrations of chemicals of concern (see section II-7.1), and/or significant acute toxicity in sediment bioassays. [When a high rank is indicated for an area based on preliminary data, then a "high" rank is assigned to the area as a protective measure (i.e., there is no rank of "high-moderate").]

(a) For these ranks, sufficent data must be available to characterize the chemical and
biological variables of concern.

2. The available information on chemical and biological-response characteristics of the sediments.

Initial rankings describe relatively large areas (bays and waterways). Because of the paucity of environmental data in many dredging areas in Puget Sound, these area rankings were estimated based on knowledge of potential sources of chemicals of concern, as confirmed by chemistry and biological response data where available. Area rankings for the Phase I study area are expected to be changed as specific dredging projects gather additional information. In addition, ranking within projects will likely occur. Finally, use of the limited data required heavy reliance on past experience with dredging in Puget Sound. Therefore, until additional data become available, the rank assigned to many of the areas will remain as currently assigned (see section II-3.1.6).

3.1.3 Relation to Disposal Guidelines. No direct relationship exists between the area rankings and the disposal guidelines. This potential discrepancy exists because the rankings are based primarily on knowledge of chemical sources, with less reliance on the limited chemistry and biology data that might be available for an area. Additionally, the initial rankings are applied over large areas (bays, or segments of a waterway). The disposal guidelines, on the other hand, are intended for application to well-defined management units of dredged material covering a much smaller spatial scale. It is important to note that the ranking does not affect the kinds of information required for a dredging project, but does affect the intensity of sampling and analysis effort that a project would need.

After consideration of sources, area rankings are driven by the most elevated chemistry values and most significant adverse biological response observed in an area. Chemistry and biology act as separate factors, either of which could drive the final ranking of an area. For example, areas that exhibit sediment chemical concentration above the concentration that might be acceptable for unconfined, open-water disposal (see section II-7.4) or that exhibit an acute toxicity response of greater than 30 percent would be ranked high. Areas with chemical concentrations less than screening levels (see section II-7.3) and that do not exhibit acute toxicity response, would be ranked low. Other areas would fall in the moderate ranking.

3.1.4 Reranking of Areas/Projects. Refinement of the initial rankings can occur within a bay, within a project, and even within a dredge cut (i.e., subsurface sediments only). Areas can be ranked higher based on the results of a single testing period; however, consistent results from two testing periods are recommended before an overall area ranking would be lowered. Specific projects within an area may be ranked higher or lower based on the results of sediment-specific tests (see section II-5.2.4 for partial characterization guidelines).

3.1.5 General Rankings. Certain categories of dredging areas were assigned a general rank. In the absence of additional information, urban and industrialized areas are ranked high. Marinas and ferry terminals are initially ranked moderate, given the typical absence of industrial or municipal discharges. High energy areas that are characterized by coarse-grained material (coarse sand and gravel) and are distant from potential sources of chemicals of concern are ranked low-moderate or low. Dredging areas located close to moderate-sized sewer outfalls are ranked moderate.

3.1.6 Specific Rankings. Initial ranks assigned to areas in the Phase I study area of PSDDA are shown in table II.3-2). In defining these rankings, agency experience and data available from agency files were reviewed relative to information contained in the Puget Sound Environmental Atlas. There are few active dredging areas in central Puget Sound (table II.3-2) ranked "low-moderate" at this time. Dredging typically is concentrated in areas where there are many sources of chemical concentrations. Because industrialized zones are located throughout the Phase I area, many of the areas were ranked high. Past data collection efforts were aimed at identifying chemicals of concern areas. Therefore there are also few data in areas of potential low concern. For these reasons, few areas were ranked low-moderate. Containing chemicals of concern areas in the deep portions of central Puget Sound were not ranked because dredging is not likely to take place in these areas.

3.2 Project Size. Project size can affect the need for testing and the types of tests required. For small projects, the cost of testing must be balanced against the environmental risks posed by a very small volume of dredged material. As a result, the proposed volume of sediment to be removed at a dredging site, if unusually small, affects the need for testing. EPWG recognized that very small volumes of dredged material (less than a sampling unit) individually represent a very low potential for unacceptable adverse effects at the disposal site. Although cumulative effects of many small projects are of conceptual concern, the cost of mobilizing large dredging equipment generally has discouraged many small projects from using multiuser disposal sites. As a result, very small projects constitute only a small percentage of the volume disposed at the existing DNR sites over the last 15 years (Envirosphere 1986).

Complete chemical and biological testing of a single sample according to the recommended evaluation procedures will likely exceed $2,000 to $3,000. Because of the low potential for unacceptable adverse effects, this high cost was considered unwarranted for very small projects, especially for projects in low-ranked areas. Consequently, under certain circumstances, reduced testing and testing exclusions are considered appropriate.

The volumes of very small projects for which no testing is recommended be conducted are shown in table II.3-3.

January 1988 rev.

TABLE II.3-2. INITIAL AREA RANKINGS IN THE PHASE I STUDY AREA
(RELATIVE TO POTENTIAL FOR CONTAINING CHEMICALS OF CONCERN)

High rankings:

East Waterway, Everedt Harbor
Intertidal areas of Snohomish River through upper settling basin
Mukilteo
Edmonds (except at Chevron tanks)
Kenmore
Eagle Harbor (the creosote plant and west)
Salmon Bay
Lake Washington ship canal
Elliott Bay
Duwamish River (except upper turning basin)
Sinclair Inlet
Commencement Bay (except Milwaukee Waterway)
Lake Union

Moderate rankings:

Snohomish River from the mouth up through the upper settling basin (excluding intertidal areas)
West Port Susan (near Cavelero Beach)
Ferry terminals Clinton and Gedney Island
Chevron tanks near Edmonds
Port Madison
Kingston ferry terminal
Upper turning basin of the Duwamish River
Lake Washington (except Kenmore)
Dyes Inlet
Ferry terminal at Fauntleroy
Gig Harbor
Upper portion of Quartermaster Harbor
Ferry terminals at Point Defiance and Vashon Island
Milwaukee Waterway, Commencemend Bay

Low-moderate:

Inner Eagle Harbor (west of creosote plant)
Outer Quartermaster Harbor
Port Orchard

TABLE II.3-3. "NO TEST" VOLUMES FOR SMALL PROJECTS(a)

Area Rank(b)	"No Test" Volume
Low	8,000 c.y.
Low-Moderate	500 c.y.
Moderate	500 c.y.

(a) Small projects that involve total volumes of dredged material less than those listed may dispose of the material at unconfined, open-water sites without testing unless there is a reason to believe that the material is unacceptably containing chemicals of concern. In such cases, the regulator may require testing for specific chemicals of concern.

(b) Area ranks are defined in section II-3.1.2 and table II.3-1.

For very small projects in low, low-moderate, or moderate ranked areas, volumes for which no testing need be conducted are shown in table A.2. In the absence of specific, conclusive evidence of unacceptable material, projects with these or lesser volumes would be categorically considered acceptable for unconfined, open-water disposal.

For low ranked areas (i.e., data are available to verify the initial ranking), the "no test" volume is equal to the dredged material sampling unit (i.e., 8,000 c.y.). For low-moderate and moderate rankings, the "no test" volume is representative of the capacity of smaller barges in use in Puget Sound. Limited biological testing requirements are discussed in section II-6.7.1 (see table II.6-3) for projects with volumes greater than the "no test" volume and less than the sampling unit volume (see also section II-3.3.2).

Two key qualifiers of these volumes were provided. First, intentional partitioning of a dredging project to reduce or avoid testing requirements is not acceptable. Second, recognizing that multiple small discharges can cumulatively affect the disposal site, regulatory agencies are expected to define "project volumes" in as large a context as possible. One example of the application of this latter qualifier is recurring maintenance dredging of a small marina where "project volume" would be the summed volume over the permit life (often 5 years). Another example is multiple-project dredging contracts, where a single dredging company dredges for several projects under a single contract or contract effort. Again, the "project volume" would be summed across all projects (as would any sampling and compositing efforts prior to testing).

3.3 Assessment of Existing Information.

3.3.1 "Safety Net" Concept. Prior to considering the need for additional testing, an initial assessment of existing data is conducted as described in the Section 404 (b)(1) Guidelines. The initial assessment is used to answer the question: Is there reason to believe that the sediment contains chemicals of concern? For example, the Section 404(b)(1) Guidelines allow coarse dredged material that is isolated from any chemical sources to be excluded from testing (even in the absence of any data on sediment concentrations of chemicals of concern). Sources of information to be collected by the dredger for this review include past studies and land use records (see figure II.3-1). Properly conducted, this review is complex, difficult, and time consuming, and all pertinent data sources are rarely reviewed for a dredging project.

Even if all existing data are reviewed, the minimum information required to establish whether there is any reason to believe that the chemical levels may cause unacceptable adverse effects often cannot be obtained. Rather than exclude this kind of material from testing, these areas are ranked low (if adequate sediment data are available from nearby areas) or low-moderate (if sediment data are not adequate). According to this ranking scheme, testing and data requirements are minimized, and existing information remains adequate for more than 5 years.

The possibility for "surprises" in the dredged material was recognized in the decisionmaking framework for disposal of dredged material recommended by the Corps Waterways Experimental Station (U.S. Corps of Engineers 1986a). The minimum of one bulk chemical analysis (project composite) recommended in this framework will be used as a "safety net" against unexpected chemical concentrations not indicated by historical data. The "safety net" concept is an appropriate replacement for the Section 404 testing exclusion because it minimizes "surprises", relaxes the need for extensive data searches, and provides sediment-specific data of use in managing the disposal site. Chemical data resulting from this analysis can be compared to screening level values to determine if there is reason to believe that biological testing is warranted.

Because data resulting from the "safety net" analysis overtime will improve agency ability to characterize the distribution of chemicals of concern in Puget Sound, it is likely that an eventual reduction in sampling and analysis requirements would occur. Data from the "safety net" analysis can be used to rerank an area, to modify the chemicals of concern list for a project, and can (within the limits of professional judgment, data recency, quality assurance, and other technical factors) be extrapolated to adjacent projects. For example, there may be no reason to believe that hexachlorobutadiene (a PSDDA chemical of concern; see section II-7.1) is present in a particular dredging area based on available historical evidence and information concerning potential sources. If the "safety net" analysis demonstrates that this

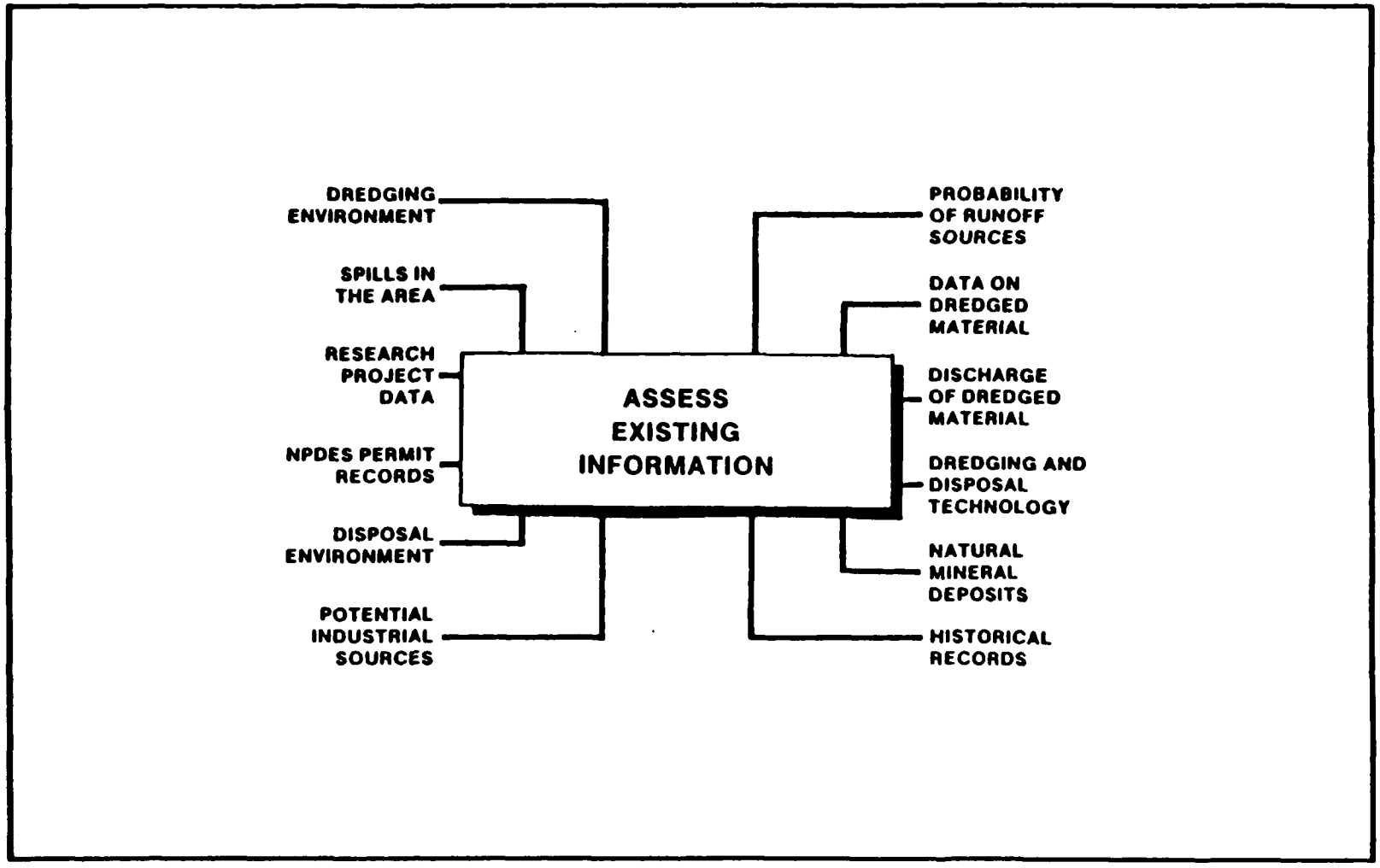


Figure II.3-1. Sources of existing information.

compound is not present at acceptable detection limits, then the list of chemicals for a given project area may be modified to exclude hexachlorobutadiene from further routine analyses.

In practice, most projects will likely require more than one analysis for adequate characterization. Use of the "safety net" would be appropriate in confirming sediment chemistry in low-rank areas for moderate-sized projects, as well as for sampling in "nonsampling" years (see II.3.3.2 below).

3.3.2 Recency and Frequency Guidelines. The need for further testing also depends upon how long the existing data can be considered representative of the conditions at the proposed dredging site. "Recency" guidelines for existing information refer to the duration of time for which chemical and biological characterization of a given sediment (that might be dredged) remains adequate and valid for decisionmaking without further testing. These guidelines are based on the number and operating status of chemical sources near the area to be dredged, and on whether the sediment is close to the sediment-water interface (i.e., surface sediments, less than 4 feet) or not (subsurface sediments, greater than 4 feet). For the dredging of surface sediments in areas with ongoing, active chemical sources, the PSDDA guidelines provide for information to be valid for a period of 2 years (from date of sampling). The 2-year recency guideline is based on a consideration of the average (and reasonable) time required after initial sampling to complete a dredging project, including permitting and contracting time. Other factors considered included the shoaling and sedimentation rate in Puget Sound waterways, and the degree of change in sediment chemical concentrations that has been observed historically in high-ranked areas. In all other areas (i.e., surface or subsurface sediments, without active sources (NPDES permitted outfalls, stormwater systems draining areas of major pollution, etc.)), a period of 5-7 years is recommended in the guidelines for data to be considered valid.

The recency guidelines are not applicable when a "changed" condition is known (e.g., where spills or new discharges have occurred since the most recent samples were obtained). The guidelines are also not considered firm rules that can not be exceeded, but instead are references to assist the regulatory process. In many cases, missing information will require sampling and testing regardless of available data, and exceeding the time guidelines does not invalidate all past data. Instead, follow-up sampling may be sized to the degree of concern presented by past data, as long as these past data were adequately complete relative to chemical and biological analysis.

Recency guidelines only apply to data for a given sediment that was sampled and characterized, not for an entire area. When a substantial layer (greater than 2 feet) of new material has settled on the area previously characterized, new information will be required.

A related case involves repeat dredging that occurs more frequently in an area than the recency guideline period. Because recency guidelines do not apply to material dredged in a "nonsampling year" (e.g., year 1-4 of a 5-year recency

period), a separate "frequency" guideline was developed. This guideline requires full sampling and testing under the new evaluation procedures for the first 2 years (for nonannual dredging, the first two dredging periods within the recency guideline window), establishing a trend for the dredging area. Barring changed conditions, future "nonsampling years" would only require a single bulk sediment chemical analysis (i.e., to provide a "safety net" for the screening of sediments). Full analysis would be required at the end of each recency window (every 2 or 5-7 years).

Although decisions on the need for further sampling will usually follow the recency and frequency guidelines for most projects, the PSDDA procedures allow special consideration for dredging projects that must dredge recently settled material before testing results can be obtained. Some projects are constrained such that a large portion (or all) of the material to be dredged settles just prior to dredging. As a result, testing of the material will not provide results in a time for dredging. Material that is planned for disposal at unconfined, open-water sites should be approriately characterized. Hence, sampling will be arranged on a case-by-case basis for these exceptions.

The first preference for projects where sampling and testing time is constrained by impending dredging (to remove rapid shoaling) is to postpone dredging to a later period or window. Given the monitoring and site management plans for the unconfined, open-water disposal sites, it is worth avoiding, if possible, the responses potentially required to address discharge of unacceptably containing chemicals of concern sediments. Postponement of dredging is a project-specific decision, although smaller projects can typically fit in smaller dredging windows available at other times of the years.

3.3.2 Quality Assurance of Existing Data. The requirements for quality assurance (QA) that can be applied to historical data are less than can be expected for data generated according to recent protocols recommended by PSEP and PSDDA (Tetra Tech 1986k). However, lesser quality data may be useful during the initial assessment phase to rank a project. Such data provide a relative listing of the kinds of chemicals that might be found within the project area. When the data are used to characterize the dredged material, the following information must be reported and considered:

- o Sampling and analytical method (chemistry and bioassay results)
- o Chemical detection limits
- o Bioassay control sediment
- o Quality control measures (chemistry and bioassay results) appropriate to the method.

4. SAMPLING ISSUES AND CONCERNS

A number of procedures for sampling dredged material required clarification by EPWG. The resulting sampling and analysis protocols address the following questions:

- How should the dimensions of a "dredged material management unit" be defined (i.e., based on the prism depth and extent of horizontal chemical concentrations)?
- Should these dimensions vary by the size of project? (see discussion in section II-3.2)
- Should the degree of known or suspected sediment chemical concentrations at a site influence the definition of the management unit?
- To what degree should the capabilities of "usually available" dredging equipment affect the definition of a management unit?
- Should visible lenses within the sediment column be sampled separately, composited with other samples from the sediment column, or composited among stations (i.e., is dilution of sediments with higher chemical concentrations into sediments with lower chemical concentrations an acceptable practice, or should subsamples be archived for possible analysis)?
- How many analyses per management unit are needed?
- What are the proper procedures for locating the position of stations during sampling efforts?

Guidance was also required for the characterization of material below the authorized project depth for potential problems that might be exposed after dredging. Recommendations for the resolution of these issues are addressed in the following sections.

4.1 Dredged Material Management Units. In determining the number of analyses (e.g., chemical tests) that would be required for a project, the concept of "dredged material management units" was used. The management unit recognizes the common heterogeneity of chemical distribution in sediments, allowing different management of dredged materials according to their potential for unacceptable adverse environmental effects. This approach is common throughout the country (e.g., San Francisco), and is codified in other countries (e.g., Canada, Norway). The management unit approach is also routinely employed in the design of capping projects, where cleaner project materials are placed over less clean materials. A management unit is the smallest volume of dredged material for which a separate disposal decision can be made (i.e., a unit to be managed separately). A given volume of sediment can only be considered a management unit if it is capable of being dredged and managed separately from all other sediment in the project. This requires that management

unit be properly defined relative to dredging (e.g., that cut depths, and shoal locations and lifts all be considered in the final description of a management unit). Therefore, the decision on acceptability or unacceptability of material for unconfined, open-water disposal is made on individual management units independently of other management units within the project.

Dredged material management units are summarized in table II.4-1. These units are based on 1) the cut depth at which dredging will be performed (i.e., surface or subsurface sediments of the dredging prism) and 2) the level of concern based on historical evidence of the extent of chemical concentrations in the dredged area (i.e., area rankings; see table II.3-1).

TABLE II.4-1. DREDGED MATERIAL MANAGEMENT UNITS FOR FULL CHARACTERIZATION (a)

Concern	Surface Sediment Greater Than 4 ft average cut	Subsurface Sediment Less Than 4 ft average cut
Low	48,000 c.y.	72,000 c.y.
Low-moderate	32,000	48,000
Moderate	16,000	24,000
High	4,000	12,000

(a) Each management unit is the volume of sediment that may be characterized by a single analysis.

4.2 Patchiness of Sediment Chemical Distributions. A major difficulty in identifying problems of chemicals of concern by toxic pollutants in Puget Sound is the patchiness of the most severe chemical concentrations. The critical question was how to adequately sample a proposed area for dredging to characterize the potential chemical distribution. A range of sampling strategies was considered. At one end of this range, a large number of samples could be collected and analyzed individually. Although expensive, this approach would yield the most information concerning the patchiness of sediment chemicals, and would enable effective assessment of dredged material for disposal. Alternatively, the large number of samples could be composited into a single sample for analysis. The substantial cost savings for testing by this approach would result in an estimate of the average concentration in the

dredged material management unit, but no information on the variability of the concentration. If sediment chemical concentrations were patchy, this approach could result in the unconfined, open-water disposal of a volume of dredged material that exceeds acceptable guidelines, or (more commonly) in the rejection of a large amount of dredged material that was well below the acceptable guidelines.

The sampling procedures, while not fully addressing the high degree of chemical variability known to exist in sediments, at least provide consistency in the assessment of dredged material chemicals of concern. This consistent assessment of the chemical risk is the reason why sampling and analysis requirements (per unit volume of dredged material) were not decreased for larger projects. Although employed historically, it is not believed that reduced sampling for large projects is justified solely on a cost reduction basis, and is only appropriate in sediments in which chemical concentrations do not vary substantially. For the Phase I study area, few homogenous sediments are expected to be found in the most active dredging areas (e.g., industrialized rivers and waterways).

The PSDDA procedures allow the dredger to demonstrate that the variability of chemical concentrations in the dredging prism does not warrant the collection of the recommended number of samples. Typically, this demonstration would require a pilot study to address chemical variability at the proposed dredging site and to calculate the number of samples needed for analysis.

There may still be considerable chemical heterogeneity within a management unit. EPWG fully recognizes that multiple analyses are needed to address intrastation variability. However, this replication greatly adds to testing costs and does not greatly add to the confidence in characterization. EPWG therefore concluded that testing funds should be fully allocated to decreasing the size of the management unit rather than having intrastation replicates for larger management units.

4.3 Sampling Methods and Depths.

4.3.1 Overview. Recommended sampling requirements for dredged material disposal assessments have been defined by a Regional Administrative Decision (exhibit B). Plumb et. al (1981) provide additional review of and guidance for the design of sampling plans. The number of required samples and analyses (composited) is based on the volume of sediment involved, the suspected level of chemicals of concern (i.e., area ranking), and anticipated dredging cut depth. Previous sampling programs were not as directly related to the volume of sediment represented by a particular project as now.

4.3.2 Number of Samples and Analyses for Full Characterization. The total number of sediment samples and resulting composited samples for analysis for full characterization of dredging projects of differing area ranks and sediment depths are shown in table II.4-2. Sediments with a high levels of chemical concentrations (high area rank) represent a greater environmental risk for

unconfined, open-water disposal than do sediments with little or no chemical concentrations. EPWG has identified four area rankings that describe the chemical concerns of area sediments (section II.3-1). Sampling and analysis guidelines are based in part on those rankings. An example application of these guidelines is presented in section II.4.4.4.

TABLE II.4-2. SAMPLING AND ANALYSIS GUIDELINES FOR FULL CHARACTERIZATION

Area Rank	Maximum Volume of Sediment Represented by Each Sample c.y. x 1,000		Maximum Volume of Sediment Represented by Each Analysis (Sample Composites) c.y. x 1,000	
	Above 4 ft Depth	Below 4 ft Depth	Above 4 ft Depth	Below 4 ft Depth
Low	8	8	48	72
Low-Moderate	8	8	32	48
Moderate	4	4	16	24
High	4	4	4	12

Once the area ranking is identified and the project size is known, the number of samples that may be composited for analysis can be determined according to the standards shown in table II.4-2. It is assumed that most samples to be tested will consist of composites from several sediment cores. Projects defined by a "low" area ranking require fewer samples per project volume than do similar sized projects with higher levels of concern. The fact that sediment chemical levels and distribution variability typically decrease with depth (at least at a depth of several feet) was also recognized. Hence, sediments from depths greater than 4 feet require fewer analyses per unit volume.

Use of 1 foot instead of 4 feet as the cut depth of the surface management unit was evaluated. Four feet is the typical cut of usually available dredging equipment (±2-foot vertical tolerance). Special equipment can achieve cuts of ±0.5 to 1-foot vertical tolerance, though it is often unavailable. EPWG assumed that conventional equipment and a 4-foot dredging cut would be preferred by dredgers in typical situations; however, past experience suggests that a sample composited over a larger cut containing a small sublayer of high

chemical concentrations will still not be acceptable for disposal at unconfined, open-water sites. Hence, in areas of known very high chemical concentrations (e.g., previously sampled areas, EPA Superfund sites), a 1-foot cut, and use of special dredging equipment, may be a more cost-effective option (because a smaller volume of material may require restrictions on disposal), and should be considered by the dredger.

The minimum number of samples required for a project can be determined with the following procedure. After the area ranking is known, the volumes of sediment above and below the 4-foot cut depth are calculated. These volumes are divided by the sampling and analysis requirements for the appropriate rank (table II.4-2). The allocation of samples and analyses (i.e., the compositing plan) is a subsequent step that is performed on a case-by-case basis. Additional analyses beyond this minimum number may be required to achieve a workable dredging plan (i.e., where very different sediment types warrant separate decisions).

The minimum number of samples and analyses required for a project will be determined prior to initiation of sampling. A sampling scheme would be developed based on information on the project submitted by the applicant during the initial review process. The sampling plan should be developed in close coordination with Corps, EPA, and Ecology representatives.

4.4.3 Positioning Methods for Station Location. Protocols for navigation and positioning techniques were developed by work sponsored by PSDDA in conjunction with PSEP. These protocols are summarized in exhibit E.12 (Tetra Tech 1986g and 1986l). Sample location for dredged material testing requires high positioning precision. This requirement stems from the link between sample locations and the need for construction-level detail in the dredging plan. Sampling plans must be designed to allow the dredge to discretely (i.e., repeatable accuracy $\pm$2 m) remove different management units.

4.4.4 Full Characterization Sampling and Analysis Guidelines Case Study. A simplified dredging case study is presented in this section. The case study illustrates the application of PSDDA sampling and analysis guidelines according to the seven steps in table II.4-3. The case study is a project located in an industrialized waterway and involves the removal of 49,000 c.y. to widen a channel. The dimensions of the project are shown in figure II.4-1. A new cut to a maximum of 11 feet is planned along a 6,000-foot segment.

Step 1. Determine Area Ranking. Area ranking is determined by review of existing information concerning the potential for encountering containing chemicals of concern sediments in the project sediments (section II-3.1). The project is ranked "high" based on the location in an industrialized waterway and multiple potential sources of chemicals of concern.

TABLE II.4-3. SUMMARY OF STEPS USED IN APPLYING SAMPLING AND ANALYSIS GUIDELINES (a)

1. Determine area ranking (table II.3-2).
2. Estimate the dredging volume above (i.e., surface) and below (i.e., subsurface) the four foot cut line (figure II.4-2).
3. Using the sampling and analysis guidelines (table II.4-2) for the appropriate ranking, calculate the total number of samples and analyses required for the project.
4. Determine the dredging plan (e.g., dredging cuts in lifts, cuts from the base of the slope, or cuts by completing successive segments of the channel). For an example using cuts in lifts, see figure II.4-3a.
5. Define dredged material management units (table II.4-1) based on the calculated number of analyses and the dredging volumes above and below the four foot cut line.
6. Allocate the calculated number of samples (for example, figure II.4-3b).
7. Determine the compositing plan (for example, figure II.4-3b).

(a) An example case study illustrating the application of PSDDA sampling and analysis guidelines is presented in section II-4.4.4.

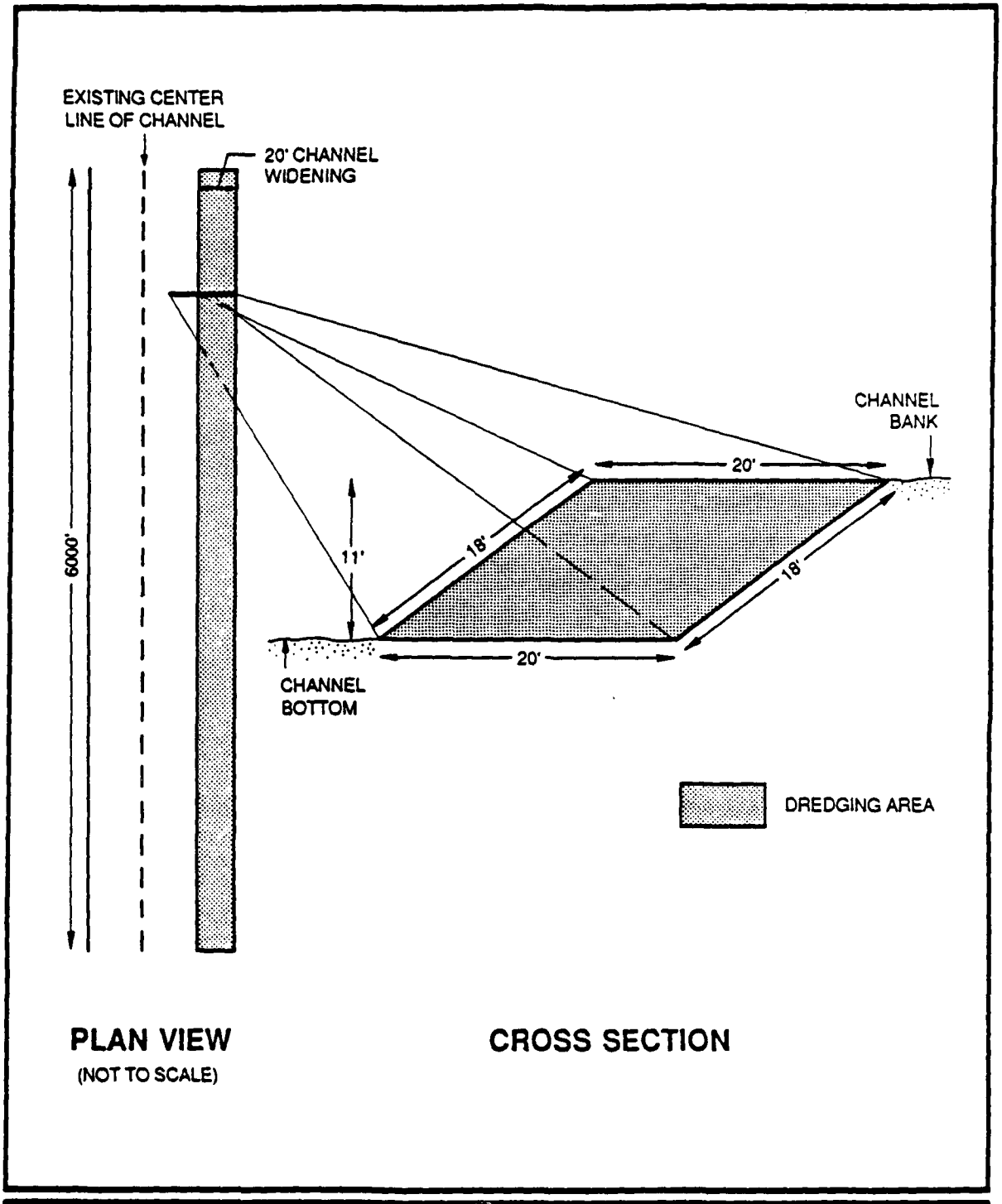


Figure II.4-1. Plan view and cross section of example dredging project.

Step 2. Estimate Dredging Volume. The surface dredging volume above the 4-foot cut line and subsurface dredging volume below the 4-foot cut line must be estimated. Using figure II.4-2, the estimated volume for the surface is 28,000 c.y.:

(horizontal surface) (slope surface)

$$\frac{4' \text{ cut} \times 20' \text{ width} \times 6000' \text{ length}}{27 \text{ c.f./c.y. conversion factor}} + \frac{4' \text{ cut} \times 12' \text{ width} \times 6000' \text{ length}}{27 \text{ c.f./c.y. conversion factor}}$$

[Note: The calculation of a discrete slope surface is often not an essential step, especially for routine maintenance dredging.]

The estimated volume for the subsurface is 22,000 c.y.:

$$\frac{7' \text{ cut} \times 14' \text{ width} \times 6000' \text{ length}}{27 \text{ c.f./c.y. conversion factor}}$$

Step 3. Calculate Total Number of Samples and Analyses. Using the sampling and analysis guidelines in table II.4-2, the number of samples needed for characterizing the surface material is seven:

$$\frac{28{,}000 \text{ c.y. in the surface volume}}{4{,}000 \text{ c.y. maximum volume represented by each sample}}$$

From table II.4-2, the number of analyses (sample composites) needed for these seven surface samples is also seven (28,000 c.y./4,000 c.y. maximum volume).

The number of samples needed for the subsurface material is six:

$$\frac{22{,}000 \text{ c.y. in the subsurface volume}}{4{,}000 \text{ c.y. maximum volume represented by each sample}}$$

From table II.4-2, the number of analyses (sample composites) needed for these six subsurface samples is two (i.e., 22,000 c.y./12,000 maximum volume represented by each analysis). Therefore, the total number of samples needed for the project is 13 (seven surface and six subsurface); the total number of analyses needed is nine (seven surface and two subsurface).

Step 4. Determine Dredging Plan. There are a number of ways to conduct dredging for a project like the one described in this case study. For this illustration, it is assumed that the dredged material will be removed in three vertical lifts (figure II.4-3a) for the entire length of the channel (i.e., no segmentation is assumed). Each lift is approximately 4 feet in cut depth (figure II.4-3a). Many projects may have a substantially more complex dredging plan than that assumed here. This complexity would need to be appropriately reflected in the sampling plan.

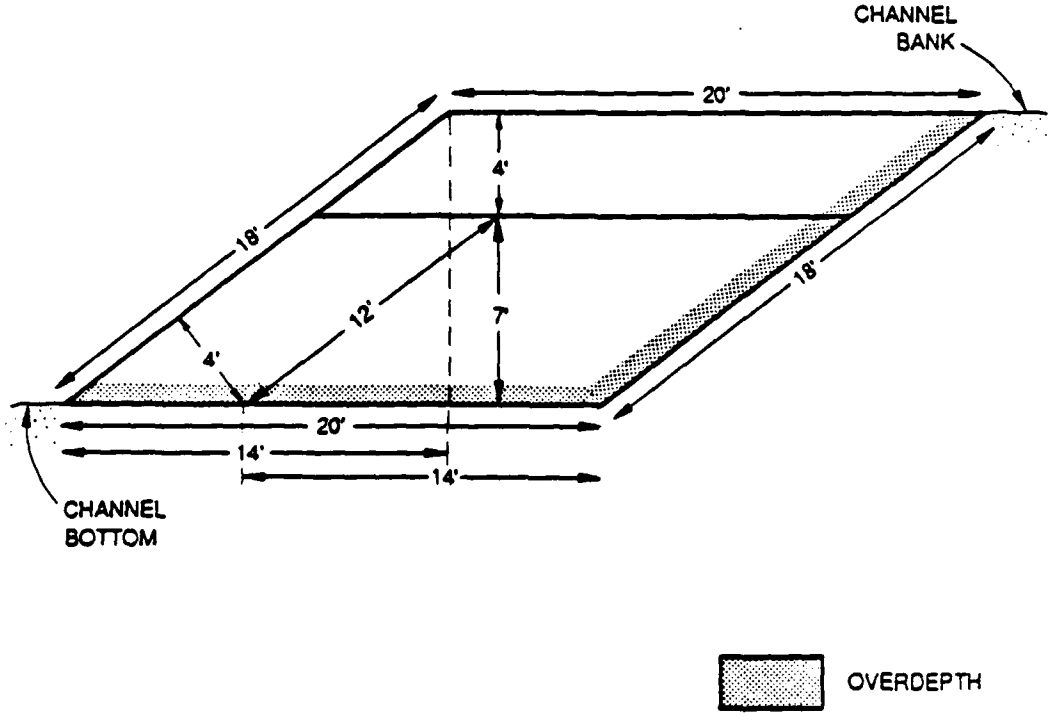
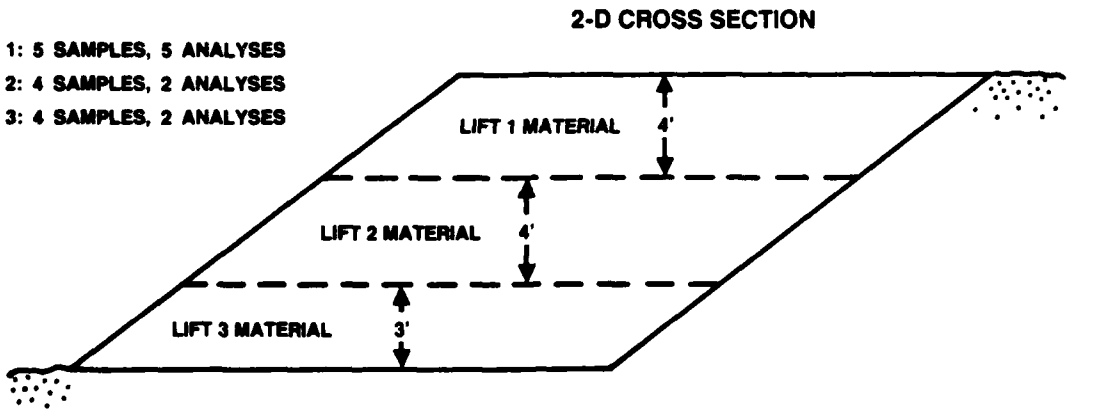


Figure II.4-2. Dimensions of example dredging prism used to estimate dredging volumes.

A

LIFT 1: 5 SAMPLES, 5 ANALYSES
LIFT 2: 4 SAMPLES, 2 ANALYSES
LIFT 3: 4 SAMPLES, 2 ANALYSES



B

COMPOSITE ANALYSES:		SAMPLES USED:
LIFT 1:	A	1
	B	2
	C	3
	D	4
	E	5
LIFT 2:	F	6, 7
	G	8a/b/c, 9a/b
LIFT 3:	H	10, 11
	I	12a/b, 13a/b/c

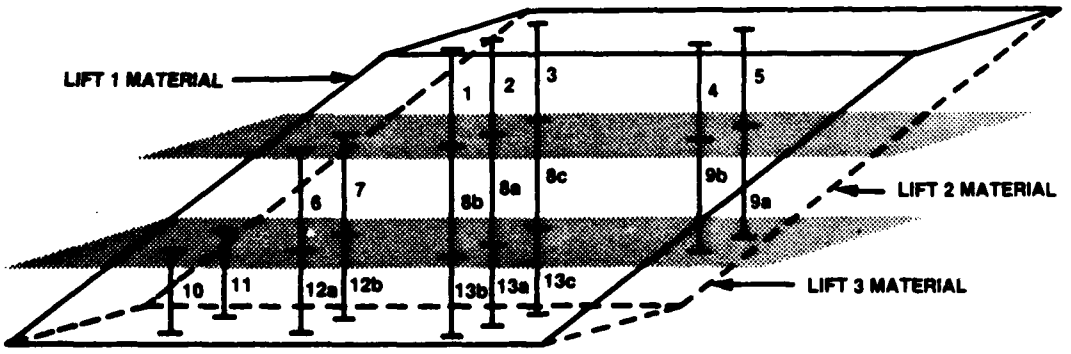


Figure II.4-3. *Example of (A) vertical lifts in dredging prism, and (B) allocations of samples among lifts.*

Step 5. Define Dredged Material Management Units. The nine analyses determined in Step 3 allow nine management units (see section II-4.1). The management units must be defined according to the dredging plan, in this case allocated among the three lifts. A dredging area ranked "high" should have no more than 4,000 c.y. of surface material represented by a single analysis (table II.4-1). Hence, the first lift of material (figure II.4-3b) represents 4-5 of the analyses:

$$\frac{\left[\begin{array}{l}\text{4' cut x 20' width x 6000' length} \\ \text{27 c.f./c.y. conversion factor}\end{array}\right]}{\text{4,000 c.y. maximum volume characterized by a single analysis}}$$

The two remaining lifts are similar in their relative distribution of surface and subsurface material (figure II.4-3b) and would likely warrant similar treatment. Therefore, it is appropriate to assign five analyses (composites A-E in figure II.4-3b) to the surface lift, and the remaining four analyses (composites F-I figure 11.4-3b) can be allocated between the surface (slope) and subsurface material of the two lower lifts. The two lower lifts could have one analysis each for the material on the slope of the dredging prism, and a second analysis for the subsurface material in each lift.

Step. 6: Allocate the Calculated Number of Samples. The distribution of samples among lifts is shown in three dimensions in figure II.4-3b. The 13 required samples (samples 1, 2, 3, 4, 5, 6, 7, 8a, 9a, 10, 11, 12a, and 13a) can be allocated to each of the lifts as follows:

- 5 samples to the surface lift (samples 1-5)
- 4 samples to the surface (slope) material of the lower two lifts (samples 6, 7, 10, 11)
- 4 samples to the subsurface material of the lower two lifts (samples 8a, 9a, 12a, 13a).

This sample allocation directly reflects the degree of potential concern for surface and subsurface material as built into the volumes based on sampling and analysis guidelines.

Step 7. Determine Compositing Plan. Compositing is not required for the surface lift, as the number of samples and analyses (composites) are the same. However, the sampling stations should be located in consideration of the subsurface sampling requirements because the core samples can be segmented to represent the different lifts. An appropriate, nonrandom field sampling plan for this case study is shown in 3-dimension in figure II.4-3b, and in

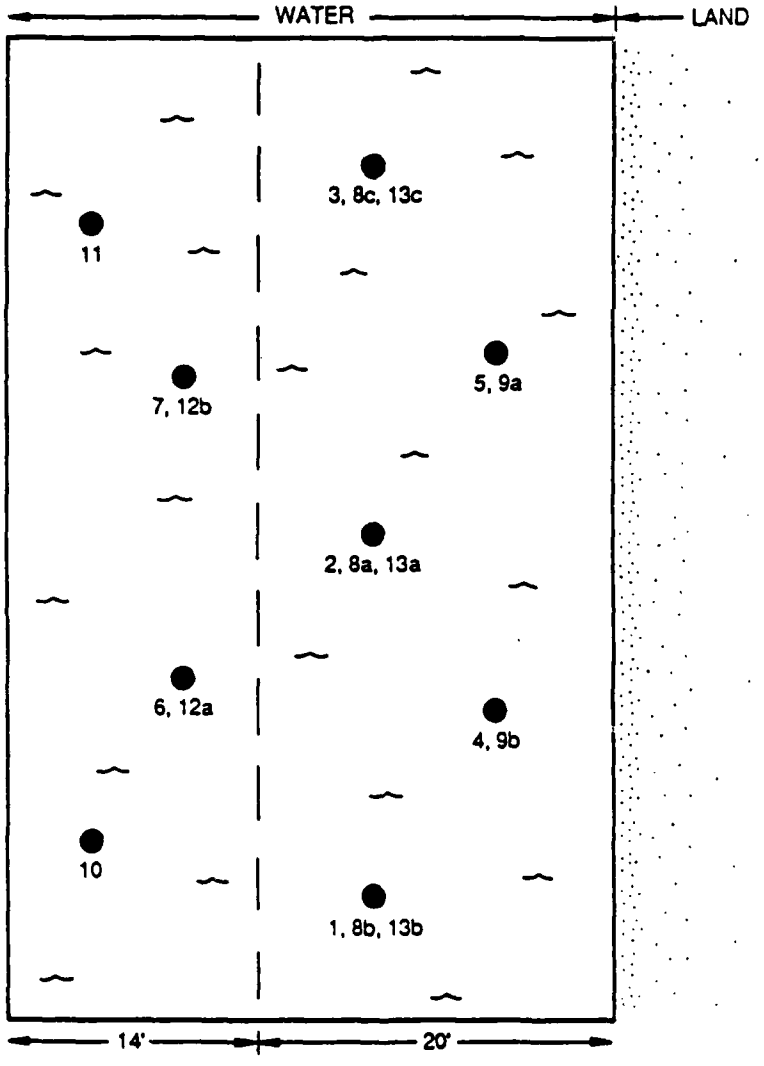


Figure II.4-4. Plan view of sampling stations in dredging prism.

plan view in figure II.4-4. The sampling plan results in nine coring stations. Optional samples 8b, 8c, 9b, 12b, 13b, and 13c can result incidentally when the coring device is used to gather material from a higher lift (e.g., samples 2, 3, 5, and 7). The inclusion of these optional samples in the appropriate composite for each lift would improve the representation of the dredging prism, and would not increase analytical costs.

4.5 Sample Storage, Archiving, and Management.

4.5.1 Storage and Archiving of Sediment for Chemical Tests. Storage and archiving procedures for sediments are summarized in "Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound," prepared for PSEP (Tetra Tech 19861). Sediment samples for chemical analyses should be stored in appropriate containers (e.g., solvent-cleaned glass jars for organic analyses), and stored in the dark at 4 degrees C for a maximum of 2 weeks. Freezing of samples at -20 degrees C is recommended to further retard chemical changes, and is required for samples stored longer than 2 weeks. The effects of long-term freezing at -20 degrees C have not been determined for all chemicals, but frozen storage for up to 1 year has been accepted for Puget Sound investigations (metals and some organic chemicals have been shown to be stable for much longer time periods).

4.5.2 Storage and Archiving of Sediment for Biological Tests. It is recommended that archived sediment samples for biological testing be stored for no more than 6 weeks. These samples should be stored at 4 degrees C and sealed with a nitrogen gas layer above the sediment surface. Without a nitrogen atmosphere, some significant changes in the toxicity of samples have been documented for samples stored for 4 to 6 weeks. Studies at the EPA Environmental Research Laboratory at Narragansett, Rhode Island (Rubenstein, N., June 1986, personal communication) suggest that a nitrogen atmosphere in the sample storage container preserves the quality of the sample over this time period.

Storage under nitrogen for more than 6 weeks, while discouraged, will be acceptable pending more definitive information concerning the effects of storage on bioassay results. Freezing of sediment prior to biological tests is not allowed because toxicity responses may increase (or sometimes decrease). A likely explanation is that freezing alters the physical structure of the sediment, which may directly affect toxicity or the bioavailability of chemicals of concern. An increase in toxicity over time was found in 20-week studies conducted at the Corps Waterways Experiment Station with sediment samples stored at room temperature, 4 degrees C without nitrogen, and at freezing temperature (Dillon, T., June 1986, personal communication).

Storage procedures specified by PSDDA differ from those recommended by the PSEP protocols (see section II-5.2.2).

4.6 Other Issues. Several additional issues related to sampling were addressed, including the following:

- Dilution of material containing high chemical concentrations with material containing low concentrations -- this practice is acceptable within a management unit (by definition the smallest volume of material requiring separate analysis) because it is an artifact of compositing. However, dilution of sediment chemicals by combining management units is unacceptable because it is counter to the concept of a management unit (see section I.6 discussion of mixing).

- Subsamples for later analysis -- a subsample from cores collected at a proposed dredging site should be archived for later analysis as indicated by the results for overlying sediments. Visibly different sediment layers within a core section should be discretely archived for possible later analysis. The results of such analyses could influence the dredging plan.

- Compositing plans -- compositing of several samples from a single management unit potentially compensates for the variabliltiy of chemical distribution within the sediments. Compositing plans are needed for approval by regulatory agencies prior to sampling. Some projects, especially smaller ones, can be efficiently sampled before compositing is considered. This sampling allows visual observations to influence compositing and dredging plans. Prior arrangements with the regulatory agencies are needed for this option.

- Documentation -- each core should be photographed after the core liner has been split open for sampling. Adjustments to the compositing plan, which must keep within the required sampling intensity of the approved plan, are necessary and encouraged, with appropriate documentation.

- Push core sampling -- projects that use unlined push cores, often used with small projects and shallow cut depths, rely on extrusion of the sample from the core. Push cores prevent easy photo documentation of softer sediments, although lenses within the cores may still be subsampled. Despite limitations, these sampling devices are considered acceptable.

- Grab sampling -- such sampling is not preferred, but may be appropriate when large volumes of sediment must be collected from the surface management unit, or when the dredge cut is shallow (e.g., less than 2 feet).

- Sample tracking -- PSEP protocols for sample tracking and auditing are required (Tetra Tech 1986). Proper chain-of-custody procedures enable

the possession of samples to be traced from collection to final disposition. Documents needed to maintain proper chain-of-custody include field logbook, sample labels, chain-of-custody records, and custody seals (only needed when the data may be used in court proceedings). The minimum information required in a sample tracking log includes sample identification number, location and condition of storage, date and time of each removal of and return to storage, signature of the person removing and returning the sample, reason for removing from storage, and final disposition of the sample.

5. SAMPLING AND TESTING SEQUENCE

When the assessment of available information indicates the need for further sampling and analysis, a cost-effective sequence of actions is necessary. The sequence for sampling actions is summarized in section 5.1. The testing sequence is summarized in section 5.2.

5.1 Sampling Sequence. Biological testing of sediment will be required only if the chemical concentrations lies within a certain range (see section II-2.4; II-7.3, and II-7.4). There are three sampling choices for the dredging applicant:

1. Collect sufficient sediment for all chemical and biological tests potentially required and run these tests concurrently.

2. Collect sufficient sediment as above, but archive some material pending the results of the chemical analyses.

3. Collect only enough sediment to conduct the chemical analyses and, if biological testing is required, resample the site.

The sampling strategy may be selected by the dredger with appropriate coordination with the PSDDA agencies. The first alternative is the least time consuming, and is likely the most cost-effective when the need for biological testing is expected. Because alternatives 1 and 2 provide chemical and biological data on subsamples of one sediment, their use is encouraged because additional information will be gained concerning the relationship between sediment chemistry and biological effects. This information will be useful to expand the sediment quality data base for future Puget Sound-wide needs (see section II-14.3). These alternatives also preclude additional mobilization and demobilization costs that would be required for resampling efforts. For the alternatives 2 and 3, the procedures balance the cost consequences of each option. For alternative 2, storage procedures for sediments to be used in biological testing are recommended (see section II.4.5.2) to allow chemical tests to be completed first. For alternative 3, biological testing of sediments resampled at the same stations without reanalysis of the sediment chemistry is allowed.

5.2 Testing Sequence.

5.2.1 Chemical and Biological Testing of Marine Sediments. After samples have been collected, the following testing sequence is begun:

Tier 2: Bulk chemical analyses

Tier 3: Acute toxicity bioassays
Bioaccumulation analyses

When existing data are inadequate, chemical tests (see section II-7) are the first tier of testing (tier 2) in the overall assessment, unless the dredger opts to pursue biological testing directly (see section II-2.5). Biological tests (see section II-6) comprise the second tier of testing for dredged material, but are conducted over a relatively wide range of chemical concentrations. Dredged material with intermediate chemical concentrations constitutes a chemical "gray zone" that must be interpreted using biological tests. Results of these second tier tests, rather than the chemical tests, determine the acceptability of such dredged material for unconfined, open-water disposal.

To reduce testing costs, chemical-specific sediment quality values are used as broad screening tools for identifying when biological testing is necessary to make a disposal decision. Only at low chemical concentrations can these values indicate when dredged materials are clearly acceptable and clearly unacceptable without further biological testing. At very high concentrations (i.e., above the ML), there is reason to believe that the dredged material is unacceptable for unconfined, open-water disposal. The dredger has the option of accepting the indications of the chemical maximum levels, or of conducting additional biological testing (see section II-2.5).

5.2.2 Protocols. Sampling and testing protocols to be used with the PSDDA evaluation procedures are generally those recommended by PSEP in their "Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound" (Tetra Tech, 1986). When available, and wherever possible, the standard PSEP protocols will be required for dredged material sampling and testing. Those exceptions to the standard protocols are summarized here.

Several of the tests required by the PSDDA evaluation procedures are not currently addressed in the PSEP protocols (e.g., measurements of ammonia in sediment, Macoma bioaccumulation exposures, juvenile bivalve acute toxicity testing, water column larval tests, etc.). For some of these measurements, other available protocols were specified (e.g., for ammonia and water column larval tests). The remaining tests are relatively simple to conduct and can be done by adapting existing protocols and using available lab experience (e.g., juvenile bivalve testing, Macoma exposures).

Several modifications to the PSEP protocols are needed in order to adapt them to dredged material assessments. These are noted below.

The PSEP protocols specify a hydrofluoric acid/aqua regia digest for metals analysis in sediments, a total acid digest that is a relatively thorough extraction of sediment metals. Additional comparisons are recommended between the two digest techniques to assess whether sediment metals data derived from this digest will be fully comparable to the screening and maximum levels derived from past Puget Sound data.

Two modifications of the sediment toxicity bivalve larvae test are specified. First, to allow chemical tests to be conducted prior to biological tests (tiering), sediment storage will be allowed beyond the-PSEP recommended limit (2 weeks in the PSEP protocol) (see section II-4.5.2 for storage requirements specified by PSDDA). Second, dissolved oxygen (DO) in the larval test medium will not be allowed to drop below 4 ppm during the test (as recommended by EPA/Corps national protocol guidance). If a DO drop below 4 ppm is anticipated (or detected during the test), aeration of the test is specified, though care must be taken not to over agitate the medium and further resuspend sediment particles. In these cases, reference and control samples should also be aerated.

To ensure comparability with the larval test, the embryo test should be conducted with sediment present in the test chamber. This modification of the PSEP protocol is necessary to ensure complete exposure of test species.

Finally, Microtox tests conducted pursuant to the PSDDA evaluation procedures should use the PSEP protocol for the saline extract method. Though the PSEP protocols slightly discourage widespread use of this extract pending further developmental work with the test, recent studies (in Puget Sound and San Francisco Bay) suggest that the saline extract method is perferred over the organic extract method when comparing the Microtox test to other lab and field biological indicators. This is thought to be in part due to the saline extract better representing the bioavailable fraction of sediment chemicals of concern.

5.2.3 Data Verification. Verification of test results is an important part of the agency review process for dredging permit applications. Data verification assures that the data provided with these applications are technically appropriate. Verification procedures will be included in the user manual for implementing the PSDDA plan (see MPTA). These procedures will address the extent to which data can deviate from optimal standards and still be considered acceptable. Application of the procedures will enable managers (e.g., environmental officers, permit officers) to determine the relevance of data, including whether the data were generated using specified methods and whether the results reported are within acceptable limits. The development of data verification procedures requires application of experienced professional judgment and review.

5.2.4 Partial Characterization. For relatively large projects the dredger may elect to perform partial characterization (PC) of sediments contained in the proposed dredging area if the dredger is of the opinion that the project area is over ranked. The partial characterization is based on chemical analysis of a limited number of samples. If this analysis indicates that the area has been over ranked, then down ranking is possible for full characterization which may substantially reduce the overall cost of sampling and testing.

Full characterization (FC) of dredged material includes sampling, compositing and testing as a basis for regulatory decisions on the acceptability of the material for unconfined, open-water disposal. FC guidelines are presented in section II-4.3.2.

Various areas of central Puget Sound have been ranked for purposes of FC on the basis of known or potential sources of chemicals of concern (see table II.3-1). Specific areas that have been ranked are classified in table II.3-2 as high, moderate, or low-moderate. No dredging area in central Puget Sound, at this time, has been given a low ranking.

PSDDA agencies have agreed that it is appropriate to allow dredgers to perform partial characterization as a means of acquiring information which may allow classifying a specific project lying within the ranked area lower than the overall area ranking. Without PC, project FC sampling and analysis would be based on the area ranking and accomplished in accordance with table II.4-2. Project rankings via PC will be based on sediment chemistry data. If PC data for a given sampling station indicates a need for upranking, then the regulatory agencies may uprank the area in the vicinity of that station and FC will be conducted in this limited area on the basis of the upranking.

The PC is intended to be accomplished at relatively low cost but provide a reasonable level of confidence in support of a project reranking decision by the appropriate regulatory agencies (Corps, Ecology, EPA).

Criteria for PC Guidelines:

- o Simple and straightforward
- o Adequate environmental protection
- o Provide opportunity for relatively low-cost initial sampling and analysis that may yield substantial cost savings

5.2.5 Partial Characterization Guidelines. The PC guidelines that are presented below are appropriate to most dredging projects. However, because of anomalies that may exist at a given project, regulatory agencies may depart from these guidelines if conditions so warrant, e.g., complex chemical source environment, ambiguous and/or highly variable characterization data, etc. As with all aspects of the PSDDA dredged material evaluation procedures, professional judgment will be an important factor in the decisionmaking process.

o PC sampling station delineation must be approved in advance by the regulatory agencies.

o Except, as noted below, PC is not a substitute for FC but only a means for establishing a "reason to believe" that a lower level of ranking is appropriate.

o PC data (for a given sampling station) may also be used as FC data for characterization of the upper 4 feet of the dredging prism (surface sediments). However, PC data can not be used for FC for depths below 4 feet (subsurface sediments). If the dredger wants the option of using PC data in FC of subsurface sediments, then FC protocols (i.e., vibra core sampling) are required.

o Dredger may also be required to perform subsurface sampling and analysis during PC if there is reason to believe that subsurface sediments have a lower quality than sediments in the upper 4 feet of the dredging prism.

o For the option of lowering the ranking one level, the number of PC samples would be 10 percent of FC minimum surface sample requirements (see EPTA, table II.4-2), e.g., for a 100,000 c.y. project (all surface sediments) located in a high ranked area the required number of PC samples would be 100,000 divided by 4,000 multiplied by .10 or say 3 samples (2.5 rounded up). In no case would less than two samples be taken. All samples would be analyzed for all chemicals of concern.

o For the option of two levels of downranking, the number of PC samples will be 20 percent of FC minimum sample requirements, but no less than three for a project.

o The dredger would have the option of performing a PC on subareas of the dredging project as long as those subareas were selected with the approval of the appropriate regulatory agencies. A minimum of two samples would be required for each subarea.

o The project (or subarea) will be ranked on a "worst case" basis, i.e., the sample having the highest level of a chemical of concern will be the basis for the ranking. No compositing will be allowed.

o Rankings based on PC data will be as follows:

High - Any chemical of concern > ML (see table II.11-2 for maximum level (ML) and screening level (SL) values).

Moderate - One or more chemicals of concern > (SL + ML)/2 and < ML

Low-moderate - One or more chemicals of concern > SL and < (SL + ML)/2

Low - All chemicals of concern below SL

o PC may also be used as a reason to believe test regarding the presence of chemicals of concern. Some chemicals may be deleted from FC if not detected by PC and are not known to be available from nearby sources.

6. BIOLOGICAL TESTING

6.1 Biological Testing Issues. At the beginning of the PSDDA study, a number of issues were discussed by EPWG concerning biological testing in the aquatic environment. These included:

- o Should reference sediments be used in interpreting biological tests?
- o What are appropriate reference areas for biological tests?
- o For acute tests, what species are appropriate?
- o Should species of commercial, recreational, or ecological importance be selected for acute tests?
- o What life stage of the organism (i.e., eggs, larvae, juvenile, adult) should be used in acute tests to ensure an appropriate level of sensitivity?
- o Should single or multiple species be used in acute tests?
- o Should only demonstrated acute tests be used, with species from Puget Sound that can be cultured in the laboratory, or should development of new tests be considered?
- o Should acute tests be conducted with a specialized laboratory organism or with a field-representative species?
- o For chronic/sublethal tests, what are the significant biological indicators and associated variables?
- o In chronic/sublethal tests, should single or multiple variables be examined?
- o Are evaluation of both sediment toxicity and potential water column effects necessary on a routine basis?

Though chemical testing is conducted prior to biological testing in the test sequence, the latter is addressed first in this portion of the text. This is because the evaluation procedures were developed to avoid unacceptable adverse biological effects, and initially defined what is acceptable in terms of biological test results. Chemical tests were considered as a subsequent step in developing the procedures.

Discussion of the reference area issue is presented in section II-6.2. Resolution of many of the acute testing issues was accomplished by a series of workshops sponsored by PSEP. The resulting acute protocols are described in section II-6.3. In these bioassays, laboratory survival of sensitive species is used as a proxy for the many other kinds of effects that are of potential concern with dredged material disposal. Chronic/sublethal testing issues (sections II-6.4 and II-6.5) were addressed in a report developed by the National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration (NOAA) for EPWG (exhibit E.22) and by additional follow-up work by EPWG. Alterations in biological testing protocols needed for freshwater sediments and soils are summarized in section II-6.6. A summary of recommendations concerning additional issues (e.g., reduced biological testing requirements for small projects and biological tests on "anomalous" sediments) is presented in section II-6.7.

6.2 Biological Testing Reference Areas. For all biological tests, both a control and a reference sediment will be included. Sediment from designated reference bays will be used as the reference sediments in biological testing for both Section 404 and Section 401 evaluations. The primary reason for this is to provide consistency in reference test results and interpretation (both within a site over time and between different sites within the Phase I area). In addition, the reference sites provide a range of sediment grain sizes that allow a match to the dredged material grain size in the biological tests.

Biological testing reference areas identified by EPWG are isolated from contaminant discharge sources, contain few chemicals of concern and at very low concentrations, and support healthy and abundant biological communities.

EPWG has developed a list of recommended sites for the collection of reference material for use in biological tests (table II.6-1). The list includes data on grain size, percent solids, and total organic carbon for six reference areas that have low or undetected concentrations of the chemicals of concern (four potential reference areas are also listed). The list is intended to provide guidance on where to collect reference sediment that is most acceptable for the dredged material being tested. Reference sediments for biological testing would correspond to the grain size distribution of dredged material samples to control for natural factors that may affect the tests.

In matching sediments to grain size from the reference areas, the reference sediments can further serve as a "control" for the physical effects of grain size on the test organisms. The testing of reference area sediments can also account for "background" effects (e.g., from low levels of chemicals or natural organic enrichment and sulfides) that may be expected even in areas that are remote from sources of chemical concentrations (especially in fine-grained reference sediments). Sediments used as controls in bioassay tests are typically native, coarse-grained sediments and serve as a consistent check on laboratory performance. These control samples are not substitutes for reference area sediments.

The sensitivity of the proposed bioassay species to fine-grained sediments and chemical constituents associated with fine-grained sediments (e.g., sulfides) strongly suggests that a sedimentologically-similar reference sediment is needed to avoid unnecessary "failure" of the dredged material. When assessing dredged material that is relatively coarse-grained, the option to rely solely on the control sediments is acceptable.

When the mortality rate in sediments from reference areas is unusually high in acute bioassay tests (i.e., much greater than in control samples) additional action is necessary. The performance standard for reference area samples is not more than 20 percent absolute mortality over control, although reference area mortality is often less than 10 percent (the performance standard for laboratory control samples). When mortality exceeds 20 percent over control for a reference sediment, the dredger must rerun the bioassay with a new sediment sample from a reference area. This ensures that dredged material testing results are compared with reference results on a consistent basis among projects.

6.3 Acute Testing Protocols. The biological testing requirements were designed to address possible sediment toxicity and the potential for adverse water column effects, as necessary. Multiple acute/lethal or acute/sublethal biological tests have been recommended to provide phylogenetic diversity that might address the different sensitivities of various taxa to a range of chemicals. The recommended acute tests are available, have been used in past studies, are sensitive to a range of containing chemicals of concern sediments, are accepted as measures of potential environmental toxicity, and have interpretable endpoints (e.g., organism mortality for acute/lethal tests, organism abnormality for acute/sublethal).

Sediment bioassay protocols were the subject of the PSEP report "Recommended Protocols for Conducting Laboratory Bioassays on Puget Sound Sediments." The report is summarized in exhibit E-11 of the Technical Appendix and appears in full in "Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound." Those areas where PSDDA differs from the PSEP protocols (or where standard protocols are lacking) are noted below.

TABLE II.6-1. SUGGESTED REFERENCE SITES FOR COLLECTION OF REFERENCE SEDIMENTS FOR BIOLOGICAL TESTING

Location	Silt (%)	Clay (%)	Total Volatile Solids (%)	Total Organic Carbon (%)
Carr Inlet	12.9	1.1	0.97	0.31
Samish Bay	58.9	24.6	6.5	1.5
Dabob Bay	24.9	20.8	7.6	1.8
Sequim Bay	44.2	33.3	10.2	2.2
Hood Canal (a)			NA(b)	NA
Nisqually Delta (c)			NA	NA

(a) Representative phi size of 3.4 has been reported for Hood Canal. Data taken from Crecelius et al. (1975), Environ. Sci. & Technol. 9:325-333. Location of the sampling site was 47o 54' 50" and 122o 37' 56". Other locations within Hood Canal having both sand and mud substrate are also identified in the publication.

(b) NA = Data not available.

(c) The delta is reported to be predominantly sand, per data from Crecelius et al. (1975), Environ. Sci. & Technol. 9:325-333. Location of the sampling site was 47o 06' 06" and 122o 42' 06".

NOTE: Other areas that have been used as reference areas include Port Madison, Port Susan, West Beach, and Bowman Bay.

Acute biological tests for dredged material assessments include several bioassay tests (10-day amphipod, 10-day juvenile bivalve, and the 15-minute Microtox bioassays, and either a 2-day oyster larvae, a 2-day echinoderm embryo, or a 2-day mussel larvae bioassay to assess potential sediment toxicity). In addition, when sediment chemical concentrations is sufficient to warrant concern for water column effects during dredged material disposal, a 4-day oyster larvae test would be conducted. These tests are described below:

- Amphipod sediment bioassay - the amphipod Rhepoxynius abronius is exposed to the test sediment for 10 days, after which the surviving amphipods are counted. A secondary (sublethal) response criterion, daily emergence of amphipods from the sediment, is not recommended by EPWG for decisionmaking use. Because there is evidence that sediment grain size may influence the results of this test, reference sediments should be similar in grain size to test sediments. The PSEP recommended protocol is used for the amphipod test.

- Juvenile bivalve bioassay - juvenile clams are exposed to test sediment for 10 days after which the surviving individuals are counted. The juvenile bivalve test can be conducted using any one of three species of filter-feeding clams found in Puget Sound: the geoduck (Panopea generosa), the giant pacific oyster/Japanese oyster (Crassostrea pacifica), or the native littleneck (Prototheca staminea). Though all three are commonly consumed by humans, the preferred test species at this time is the geoduck clam. The geoduck is available in local culture and is also an important component of the benthos at the PSDDA disposal sites. Further, it has been applied to two recent dredging projects and has been used to evaluate a range of Puget Sound sediment types. However, there is need for further experience with all three species before a firm recommendation can be made on the best test animal. Through standardized protocols for the juvenile bivalve test are not yet available, the test can be run by adapting and utilizing available method guidance (e.g., EPA/Corps 103 implementation manual, 1977).

- Bivalve larvae bioassay - during the first 48 hours of embryonic development, fertilized giant Pacific oyster (Crassostrea gigas)1/ or blue mussel (also known as "Bay Mussel and edible mussel") (Mytilus edulis) eggs normally develop into free-swimming, fully shelled larvae (Prodissoconch I). In the presence of test sediment, egg mortality (i.e., lethal effect) or the proportion of larvae developing abnormally (i.e., sublethal effect) are used as toxicity indicators. Protocols recommended for the bivalve larvae test are modified from those recommended by PSEP (see section II-5.2.2). The species can be used

1/Also known as the "Japanese oyster" (R. T. Abbot, 1968. Seashells of North America. Golden Press, New York).

either as an indicator of potential sediment toxicity (per Section 401 reviews) and/or to assess potential water column effects of dredged material disposal (per Section 404 evaluations). For the water column larval test, a separate oyster larvae test procedure is used (also described below).

- Echinoderm embryo bioassay - as an alternative to the bivalve larvae test, the echinoderm embryo bioassay may also be applicable to marine sediment testing, allowing a wider range of life-cycle testing for this group of organisms. The echinoderm embryo bioassay assesses mortality and abnormalities of sea urchin (Strongylocentrotus purpuratus) embryos exposed to toxicants over a 48- to 96-hour period. To be consistent with the bivalve larvae bioassay, it is recommended that the echinoderm embryo bioassay be conducted with sediment included in each test chamber. As with the bivalve larvae, the recommended protocol for the echinoderm embryo bioassay is a modified version of the PSEP recommendations (see section II-5.2.2).

- Microtox bioassay - the lumminescence of the bacterium Photobacterium phosphoreum is a product of its electron transport system and thus directly reflects the metabolic state of the cell. Decreased luminescence following exposure to an extract of the test sediment provides a quantitative measure of toxicity. The toxicity endpoint is the concentration causing a 50 percent reduction in light emission after a 15-minute exposure [i.e., 15-min Effective Concentration - 50 percent (EC50)]. The assay was developed for use in freshwater habitats to assess the toxicity of waterborne pollutants (Bulich et al. 1981) and has been adapted for use in the marine environment to assess toxicity of organic or saline sediment extracts (Schiewe et al. 1985; Williams et al. 1966). Recent concordance data suggests a preference for use of the saline extract when applying the test to dredged material (see section II-5.2.2). The Microtox bioassay is only required for Section 401 reviews.

When using the oyster larvae, mussel larvae or echinoderm embryo as a sediment toxicity test (per Section 401 requirements) the procedures described in the PSEP protocols should be used. The protocols utilize a test chamber with 20 g (wet weight) of sediment (dredged material) placed in 1L of seawater (about one part sediment to 50 parts water). The exposure period is 48 hours. For dredged material tests, dissolved oxygen in the test medium should be monitored and kept above 4 ppm during the test. If necessary, mild aeration should be used, though agitation of settled sediment should be avoided.

When aeration is needed, control and reference samples should also be aerated. For the sediment toxicity larval or embryo tests, a control sediment, a reference sediment, and a control seawater exposure should be run.

When water column effects are of concern (pursuant to Section 404(b)(1) evaluations), the oyster larvae can be used in a 96-hour suspended-phase bioassay as detailed in the EPA/Corps implementation manual for ocean disposal evaluation (EPA/Corps 1977). A source medium is prepared using one part water to four parts sediment. After 1 hour of settling, two ten-fold dilutions of the suspended-phase source (1:4) are prepared, resulting in exposures of 1/10 and 1/100 of the source. As a result, the oyster larvae are exposed to suspended phase concentrations of 100 percent (1:4), 10 percent (1:40), and 1 percent (1:400) for a period of 96 hours. Control or reference sediment is not used in this, only seawater controls. Aeration to maintain dissolved oxygen above 4 ppm is used as needed.

All of the above tests have strengths and weaknesses with respect to indicating environmental effects of sediment chemical concentrations. The amphipod test relates most directly to sediment chemical concentrations because the test organisms burrow into the sediment in each test chamber. Although the bivalve larvae test and the recommended echinoderm embryo test require that sediment be included in each test chamber, the test organisms are suspended in the water column of the test chamber. The bivalve larvae test originally was used only with sediment saline extracts to evaluate dissolved and suspended phase chemicals, but recently has been modified to include deposited sediment in the test chambers. The oyster larvae can be used to assess either sediment toxicity and/or water column effects. The saline-extract Microtox test is conducted on sediment extracts only, and therefore relates most directly to effects in the interstitial water or water column after dredged material has passed through it.

Benthic filter feeders such as juvenile bivalves provide an integration of potential effects from exposure to sediments primarily through three exposure routes: (1) direct contact with the bedded sediment, (2) ingestion of resuspended particles during feeding, and (3) passage of resuspended particles over respiratory surfaces during gas exchange. For many species (e.g., filter feeding bivalves), exposure routes (2) and (3) occur simultaneously because the feeding apparatus and respiratory surfaces perform the dual function of food gathering and gas exchange.

The organic extract Microtox test uses an extraction technique that is much more complete than would be expected under natural conditions. It therefore represents a worst-case, yet somewhat unrealistic, evaluation. Because the saline-extract Microtox test more closely approximates natural conditions than does the organic-extract test, it is the more preferred of the two tests. Results of recent studies (e.g., True and Heyward in press) support this assertion. In addition, the concordance of the saline-extract Microtox test with other environmental indicators has been demonstrated (Williams, et al. 1966).

Four of these bioassays are recommended as acute sediment toxicity indicators. The choices of the particular sediment toxicity larval bioassay and the juvenile bivalve species are at the discretion of the dredger.

6.4 Chronic/Sublethal Testing Protocols. None of the four acute test species are used to measure chronic/sublethal effects (longer term than 10 days, involving partical life-cycle testing), although the abnormality measure in the bivalve larvae and echinoderm embryo bioassays represents an indication of sublethal effects based on acute (short-term) exposure.

6.4.1 Recommended Tests. The only recommended chronic/sublethal biological test for dredged material assessment in Phase I is a bioaccumulation test using a bivalve species of the genus Macoma. The bioaccumulation test requires a chemical tissue analysis. Bioaccumulation is the overall process of biological uptake and retention of chemicals of concern obtained from food, water, contact with sediments, or any combination of exposure pathways. The Macoma spp. bioaccumulation test measures tissue residue tozicant content in the bivalve over a 30-day period. Macoma is preferred because it is a surface deposit feeder and thus is intimately associated with the sediments. Though the geoduck is another readily available test organism, it is a suspension feeder with less direct contact with sediment. In addition, Macoma has been more widely used then geoduck.

Options considered for use of bioaccumulation tests in the PSDDA evaluation procedures included:

1. use as an indicator of both human health effects and ecological effects (a common practice in many parts of the country),

2. use as an indicator of human health effects only, and

3. no role in the decisionmaking process.

EPWG chose to apply bioaccumulation data only as a human health indicator (Option 2) for several reasons:

- The chronic/sublethal ecological effects of observed body burdens are essentially unknown at present (though research is currently underway to better determine effects of tissue chemical accumulation).

- Many key chemicals of concern are metabolically altered into different forms (e.g., conversion of PAH or PCB's to oxygen-containing metabolites), thus complicating any possible thorough analytical approach.

- Despite metabolic alterations, the remaining body burdens are still available to humans consuming the containing chemicals of concern organisms.

The Clean Water Act requires consideration of possible transfer of chemicals of concern into the food web as a result of dredged material disposal. The determination of whether the material is acceptable for open-water disposal would include the potential effects of any potential food web transfer. The

TABLE II.6-2. SEDIMENT BULK CHEMISTRY TRIGGER VALUES FOR BIOACCUMULATION

Chemical	Concentrations (a)
Metals (mg/kg dry weight)	
Antimony	19
Arsenic	510
Mercury	1.5
Nickel	43
Silver	4
Organic Compounds (ug/kg dry weight)	
Benzo(a)pyrene	5,000
Fluoranthene	4,600
1,2-Dichlorobenzene	41
1,3-Dichlorobenzene	1,200 (b)
1,4-Dichlorobenzene	190
Dimethyl phthalate	1,200 (b)
Di-n-butyl phthalate	10,200 (b)
Bis(2-ethylhexyl)phthalate	13,900 (b)
Hexachloroethane	1,000
Hexachlorobutadiene	210
Phenol	880
Pentachlorophenol	1,000 (b)
Ethylbenzene	27
N-Nitrosodiphenylamine	160
Hexachlorobenzene	170
Trichloroethene	1,200
Tetrachloroethene	100
Total DDT	50
Aldrin	37 (b)
Chlordane	37b
Dieldrin	37b
Heptachlor	37b
Total PCB's	1,790

(a) Concentration = 0.7 * (ML2 - SL) + SL; When the concentration of any chemical is above this value, a bioaccumulation test must be conducted on the sediment. As a result of information received during public review of the Phase I documents, several of the SL and ML values have been updated (see table II.11-2 for current values). The older SL and ML values were used to calculate these bioaccumulation sediment guidelines, which were left unchanged pending development of additional information and annual review of the PSDDA program.

b) These chemicals do not have an ML2 value. Therefore, the concentration = [(10SL - SL) * 0.7] + SL = 7.3 * SL.

1980 testing guidance for Section 404(b)(1) evaluations stated that bioaccumulation testing need not be conducted if interpretation of test results is not possible, as is the case for ecological effects to aquatic animals. However, the food web effects of ultimate concern are those associated with human health risk of consuming containing chemicals of concern seafood. Thus, EPWG identified a list of chemicals of human health concern for use in conducting bioaccumulation tests.

Bioaccumulation tests are required only when chemical concentrations in sediments exceed the values shown in table II.6-2. The use of bioaccumulation data as an indicator of human health effects is summarized in section II-8.3.4. The rationale for how the sediment chemistry trigger values were derived for bioaccumulation is also presented in section II-8.3.4.

6.4.2 Other Chronic/Sublethal Tests. EPWG has considered a number of other options for chronic/sublethal tests that could be used in evaluating dredged material. During Phase I, PSDDA funded a study by NOAA/NMFS to develop a chronic/sublethal bioassay that could be used either with geoduck or sand dollars as the test organism (exhibit E.22). The results of this report are summarized in the following section II-6.5, and indicate that the tests investigated are not sufficiently developed for use in PSDDA. Further development of a sublethal/chronic test is being considered under PSDDA Phase II. Possible tests include a measure of intrinsic rate of population growth, or a growth bioassay (see section II-6.5). If such tests cannot be developed, it may be appropriate to consider sublethal interpretations for some of the acute bioassays, use of the anaphase aberration bioassay, or enhance ongoing development of ecological interpretations of bioaccumulation.

Pending development of an appropriate sublethal bioassay, assessments of sublethal effects of dredged material will depend on the other biological indicators already recommended as evaluation tests: abnormality in the bivalve larvae and echinoderm embryo bioassays, sublethal effects in the Microtox bioassay, and use of Apparent Effects Thresholds (AET; see section 7.2) based on benthic infaunal abundances for in situ sediments (e.g., at dredging site). While none of these indicators is adequate to independently assess the effects of concern, they combine to provide a weight of evidence that is useful in the interim in characterizing potential sublethal effects.

Although there are a variety of factors, including natural variability and nonsediment anthropogenic influences (e.g., ship passage, water quality, etc.) that can influence the condition of the bottom-community, benthic infaunal invertebrates are useful indicators of the biological effects of sediment chemical concentrations for the following major reasons:

- All species live in close contact with bottom sediments and interstitial waters
- Many species feed upon the particulate organic matter that contaminants absorb onto

- Most species are relatively stationary during most of their life cycles.

In addition, benthic infauna are important within the ecosystem because they are prey for many demersal fishes and larger invertebrates.

By contrast with laboratory sediment bioassays, benthic infaunal evaluations allow an assessment of in situ biological effects on indigenous organisms. Community analysis results represent the net influence of both chronic (e.g., reduced fecundity) and acute (e.g., mortality) effects of chemical contaminants from a variety of sources on all or most life stages of the organisms.

Many characteristics of benthic infaunal assemblages can be dependent upon the following variables:

- Season
- Depth
- Water quality
- Sediment character/quality
- Salinity
- Temperature
- Runoff
- Ship traffic
- Outfalls

To avoid confounding the effects of chemicals of concern, it is essential that comparisons with reference conditions be controlled for the influence of these natural variables. A common method of controlling for this variability is to make comparisons only among stations having the same depth and sediment characteristics and sampled during the same season (though other factors are not controlled).

Several kinds of variables may influence the characteristics of benthic assemblages, but cannot be accounted for because of their unpredictable nature. Examples include unpredictable anoxic conditions, physical disturbances (e.g., storm-induced scour, anchor dragging, etc.), and intense predation. In all of these cases, the resulting alterations of benthic assemblages could erroneously be attributed to chemical concentrations. Because it rarely is possible to control for the effects of unpredictable events, it is essential that their influence on any method used to develop sediment quality values be minimized.

It is presently unknown to what extent shallow water benthic infauna analysis results are meaningful in predicting potential effects on organisms in deeper water. As noted earlier, the characteristics of benthic infaunal assemblages vary with depth naturally. It might be surmised that because organisms in deeper water generally experience a lesser degree of variability in environmental conditions than do organisms in shallow water, the former individuals would be more sensitive to chemical concentrations. Because this supposition has not been tested, caution must be used when results are extrapolated across depth contours. If the supposition is correct, criteria based on assemblages in shallow water would be less protective of assemblages in deeper water.

6.5 Alternative Tests Considered. Biological tests considered in addressing Regional Administrative Decisions are listed in exhibit B.

6.5.1 Geoduck Acute Bioassay. The geoduck (Panope generosa) bioassay testing variables are modeled after the amphipod mortality bioassay (section II-6.3). As in the amphipod bioassay, the primary response criterion is percent survivorship after 10 days exposure to test or control sediment. Work performed by NOAA/NMFS (1986; see exhibit E.22) indicates that this bioassay is relatively insensitive to toxic chemicals that generate a response in other bioassays. The use of geoduck will be reviewed after receiving results of ongoing studies in which geoduck and other bioassays are being evaluated further.

6.5.2 Geoduck Growth Test. The geoduck growth test is a sublethal measure of marine sediment toxicity. The growth test involves monitoring toxic effects in geoducks exposed to chronic/sublethal concentrations of toxicants over a 30-day period. Recent work by NOAA/NMFS (1986; exhibit E.22) included measurements of growth (based on shell width and concentration of tissue total protein), burial behavior, concentration of tissue triglycerides, and adenylate energy charge (ADC) in juvenile geoduck and the sand dollar (Dendraster excentricus). The preliminary results do not support the use of either organism in long-term sediment bioassays because of a lack of sensitivity to sediment-associated chemicals of concern in several highly containing chemicals of concern samples. No other long-term marine sediment bioassays have undergone sufficiently rigorous testing to merit recommendation. Long-term bioassays were recommended by NOAA/NMFS as a requirement as soon as a scientifically defensible bioassay is available. In the interim, a battery of short-term tests utilizing phylogenetically diverse test species and life stages was recommended.

6.5.3 Intrinsic Rate of Population Growth. In principle, the use of an intrinsic rate of population growth (IRPG) test as part of the biological evaluation procedures is an excellent potential decisionmaking tool. This test is a measure of the instantaneous rate of population change in numbers under conditions where the population is not self-limited. The test indicates whether the population is growing at a rate comparable to reference conditions.

No species has been identified as being acceptable for application of this test in Puget Sound. Efforts to identify an acceptable species resulted in the following conclusions:

- An amphipod species (Melita nitidia) has been tested at the EPA Environmental Research Laboratory at Newport, OR. This epibenthic gammarid amphipod lives on or in detrital material and does not appear acceptable for solid phase sediment tests.

- Nematodes have been examined for use in IRPG tests by Tietjen (1984), but the species used is no longer cultured and there are few recognized experts capable of conducting such work.

- Harpacticoid copepods have been suggested as a possible culture species. A harpacticoid copepod species now in culture by the National Marine Fisheries Service takes approximately 120 days to complete a life cycle. This time period is too long to be acceptable for a routine regulatory IRPG test, although large projects may have the time to conduct the test.

- Two species of polychaetes with suitably short life cycles have been cultured at Battelle Marine Laboratories. Neither species (Ophiotrocha costlowi and Dinophilus gyrocilatus) will culture well in sediment.

- A mysid species (Mysidopsis bahia) has been demonstrated by the EPA Environmental Research Laboratory in Narragansett, RI to be amenable to short-term (less than 30 days) IRPG tests. Some uncertainty exists concerning its sensitivity because most of the tests were conducted with suspended solids rather than sediments. This species is not indigenous to Puget Sound.

At present, the IRPG test is not recommended until a more acceptable species can be identified. Research should test M. bahia and an acceptable local species, if one can be found. After reviewing possible sublethal tests, use of surrogate species in routine regulatory tests in Puget Sound was not recommended. Besides the problem of availability, many of the potential surrogate test species are not adapted to survival in the cold waters of Puget Sound. Few local laboratories are equipped to conduct flow-through bioassays with warmer seawater, and the temperature change further complicates correlating the laboratory results to potential field toxicity. However, these concerns do not preclude the eventual demonstration and availability of an acceptable surrogate species.

6.6 Biological Testing of Freshwater Sediments and Soils. Biological testing and evaluation procedures require modification before application to freshwater sediments and soils. These materials, if proposed for unconfined,

open-water disposal, must be tested for their potential effects at the disposal site. The requirements for testing freshwater sediments are:

- Perform a complete chemical analysis as described in section II-6 and compare against screening level and maximum level guidelines in section II-11.

- Perform bioassays described in section II-6. Prior to conducting bioassays, the interstitial salinity will be raised to saline (i.e., greater than 28 ppt) conditions. This adjustment should be accomplished as described in PSEP protocols that call for stirring sediment in saline water (Tetra Tech 1986h; and see exhibit E). The sediment may also be aged (see section II-6.7.2) prior to the bioassays at the project proponent's option.

- Determine whether the disposal of freshwater soils results in a higher loss of chemicals of concern to the seasurface microlayer (exhibit E.10). As noted in section II-13.2, additional research to address this issue is recommended. Although biological test methods specific to freshwater environments are available, these methods would not aid in assessing the possible effects of the dredged material once it had been discharged in the marine waters of Puget Sound. Soils are different from marine sediments in that physical structures of the soil can influence effects on aquatic species. This potential additional effect is not expected to warrant a separate testing strategy.

Soils that may be included as dredged material are described in section I-2.1 (Definition of Dredged Material). The requirements for testing soils as dredged material are identical to those outlined for freshwater sediments. Additionally, an assessment of losses of material to the water column and subsequent effects is needed. If soils are used for aquatic capping, a check of the habitat condition presented by the soil cap may be necessary.

6.7 Additional Issues.

6.7.1 Reduced Testing Requirements for Small Projects. As discussed in section II-3.2, biological testing requirements are reduced for projects with planned volumes greater than the "no test" volume (see table II.3-2) and less than the sampling unit volume (see table II.6-3). Complete chemical and biological testing of a single sample according to the recommended evaluation procedures will likely exceed $2,000 to $3,000. Given the low potential for unacceptable adverse effects, this high cost is unwarranted for very small projects. Consequently, under certain circumstances, reduced testing or testing exclusions are appropriate. A single acute bioassay (i.e., amphipod mortality) is used in this testing strategy to ensure a minimum biological test of the dredged material without imposing a major cost burden on a small project.

TABLE II.6-3. REDUCED BIOLOGICAL TESTING REQUIREMENTS FOR SMALL PROJECTS ABOVE "NO TEST" VOLUME(a)

Area Rank(b)	Volume (Greater Than or Equal to)	Required Biological Tests(c)
Low	8,000 c.y.	All biological tests required(d)
Low-Moderate	500-4,000 c.y.	Single acute bioassay (amphipod)
Moderate	500-4,000 c.y.	Single acute bioassay (amphipod)
High(e)	500-4,000 c.y.	Single acute bioassay (amphipod)

(a) "No test" volumes are defined in table II.3-3.

(b) Area ranks are defined in section II-3.1.2.

(c) Chemical tests are required of all such projects. Biological tests as listed are required if chemical results indicate that the dredged material is containing chemicals of concern above the screening level (see section II-7.3).

(d) Biological tests are defined in section II-6.

(e) There is not a "no test" volume for high rank areas. For projects with less than 500 c.y. in high rank areas, the dredger will have the option to conduct either a single chemical analysis for all chemicals of concern (without the required quality assurance), or to conduct acute bioassays (amphipod and Microtox bioassays only; see section II-6) on a single sample (without companion chemical analyses, but with appropriate bioassay replicates).

Very small volumes of dredged material (less than a "management unit") individually represents relatively minor potential for unacceptable adverse effects to the disposal site according to Section 404 guidelines. Although the cumulative effects of many small projects are of conceptual concern, the cost of mobilizing large dredging equipment generally has discouraged many small projects from using the multiuser sites. As a result, very small project constitute only a small percentage of the volume disposed at the existing DNR sites over the last 15 years (Envirosphere 1986).

For high rank areas, there is not a "no test" volume. For projects with less than 500 c.y. in high rank areas, the dredger will have the option to conduct either a single chemical analysis for all chemicals of concern (without the required quality assurance), or to conduct acute bioassays (amphipod and Microtox bioassays only; see section II-6) on a single sample (without companion chemical analyses, but with appropriate bioassay replicates).

6.7.2 Biological Testing of "Anomalous" Samples. "Anomalous" samples that may require biological testing below the chemical screening level (section II-7.3) are expected to be rare. The necessary justification needed to require biological testing of these samples must be provided by the regulator based on best professional judgment. The primary factors that would be considered in this evaluation is the presence of a very unusual chemical sources in the dredging area.

For a different "anomalous" case, additional testing is required to establish that a positive bioassay response for a dredged material sample is anomalous. For example, apparently ancient sediments collected at depth have sometimes yielded positive bioassay results although the sample does not appear to contain chemicals of concern. To establish that such a bioassay result is anomalous, the following procedure is recommended:

1. Chemical and bioassay tests must be conducted on the original homogenized sample (i.e., time t=0 tests). Two separate samples should not be used. Because this procedure is recommended in the PSEP protocols, it is assumed that it will be achieved in all cases.

2. A review is conducted to ensure that few, if any, chemicals of concern barely exceed the screening level (section II-7.3).

3. A review of the chromatogram for extractable or volatile organic compounds extracted from the sample and should not reveal any unusual compounds not quantified in the analysis.

4. The sample is retested after aging under refrigeration (to enable the sample to equilibrate to present day conditions while minimizing biological degradation) for 30 days; the sample is stirred once before testing to dislodge any surface skin that may have formed. High concentrations of these chemicals may confound bioassay responses in the time t=0 test. This is especially true for the bivalve larvae and echinoderm embryo tests.

5. The PSDDA regulatory agencies must approve the test procedure, results, and conclusions.

6. A reversal of the original bioassay results requires that any difference between the original and new bioassay results be statistically significant P less than 0.05).

If it is suspected that the aging technique may be required for a particular sample, it is most cost-effective if adequate sediment for both the initial testing and the aging are collected, and the aging technique is initiated at the same time as the initial testing. If subsequent results show that aging is not needed, the aged sediment can be discarded. If the above procedure is not followed and results of the initial testing indicate that aging is required, additional sediment may need to be collected. If an additional sample must be collected, the initial testing and chemical analyses must be repeated to ensure that the initial and additional samples are comparable.

In conclusion, the recommended evaluation procedures are considered to address sublethal and chronic effects of dredged material disposal. In particular, the following actions strengthen the evaluation procedures:

- The inclusion of a benthic infaunal indicator in the development of sediment quality values has resulted in guidelines that address protection of benthic communities

- Bioassays for larval abnormality and microbial sublethal effects contribute to the assessment of chronic/sublethal effects

- The disposal siting process and the monitoring plan add an additional level of protection

Also further consideration of developing chronic/sublethal evaluation procedures will be given during PSDDA Phase II.

7. CHEMICAL TESTING

Chemical tests are used to measure the concentration of potentially toxic substances in dredged material. This testing is often conducted in concert with biological testing. Four possible uses of chemistry data in evaluating dredged material were considered:

1. No use
2. Use concentrations of chemicals in sediments to set a screening level above which biological testing would always be required.
3. Use concentrations of chemicals in sediments to set a maximum level above which the material would likely be unacceptable for unconfined, open-water disposal.
4. Use concentrations of chemicals in sediments to set both a screening level and maximum level.
5. Use concentrations of chemicals in sediments to inventory detectable chemicals of concern.

Option 4 was selected; although a dredger option to conduct biological testing is included for material above the maximum level values. Sediment quality values were used as the basis for determining acceptable screening and maximum levels of chemicals of concern in sediments for unconfined, open-water disposal (i.e., to make screening/tiering decisions discussed in sections II-7.3, II-7.4, and II-8).

7.1 Chemicals of Concern. A total of 58 individual chemicals or chemical groups of concern for dredging and disposal operations are listed in table II.7-1. An additional eight chemicals are listed in table II.7-1 that will be measured only in certain areas, or for reasons other than concern for chemical concentrations (e.g., as chemical tracers - manganese). Only a few of the chemicals of concern are already included on the Puget Sound Interim Criteria (table II.1-2), primarily because data for a wide range of chemicals of concern have only recently become available.

All of the chemicals of concern have been shown to accumulate in sediments of Puget Sound. EPA priority pollutants that have been undetected in Puget Sound sediments at reasonably low detection limits (e.g., 50 ug/kg dry weight) are not included in table II.7-1. The chemicals of concern generally have the following characteristics (Tetra Tech 1986j):

TABLE II.7-1. CHEMICALS OF CONCERN

Metals and Metalloids

Antimony	Copper	Nickel
Arsenic	Lead	Silver
Cadmium	Mercury	Zinc

Phenols and Substituted Phenols (organic acids)

phenol	2,4-dimethylphenol
2-methylphenol(a)	pentachlorophenol
4-methylphenol(a)	

Low Molecular Weight Aromatic Hydrocarbons (neutrals)

naphthalene	fluorene
2-methylnaphthalenea	phenanthrene
acenaphthylene	anthracene
acenaphthene	

High Molecular Weight PAH (neutrals)

fluoranthene	benzo(a)pyrene
pyrene	indeno(1,2,3-c,d)pyrene
benz(a)anthracene	dibenzo(a,h)anthracene
chrysene	benzo(g,h,i)perylene
benzofluoranthenes	

Chlorinated Aromatic Hydrocarbons ,neutrals)

1,2-dichlorobenzene	1,2,4-trichlorobenzene
1,3-dichlorobenzene	hexachlorobenzene (HCB)
1,4-dichlorobenzene	
Total PCBs (mono through decachlorobiphenyls)	

Chlorinated Aliphatic Hydrocarbons (neutrals)

hexachlorobutadiene	hexachloroethane

Phthalate Esters (neutrals)

dimethyl phthalate	butyl benzyl phthalate
diethyl phthalate	bis(2-ethylhexyl)phthalate
di-n-butyl phthalate	di-n-octyl phthalate

TABLE II.7-1 (Continued).

Miscellaneous oxygenated compounds (neutrals)

benzyl alcohol(a)	benzoic acid(a)
dibenzofurana	

Organonitrogen Compounds (organic bases)

N-nitrosodiphenylamine

Pesticides (neutrals)

Total DDTs (p,p')	aldrin
heptachlor	dieldrin
alpha-chlordane	gamma-HCH (lindane)

Volatile Chlorinated Hydrocarbons (neutrals)

trichloroethene	ethylbenzene
tetrachloroethene	total xylenes

Additional Chemicals to Be Measured(b)

manganese	
chromium	2-methoxyphenol (guaiacol)
trichlorobutadiene isomers	3,4,5-trichloroguaiacol
tetrachlorobutadiene isomers	4,5,6-trichloroguaiacol
pentachlorobutadiene isomers	tetrachloroguaiacol

(a) Indicates U.S. Hazardous Substance List (HSL) compound that is not also on the U.S. EPA priority pollutant list.

(b) Generally of concern in localized areas only (e.g., chromium near chrome plating industries; guaiacols only in areas adjacent to pulp mills). Chromium is recommended for analysis in all areas until additional information is acquired regarding its toxicity in reference areas that contain high levels of chromium from natural sources. Tri-, tetra-, and pentachlorobutadienes are non-priority pollutants that have been detected at highly elevated levels in certain areas of Puget Sound (e.g., Hylebos Waterway in Commencement Bay). Because standards are generally unavailable for these compounds, they are recommended for analysis only where chlorinated butadienes are suspected to have a major source (standards are available for hexachlorobutadiene). Manganese is recommended for measurement due to its potential to bioaccumulate in clams - see section II-7.1.3.

- o A demonstrated or suspected effect on ecology or human health (i.e., the focus of chemical concerns is ultimately unacceptable adverse biological effects).
- o The chemical has a widespread distribution or high concentration relative to natural conditions (i.e., one or more present or historical sources).
- o A potential for remaining toxic for a long time in the environment (biopersistent).
- o A potential to bioaccumulate and enter the food web.

Because of the potential relationship between chemicals of concern and biological effects, chemical testing for these substances can be used to relate the potential for adverse biological effects in the environment to specific contaminants. Chemical data by themselves are useful independent indicators of the potential for adverse effects because not all biological effects can be measured directly by available biological tests. Knowledge of the specific types of chemicals is also important to the management of dredged material, because different chemicals may require different controls.

The list of chemicals of concern developed by PSDDA would be specifically reviewed during the initial assessment of a project. If available data show that certain chemicals are not present in the project vicinity, these chemicals need not be included in any further testing. Where such data are not available, the "safety net" test of a composite sample can provide the necessary information on which chemicals of concern are present, for both current and near-future projects.

7.1.1 Chemicals of Concern in Limited Areas. In general, it is preferable to use a more limited list of chemicals of concern for routine analyses (i.e., for all projects), and then add chemicals to the list for individual projects that are located near specific sources of chemicals of concern that do not exhibit a wide distribution. However, few of the chemicals of concern can be reliably tied to specific geographic areas because many have widespread or multiple sources. Guaiacols, chlorinated guaiacols, and chromium were identified by EPWG as having a need to be measured, but will not have guidelines developed for screening or maximum levels in dredged materials (see sections II-7.3 and 7.4) because of the limited data base at this time. The purpose of requiring measurement of these chemicals of concern is to develop the database to the point where screening and maximum levels can be defined.

Guaiacols and chlorinated guaiacols are to be measured in areas where kraft pulp mills are located. Only guaiacols are recommended near sulfite pulp mills (chlorinated guaiacols are not expected in processes that do not involve bleaching).

Trichlorobutadiene, tetrachlorobutadiene, and pentachlorobutadiene are to be measured in areas around industries that produce chlorinated products or may have chlorinated compounds in an effluent. These three compounds are non-priority pollutants that have been detected at highly elevated levels in certain areas of Puget Sound.

Chromium appears to derive largely from the natural erosion of crustal rocks into Puget Sound, but localized sources of chromium also exist (e.g., plating industries and some chemical manufacturing facilities). Until additional data regarding the potential biological effects of chromium in Puget Sound are available, EPWG recommends that chromium be measured routinely in all dredged material testing in the Puget Sound. Sediment quality values for chromium will not be used in the PSDDA program until these additional data are acquired and evaluated.

Reduction in the routine chemicals of concern list may be considered as a future research effort (see section II-13.2), and is a possible topic for the periodic reviews of the PSDDA program.

7.1.2 Comparison with Alternative Lists of Chemicals of Concern. An initial pollutants of concern list developed for PSEP is nearly a subset of the list developed for the PSDDA program. The following chemicals are found on the PSEP list, but are not listed in table II.7-1:

- o Cyanides
- o Organotin complexes
- o Chloroform
- o 2,3,7,8-Tetrachlorodibenzo-p-dioxin.

Cyanides are a potential chemicals of concern in the environment, primarily because of potential water column effects. However, total cyanides have recently been reported in high concentration in sediments from Hylebos Waterway in Commencement Bay. EPWG recommends additional research to determine whether cyanide should be included on the chemicals of concern list for PSDDA (see section II-13.2).

Organotin complexes have not been routinely analyzed in Puget Sound. Organotin complexes are of potential concern because of their use in some paints as an antifouling agent. Potential users include the U.S. Navy shipyards, commercial painting operations, and private individuals. Data from recent studies suggest that organotins might be a problem in aquatic waters (e.g., marinas) at concentrations as low as the parts per trillion range (Unger et al. 1986). Analytical equipment is not available for routine analyses of

organotins in Puget Sound, the analytical costs are high, and interpretation of the data is controversial. Further research on the environmental distribution and potential effects of organotins in Puget Sound is recommended. Organotins are a future contaminant of concern for areas near marinas and U.S. Navy ship terminals. Disposal site baseline studies should include analysis of sediment for organotins to provide a reference for feasible future discharge of these compounds. Measurements should also be made as soon as possible in several local marinas to determine if organotins are present (see research recommendations in section II-13.2). For these reasons, research on butyltins is being conducted (with NOAA-NMFS support) during Phase II of the PSDDA study. Butyltins have been recently (1988) detected in sediments of the Sound. However, though these chemicals are recognized as highly toxic, there are no toxic stations in the Puget Sound data base that are not identified by the measurement of current sediment variables. (See section II-7.2.3.3 for a discussion of the implications of chemicals of concern that are not currently measured in dredged material.) Ongoing PSDDA studies are evaluating concerns regarding toxicity, as well as human health. As a result, future revisions to the PSDDA chemicals of concern list may include these chemicals. Interpretation guidelines would need to be developed, and methods and lab capabilities defined, once they were identified as necessary to the list.

Chloroform is of concern primarily in the water column, where it has been observed near some discharge points at concentrations that exceed EPA acute water quality criteria (e.g., Class II survey results). Chloroform has been detected at low concentration in some sediments (Tetra Tech 1985), but is not of routine concern for dredged material.

2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) is an EPA priority pollutant of national concern. It is of potential concern for dredged material, but has only recently (1988) been detected in marine sediment and biological samples from Puget Sound. Because of its only recent detection and the requirement for a costly, separate analysis from other chemicals, TCDD is not recommended for routine analysis as a chemical of concern. As with tributyltin, the decision to add TCDD to the routine chemical list will require additional study as to the distribution, effects, and bioavailability of this chemical. Further evaluation of this issue will also occur during the annual reviews of the PSDDA program. Discussion of the implications of not analyzing dredged material for these chemicals is contained in section II-7.2.3.3.

7.1.3 Other Chemicals to be Measured. Manganese is not a chemicals of concern, but is recommended for inclusion in the category of "other chemicals to be measured" because of its potential to bioaccumulate in geoduck clams, according to 1983 data collected by DNR. Conventional variables recommended for measurement are listed in section II-7.7.

7.2 Development of Sediment Quality Values. During development of the evaluation procedures, the role that chemical analyses should have in sediment testing and decisionmaking was considered at length. In most dredging programs throughout the country, sediment analysis, if done at all, is used for

informational purposes only; providing an inventory of chemicals present in the sediments to be dredged. In the Puget Sound area, however, extensive field sampling conducted over the past few years by a variety of agencies for various regulatory and management programs, has generated a comprehensive sediment chemistry/biological effects data base. This data base, compiled as part of a PSDDA/PSEP project to develop sediment quality values for Puget Sound (Tetra Tech, 1986; exhibit E.9), contains information on sediments collected throughout Puget Sound. The urban/industrial waterways are represented, as are "clean" reference areas (nonurban/nonindustrial) and most of the major dredging areas in the central part of the estuary.

7.2.1 Use of the Puget Sound Sediment Quality Data Base. Information currently contained in the Puget Sound data base represents over 190 stations, sediment chemical analyses on 71 chemicals, information on a variety of conventional sediment parameters, and the results of multiple species bioassays. The bioassays (which varied among stations within the data base) include an amphipod test, an oyster larval test, and a Microtox test, many of the same biological tests recommended for dredged material evaluation by PSDDA. Also included in the data base are information about the health of the benthic community present at many stations where sediment samples were taken for chemical analysis and bioassay evaluation.

In developing the PSDDA guidelines, evaluation of the Puget Sound data base was valuable in revealing general observations about biological effects associated with specific levels of sediment chemical concentrations; however, it is important to note that conditions observed in sediments taken from urban waterways will not necessarily be duplicated if the same sediment is discharged at a deepwater site in Puget Sound. Extrapolation from site-specific correlations between sediment chemistry and biological effects, to predicted effects at the disposal site is especially uncertain when using empirical data generated from nondisposal areas. However, because the toxicity of dredged material is a principal factor in determining acceptability of sediment for unconfined openwater disposal, consideration of sediment bioassay results was important in developing guidelines for use in evaluating the relative potential toxicity of dredged material. Although there are a variety of factors, including natural variability and nonsediment anthropogenic influences (e.g., ship passage, water quality, etc.) that can influence the condition of the bottom-dwelling community, the incorporation of benthic community data was also justified. The decision to consider benthic effects information during development of the PSDDA disposal guidelines was based on evidence that community structure does have a relationship to degree of chemical concentrations (and other factors - see section II-6.42) and, more importantly, the belief that inclusion of the data would provide some degree of protection against unacceptable adverse impacts unaccounted for by single species bioassays or limited chemical analyses.

Analysis of the Puget Sound data base yielded several findings that were important to the role that consideration of sediment chemistry would have in the PSDDA dredged material evaluation process. First, evaluation of the data base indicated that sediment chemistry can be used for more than just providing general information about an individual sediment sample. Although the data do not elucidate cause and effect relationships, they do provide empirical observations of biological impacts associated with certain levels of chemicals. When properly analyzed, the Puget Sound data can be interpreted to reveal general conclusions about the concentrations of specific chemicals present in sediment and the biological effects associated with the same sediment. The three most significant conclusions are presented below:

(1) Data analysis indicated that most of the chemicals measured were found to co-occur in the majority of the Puget Sound sediment samples tested. Most samples contained the same suite of chemicals, although the concentrations at which the chemicals were found varied widely. The data sets compiled in the data base were derived from multiple studies using various techniques, thus somewhat limiting rigorous comparison of the data. However, the data base contains information for individual chemicals measured at wide range of concentrations, at a large number of stations representing a variety of locations and conditions. PSDDA assumed that the data base could be treated, not as a series of unassociated data on sediment, but rather as a range of contaminant concentrations representative of the entire Puget Sound area.

(2) Further evaluation of the chemical concentration/biological effects data indicates that there was an identifiable concentration level in sediments for individual chemicals below which unacceptable adverse biological effects were never observed, even in the presence of other chemicals having varying concentrations. Conversely, analysis of the data base also indicated that there was an identifiable level of sediment chemistry above which adverse biological effects were always evident (e.g., all bilogical indicators used showed significant effects) at all stations with such concentrations in the database, even in the presence of other chemicals having varying levels of concentrations.

(3) Finally, and most importantly, analysis of the database indicated that there is a wide range of sediment chemical concentrations between the no effects level and the level at which significant adverse effects were always observed. At stations with chemical concentrations in this middle range, often at least one, but not all, of the biological indicators exhibited adverse effects. For the mid-range concentrations sediment chemistry alone did not appear to be a reliable indicator of sediment quality and represented a "gray" area in which sediment-specific biological testing would have to be conducted in order to determine the quality of a sediment relative to its potential impact (e.g., toxicity) to the ecosystem.

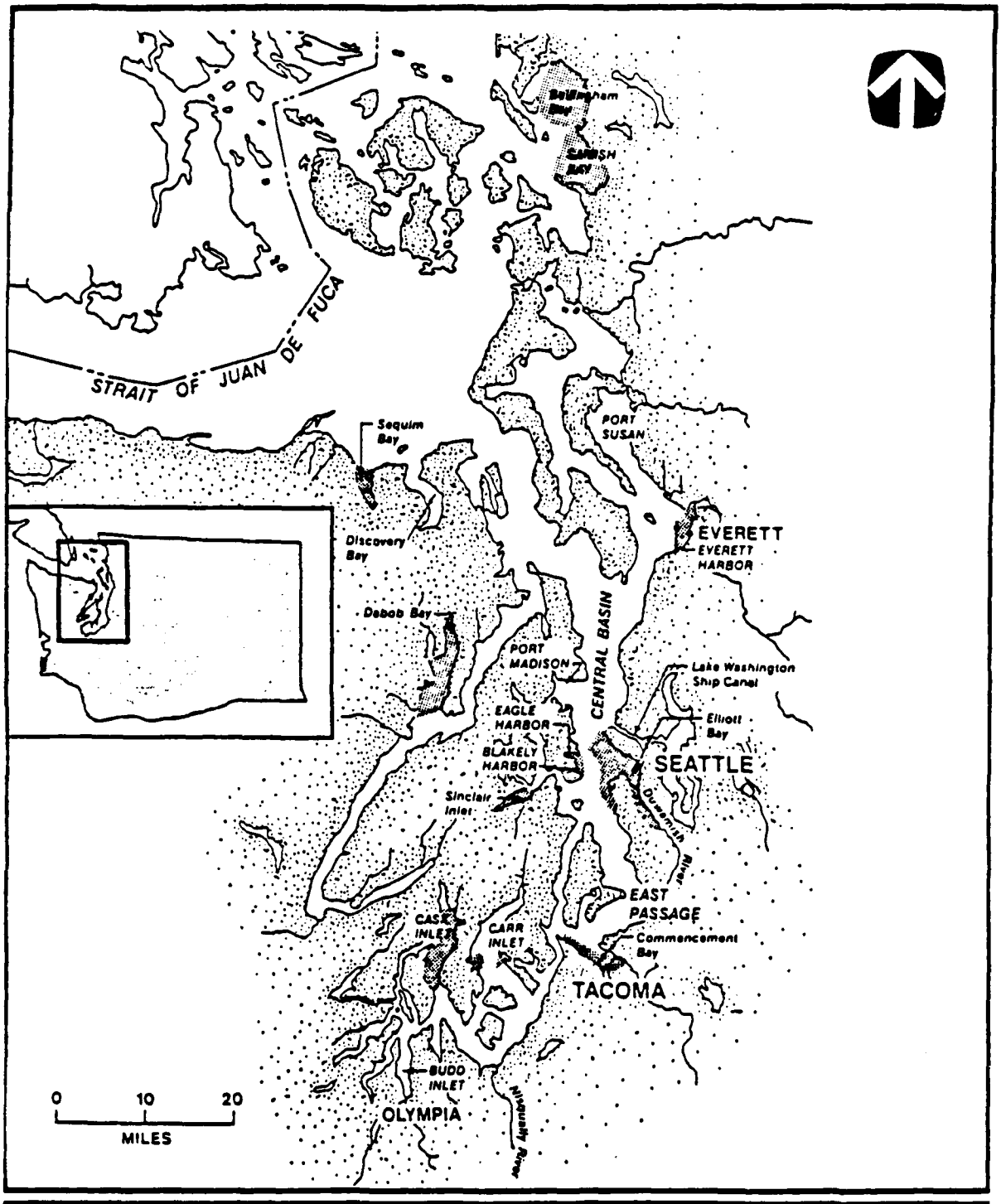


Figure II.7-1. Location of chemical and biological samples included in Puget Sound database.

7.2.2 Use of the Apparent Effects Threshold. In order to determine whether the information contained in the PSDDA comprehensive database could be used to develop sediment chemistry guidelines for dredged material evaluation in Puget Sound, a number of techniques were evaluated (Tetra Tech, 1986j). The techniques tested included two methods applying current equilibrium partitioning theory (using sediment-water interactions and sediment-biota interactions), one applying water quality criteria to interstitial water, one that based sediment quality on the presence/absence of benthic species (the Screening Level Criteria method), and one which combined both bioassay data and measurements of benthic community health (Apparent Effects Threshold (AET) method). Though all of the techniques evaluated had advantages and limitations, the AET method was selected for use in assessing dredged material in Puget Sound. (See Tetra Tech, 1986j, for details of this study.)

The AET method was originally developed for identifying chemical concentrations in sediments that warranted containment or clean-up action in Commencement Bay, a large marine Superfund site in Puget Sound (Tetra Tech, 1985a). Before considering applying the AET method as a tool under PSDDA, the Commencement Bay data base was expanded to include sediment chemistry and biological effects information from additional nearshore urban/industrial areas and "clean" reference sites. (Sources of data used to develop AET for PSDDA are summarized in figure II.7-1.) The data base was then used to identify the concentration of each chemical above which no sample examined was found to be without biological impact. This concentration, referred to as the apparent effects threshold, or AET, was identified on a chemical specific basis for 71 chemicals for each biological test independently (i.e., amphipod, oyster larvae, Microtox bioassays, and benthic community analysis).

Because of uncertainties associated with bioassay sensitivity and the relationship between benthic community analysis and potential impacts at the disposal site, no single test AET was selected as the basis for establishing the dredged material disposal guidelines. Rather, the decision was made to utilize all of the available information. Bioassay-based AET was incorporated because they provide foresight regarding material toxicity and the likely outcome of laboratory biological tests. They do this without resolving the specific cause of the observed toxic effects and, as applied as a part of a dredged material evaluation process, without implying that the laboratory toxicity will necessarily be expressed in the field at the ultimate disposal site. Benthic community-based AET were incorporated as corroborative evidence, and a means of protecting against potential impacts unaccounted for by single species bioassays or limited chemical analyses. Since an AET can be developed for each chemical of concern for multiple biological indicators, the combined effect is to provide a weight of evidence that serves as a reason to believe that potentially harmful levels of chemicals in sediments are present. The chemical guidelines developed for PSDDA during the AET method will be applied during the dredged material evaluation process only to identify sediments that provide a reason to believe they would be of very low or very high toxicity when exposed to test animals in the lab.

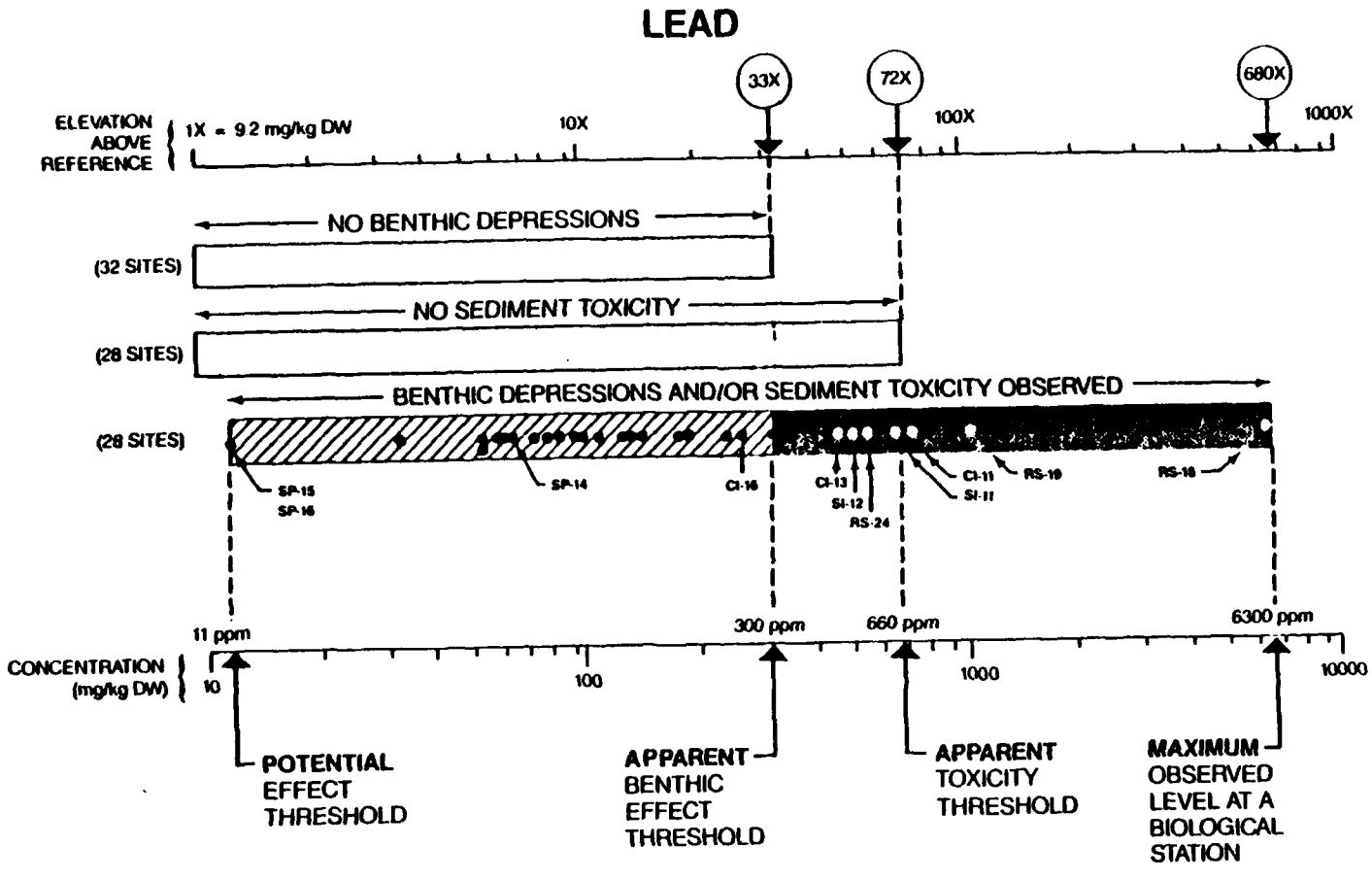


Figure II.7-2. The Apparent Effects Threshold (AET) approach applied for a single chemical (lead) [Data are taken from Tetra Tech (1985a)].

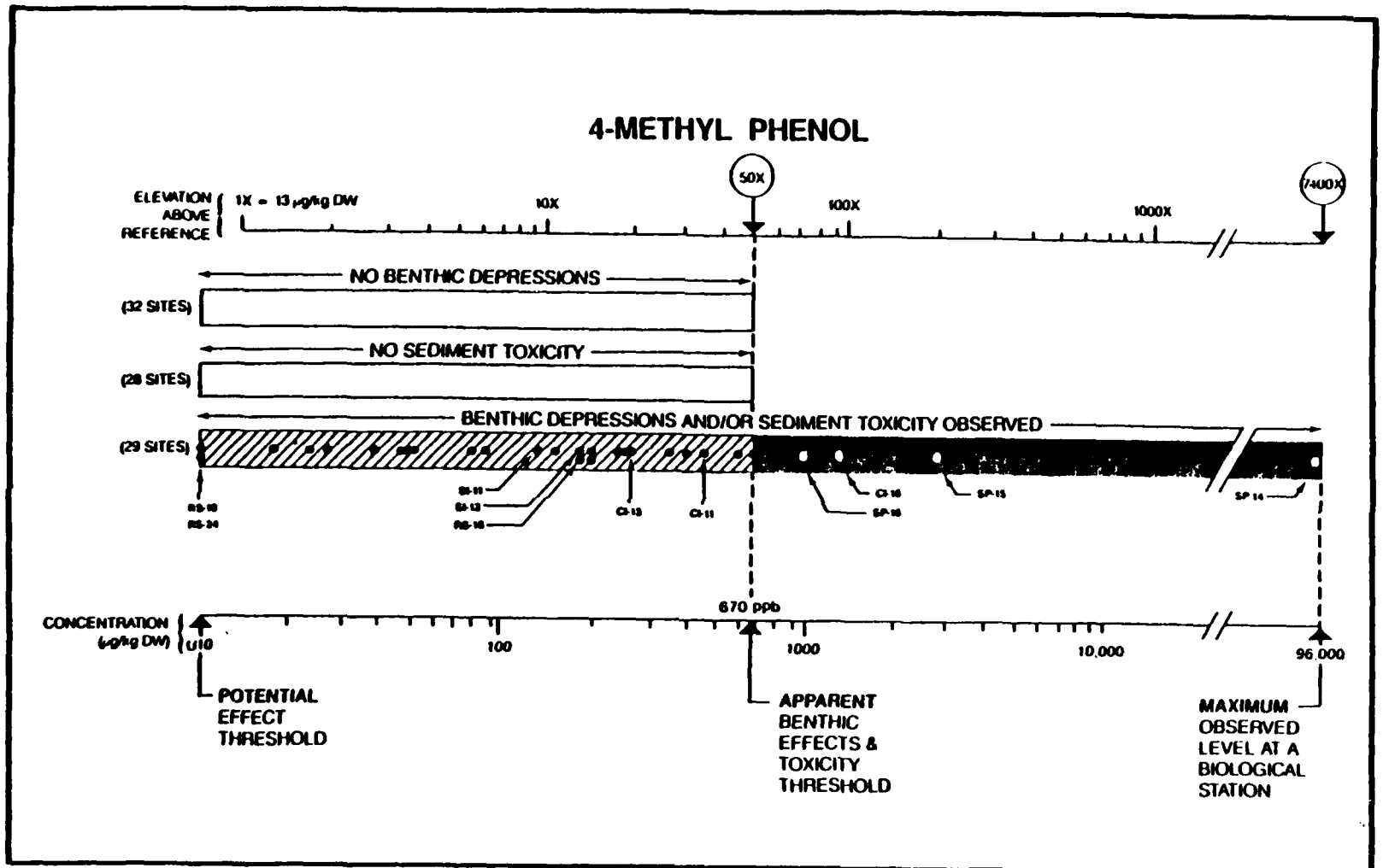


Figure II.7-3. The apparent effects threshold (AET) approach applied for a single chemical (4-methyl phenol) (from Tetra Tech, 1985a).

The focus of the AET approach is to identify concentrations of chemicals of concern that are associated exclusively with sediments having statistically significant adverse biological effects (relative to reference sediments). The approach can be used for any chemical and for any observable biological effects (e.g., bioassays, infaunal abundances at various taxonomic levels, bioaccumulation). By using these different indicators, application of the resulting sediment quality values enables a wide range of biological effects to be addressed in the management of dredged material.

A pictorial representation of the AET approach for two chemicals is presented in figures II.7-2 and II.7-3 for a subset of these data (from Commencement Bay). Those groups of sediment samples analyzed for chemistry and biological effects are represented by bars in the figures, and include:

- o Sediments that did not exhibit significant infaunal depressions
- o Sediments that did not exhibit significant toxicity
- o Sediments that exhibited either toxicity or infaunal depressions.

The horizontal axis in each figure represents sediment chemical concentrations based on lead ranges (i.e., lead or 4-methyl phenol) on a log scale. The AET for lead was based on lead concentrationranges corresponding to sediments that did not exhibit significant biological effects. The AET for 4-methyl phenol were determined analogously.

The Potential Effect Threshold (figures II.7-2 and II.7-3) is the concentration below which no statistically significant biological effects were observed in any sample. Note that this threshold for 4-methyl phenol is equal to the detection limit for the compound. The threshold is designated as "potential" because toxicity or benthic effects were found at some, but not all, of the stations with higher lead or 4-methyl phenol concentrations. The toxicity or benthic effects observed at these stations could have resulted from other chemicals of concern or physical conditions (e.g., grain size). Because the potential effect threshold for a chemical cannot be related in a meaningful way to the observed biological effects, it is not used to set sediment quality values.

Apparent benthic effect thresholds and apparent toxicity thresholds correspond to concentrations above which all samples were observed to have infaunal depressions or toxicity, respectively. Data are treated in this manner to reduce the weight given to samples in which factors other than the chemical examined (e.g., other chemicals of concern, environmental variables) may be responsible for the biological effect. For example, sediment from Station SP-14 shown in figure II.7-3 exhibited severe toxicity and depressed infaunal abundances, potentially related to a greatly elevated level of 4-methyl phenol

(7,400 times reference levels). The same sediment from Station SP-14 contained a low concentration of lead that was not critical in establishing the AET for lead (figure II.7-2). Despite the toxic effects displayed by the sample, sediments with higher lead concentrations exhibited no statistically significant biological effects. These results were interpreted to suggest that the effects at Station SP-14 were more likely associated with 4-methyl phenol than with lead. A converse argument can be made for lead and 4-methyl phenol in sediments from Station RS-18. Hence, the AET approach helps to identify different chemicals of concern that are most likely associated with observed effects at each biologically impacted site. Based on the results for these two chemicals, effects at 4 of the 28 impacted sites shown in the figures may be associated with elevated concentrations of 4-methyl phenol, and effects at 7 other sites may be associated with elevated lead concentrations.

The precision of the AET values was also estimated in the sediment quality values work performed for PSDDA/PSEP (Tetra Tech 1986j). Several potential error components were considered, including the statistical error in incorrectly classifying one or more nonimpacted stations that determined the AET. This classification error was judged to provide a reasonable estimate of the 95 percent confidence intervals for AET values. As discussed in section II-7.3, the lower 95 percent confidence interval for each AET was considered by EPWG for use as possible chemical screening levels.

7.2.3 Key Issues in Development of Chemical Disposal Guidelines. Several issues regarding the development of chemical disposal guidelines for evaluating dredged material required substantial discussion by EPWG. Summarized below, these included reliability of the resulting chemical guidelines, scientific peer review of the chemical guidelines, and the possible consequences of chemicals that are not included on the list of chemicals of concern (i.e., are not measured).

7.2.3.1 Reliability of Chemical Disposal Guidelines. During development of the PSDDA screening level (SL) (see section II-7.3) and maximum level (ML) (see section II-7.4) chemical disposal guidelines, the sediment quality values developed by different approaches were tested to determine their reliability in correctly predicting toxicity in the Puget Sound sediments data base. This reliability is the fundamental concern in using chemical disposal guidelines for dredged material management; to ensure that unacceptable adverse effects due to disposal are avoided.

Reliability of the sediment quality values was assessed by applying the chemical values to the existing data base for Puget Sound sediments, and determining the performance of the values using two measures. First, the sensitivity of the sediment quality values is the ability to correctly identify all sediments that are toxic in biological tests. The more sensitive the values, the more protective of the environment they are. Second, the efficiency of the values is the ability to correctly identify only those sediments that are toxic (excluding those that are not toxic). The more efficient the values,

the more cost effective they are. Generally, lower chemical guidelines are relatively sensitive, but also relatively inefficient (i.e., they identify all toxic sediments, but also incorrectly predict toxicity in many other sediments). Higher chemical guidelines are relatively efficient, but also relatively insensitive (i.e., they identify sediments that are always toxic, but can miss other sediments that are sometimes toxic).

Reliability testing conducted during the PSDDA Phase I studies found that the values developed using the AET approach were the most reliable values available at this time (Tetra Tech 1986j). It was also determined that no single chemical value (one for each chemical of concern) was both adequately sensitive and efficient.

For this reason, the estimated AET values were not solely relied upon in defining the SL and ML values. Rather, environmental protection was embodied in a set of lower SL values, while cost efficiency concerns were expressed in a set of higher ML values. The ML values were set relatively high (at the highest AET value for a set of biological indicators), to ensure that sediments with chemical concentrations above the ML values would indeed be toxic in biological tests. All sediments in the Puget Sound data base with chemical concentrations above the ML values have been shown to be toxic in at least one biological test. To ensure environmental protection, the SL values were set relatively low (between reference area and the lowest AET value for a set of biological indicators). The low values ensure that sediments with concentrations of all chemicals of concern below the SL level will not exceed the biological disposal guidelines (see section II-8) if biological tests were conducted. This separation of management needs (not relying on a single set of values) provides substantial additional assurance that the objectives of dredged material management can be met.

There is an additional benefit in using separate chemical indexes of sensitivity and efficiency. The different data sets within the Puget Sound data base represent a mix of different analytical protocols, which further contributes to some uncertainty in relying solely on the AET values to predict biological effects from sediment chemical concentrations. By using a relatively low screening level and a relatively high maximum level, an additional buffer is provided to compensate for the possible effect of differing protocols.

The reliability of the PSDDA SL and ML values were tested on the Puget Sound data base and on several case projects. Further testing of the Sl and ML values has also been accomplished with the Puget Sound data base after it was expanded in late 1987 and early 1988. In all cases, the tests have shown the SL and ML values to be reliable predictors of adverse effects. The SL values have been shown to be environmentally sensitive and the ML values have been shown to be cost effective.

One of the strengths of the AET approach in relating sediment chemistry to adverse biological effects is that it relies on empirical, field evidence. In deriving sediment quality values from sediments that contained multiple contaminants, interactive effects (especially those that are frequent in their occurrence in the Sound) are "built in" to the results. The more "representative" of the AET system to predict the data base is, the stronger the ability of the AET system to predict the presence of the AET values in correctly predicting the presence or absence of biological effects. It is this reliability that justifies the use of the SL and ML values in Puget Sound regulatory applications at this time.

The Puget Sound data base has been recently expanded (from about 200 to 400 stations) by EPA to include several large chemical and biological data sets. This expanded data base significantly contributes to the strength of the resulting AET values. The degree to which the data base represents the situation in the Sound has been improved, which also improves the predictive reliability of the resulting sediment quality values.

7.2.3.2 Scientific Peer Review of Chemical Disposal Guidelines. Though the AET values were not solely relied upon to develop the adopted SL and ML guidelines, completed and ongoing scientific review of the AET method and values is resulting in increasing recognition of the applied strengths and management utility of the AET approach to the development of sediment quality values. The primary forum for review of the AET approach has been the Sediment Criteria Group of EPA Region 10. This group meets at the request of EPA to provide technical input to EPA in the development of sediment criteria and management approaches. Meetings of the group have often been attended by national experts in the field. The AET methodology will also be presented to the EPA Science Advisory Board during the summer of 1988.

During development of the PSDDA evaluation procedures, input and review from regional scientists (including individuals with recognized national expertise) was obtained durng EPWG meetings. The procedures are accepted for application in Puget Sound. Further, since most of the PSDDA procedures are founded in the Puget Sound Estuary Program's Puget Sound Protocols, review and acceptance afforded to the protocols (obtained by way of consensus development workshops of technical experts) provides added support to the use of these standard methods in the Sound. These consensus protocols have been thoroughly reviewed by regional experts in Government, academia and consulting fields, both from technical and policy perspectives.

7.2.3.3 Possible Consequences of Sediment Chemicals Not Measured. A concern often expressed regarding the use of chemical guidelines is the possibility that adverse effects of a particular sediment may result from chemicals that are not measured (not included in the list of chemicals of concern). Examples of chemicals that are not on the list include butyltins (e.g., tributyltin) and chlorinated dioxins (e.g., 2,3,7,8-tetrachlorodibenzo-p-dioxin, or TCDD) (see discussion of these chemicals in section II-7.1.2).

Research on butyltins is being conducted during Phase II of the study. Both TBT and TCDD have been recently detected in sediments of the Sound. However, though these chemicals are recognized as highly toxic, there are no toxic stations in the Puget Sound data base that are not identified by the measurement of current sediment chemicals of concern and conventional variables. It is theefore possible that:

a. butyltins and chlorinated dioxins are not present in sufficiently bioavailable forms,

b. butyltins and chlorinated dioxins are not widely distributed in the sediments of the Sound, and/or

c. butyltins and chlorinated dioxins co-occur and co-vary with other, measured chemicals to a degree that allows chemical guidelines for these other chemicals to identify current butyltin and dioxin contributions to measured sediment toxicity.

These options also represent the possiblities for other, unmeasured and unidentified chemicals present in the sediments. Where toxicity that is not identified by measured chemicals is observed, more detailed analysis of the sediment chemistry would be appropriate.

Though toxic effects of butyltins and dioxins may be adequately screened by the measured chemicals, the human health consequences may not be addressed. Ongoing PSDDA studies are evaluating these concerns. For these reasons, future revisions to the PSDDA chemicals of concern list may include these and other chemicals. Interpretation guidelines would need to be developed and methods and lab capabilities defined once they were identified as necessary to the list.

7.3 Screening Levels. A screening level for chemical testing is a guideline used to define the concentration of a chemical in dredged material below which there is no reason to believe unacceptable adverse impacts would result from unconfined, open-water disposal. Dredged material that contains concentrations of chemicals of concern below screening levels is acceptable for unconfined, open-water disposal without the second tier of biological testing (see section II-7).

7.3.1 Procedure for Setting Screening Levels. A screening level concentration for each chemical of concern was set using the results of the sediment quality values task (see section II.7.2 and exhibit E.9). Seven options for screening levels were considered, including:

1. Apply a safety factor to the AET for each chemical of concern (e.g., figure II.7-2 and figure II.7-3) to obtain a screening level that is much lower than the concentration above which biological effects are always expected

2. Use the Potential Effects Threshold (see section II-7.2) as a protective concentration of a chemical below which a significant response in any of several biological tests is never observed, or increase the Potential Effects Threshold concentration by some factor

3. Use the lower 95 percent confidence limit for the AET assuming misclassification of the significance of biological effects at a single station setting the AET (see section 7.2.2)

4. Use the lower 95 percent confidence limit for the AET assuming misclassification of the significance of biological effects at two stations setting the AET (this value would be lower, or at most equal, to the value obtained in Option 3 above)

5. Use the average concentration of the chemical found in reference areas of Puget Sound, or increase this concentration by some factor

6. Use the maximum concentration of the chemical in reference areas of Puget Sound

7. Apply a safety factor to one of the values in option 2-6 above.

Option 1 was selected. Safety factors that resulted in screening levels equal to 1-75 percent of the AET were considered. The final screening level was set relative to sediment quality values as follows:

Screening Level = 10 percent of the maximum level set for unconfined, open-water disposal (see sections II-7.3 and II-8),

provided; (a) the value equals or exceeds the average concentration for the chemical in Puget Sound reference areas, and
(b) the value is less than the lowest AET (LAET) determined for a range of biological indicators.

By definition, the Potential Effects Threshold (PET) is the concentration below which there are no statistically significant biological effects in any sample. While the PET graphically appears to be a logical screening level for a given chemical, the possible influence of other chemicals present in high concentration in sediments cannot be factored out. Hence, the PET for a given chemical is strongly determined by the presence and effects of unrelated chemicals and so is relatively useless as a chemical-specific indicator. The PET can be used to indicate overall pristine conditions that will not result in adverse biological effects. However, the PET is likely too protective in identifying "acceptable" sediments because Puget Sound reference conditions exceed the PET for most chemicals. Consequently, comparison to average reference conditions is a more appropriate protective guideline for screening "acceptable" dredged material.

The decision to set the screening level at 10 percent of the maximum level was an arbitrary selection. More importantly, the screening level was equal to or above average concentrations in Puget Sound reference areas, and below the lowest AET (LAET) established for a range of biological indicators. In most cases, this screening level is closer to the reference area values than to the LAET.

7.3.2 Procedure for Setting Screening Level for Special Cases. All anomalies for setting screening levels were handled on a case-by-case basis. For example, sediment quality values are not available for some chemicals of concern of concern. For these chemicals, the procedure for determining screening levels for such chemicals was as follows:

- For phthalate esters, the screening level was set equal to the highest AET for a range of biological indicators because phthalates are common laboratory chemicals of concern and a higher screening level may be appropriate; no maximum level was established. Because phthalates are common laboratory chemical contaminants, reliable analyses for these chemicals are difficult. Although there is a need to address phthalate chemical concentrations in sediments, EPWG agreed that biological testing should not be triggered, and material should not be labeled unacceptable for disposal, solely by the routine presence of detectable levels of phthalates.

- For pesticides, the screening level was set approximately equal to the limit of quantification (i.e., 5 times the instrument detection limit). Though often not measured in Puget Sound sediments, certain pesticides are known to occur in the upper reaches of navigable waterways that drain agricultural river basins. Certain pesticides are of sufficient concern to trigger the need for biological testing once they were verified to be present in the dredged material. Hence, although insufficient data are available with which to establish "maximum levels," the recommended screening level is comparable to the low pesticide concentration seen in Puget Sound reference area sediments (1 to 3 ug/kg dry weight), and is consistent with guidance from the American Chemical Society on reliable data reporting.

- For any chemical, the screening level was never set lower than the average concentration observed in Puget Sound reference areas.

For phthalate esters and pesticides, the screening levels defined in this section will be the only chemical guidelines used in decisionmaking.

7.4 Maximum Levels. A second, higher "maximum level" (ML) for each chemical corresponds to the concentration of a chemical in dredged material above which there is reason to believe that the material would be unacceptable for unconfined, open-water disposal. The dredger has two options at this point; he may elect to accept the indication of the ML value. Biological testing is not

required for this decision. However, it is recognized that chemical levels in dredged material provide a relatively indirect measurement of possible adverse biological effects. Accordingly, the dredger will have the option to conduct additional biological testing (as described in section II-2.5) rather than rely on the indications of the ML. Factors can influence the bioavailability of these chemicals (e.g., sediment grain size, presence of organic carbon, etc.). This is why the dredger will also have an option to conduct biological testing rather than relying on the indications of the chemical maximum level.1/

7.4.1 Rationale for Maximum Level Concept. Present EPA and Ecology regulatory practices for dredged material disposal within Puget Sound require that a sediment meet a variety of standard test requirements (including an amphipod bioassay) in addition to showing that the sediment does not exceed established interim bulk chemistry levels for a variety of chemicals of concern. The use of bulk chemistry values by EPWG in setting maximum levels was based on the following conclusions:

- Bulk chemistry guidelines should be based on biological effects, not on comparison to reference conditions (i.e., maximum levels should be based on sediment quality values). There is mounting field evidence that elevated concentrations of certain chemicals in sediments (e.g., dredged material) are associated with adverse biological effects.

- Bulk chemistry does not provide a definitive answer in characterizing dredged material, but is useful for an initial assessment.

- Bulk chemistry is a valid indicator of sediment quality when chemical concentrations are very low or very high.

- No single chemistry value can determine both the acceptability and unacceptability of a sediment proposed for disposal at unconfined, open-water sites. Hence maximum and screening levels are required.

- The screening and maximum level can be used in the permitting process to define the bounds of confidence to which bulk chemistry can be applied without conducting further biological tests.

There are several arguments supporting the setting of maximum level concentrations for decisions involving chemical testing results. The major arguments are summarized below:

- Although several biological tests are available (primarily acute tests; see section II-6), it is not possible to test for all kinds of adverse biological effects of concern using these biological tests.

1/The "maximum level" is intended to define the upper limit of chemical concentrations for which the standard biological tests are a sufficient basis for regulatory decisionmaking.

- There is regulatory precedence for the use of maximum level concentrations for decisionmaking. Suitable maximum levels of chemicals in sediment samples have been applied in Puget Sound since 1972 when EPA issued the "blue book" (a listing of chemical criteria values for dredged material quality), and also applied to sediments in the present Puget Sound interim criteria (see section II-1.4.4).

- The maximum levels incorporate sediment quality values based on a range of acute and chronic indicators (e.g., acute bioassay responses as well as the long-term health of benthic infaunal communities indicated by the abundance of multiple species). Hence, use of the maximum level concept increases the ability to determine the unacceptability of sediments for disposal at unconfined, open-water sites based on a broader suite of biological indicators than possible with the available biological testing program.

Arguments against setting maximum levels for assessing the acceptability of dredged material for unconfined, open-water disposal are summarized below:

- There is uncertainty in accuracy of the relationship between concentrations of chemicals and biological effects, and in comparability of data sets within the Puget Sound data base, which implies that the maximum levels should not be used as the sole indicator of the acceptability of dredged material for disposal.

- Setting maximum levels for chemical concentrations can discourage a dredger from trying to prove that the dredged material for a particular management unit within a project will not exceed the biological effects limits set for unconfined, open-water disposal.

The advantages of setting maximum allowable level of chemical concentrations for unconfined, open-water disposal were considered to outweigh these limitations. However, as detailed in section II-2.5, the dredger has the option to conduct biological testing and, depending on test results, disposal of material exceeding ML values may be allowed.

7.4.2 Single Chemical vs. Chemical Groups Maximum Levels. Chemicals released into the environment are often distributed as unique mixtures of chemicals in different geographical areas. Some chemicals [e.g., polycyclic aromatic hydrocarbons (PAH)] tend to occur in many environments in a velatively predictable composition. The reasons for this predictability are that these chemicals derive from a source that is widely distributed or from multiple sources that discharge waste products of similar composition (e.g., hydrocarbons from the burning of oil, coal, and wood). A question debated was whether maximum levels should be set for individual chemicals that make up such groups of chemicals, for the total concentration of the chemical group, or for both cases.

Even among chemicals that tend to occur in predictable compositions, some variability remains. Therefore, it is possible for chemical concentrations in a dredged material to exceed the maximum level calculated for individual chemicals, but be within the maximum level for the group of covarying chemicals. This limitation was considered by the work group.

Most chemicals will have maximum levels set individually (i.e., only individual maximum levels will be applied to chemical analyses of dredged material). Choices between single chemical values and group values were made for the following chemicals:

- Polychlorinated biphenyls (PCB's) - maximum level will be based on the total PCB concentration only (the sum of a possible 209 congeners)
- DDT isomers (p,p'-DDT, p,p'-DDE, p,p'-DDD only) - maximum level will be determined for the sum of the p,p'-DDT isomers only
- Low molecular weight polycyclic aromatic hydrocarbons (LPAH) - maximum level will be determined for individual and group values (naphthalene, acenaphthene, acenaphthylene, fluorene, phenanthrene, anthracene)
- High molecular weight PAH (HPAH) - maximum level will be determined for individual and group values [fluoranthene, pyrene, benz(a)anthracene, chrysene, benzofluoranthenes, benzo(a)pyrene, indeno(c,d)pyrene, dibenzo(a,h)anthracene].

PAH's have a high degree of co-occurrence in the environment and a complex and interrelated toxicology. Hence, PAH will be managed as a group, with sediment quality values established for LPAH and HPAH. The single chemical allowance (see section II-2.4) is applicable to these group values.1/ Because the composition of the co-occurring group of PAH can also vary substantially, sediment quality values based on individual PAH are incorporated into the chemical disposal guidelines.

7.5 Toxic Chemical Testing Protocols.

7.5.1 Metals and Metalloids. The metals testing protocols were the subject of the PSDDA/PSEP report "Task A-4, Metals Protocol Development for Puget Sound Studies" (Tetra Tech 1986f). The report is summarized in exhibit E.13 and appears in full in "Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound" prepared for PSEP (Tetra Tech 19861).

1/When only one chemical of concern exceeds the maximum level, the standard biological tests can be used for decisionmaking, provided the chemical concentration does not exceed 100 percent of the ML value.

Required detection limits are summarized in section 7.6.1. The recommended procedures and requirements for sample sizes, sample preservation and storage, quality assurance/quality control, and data reporting closely follow those of the EPA Contract Laboratory Program (CLP; U.S. Environmental Protection Agency 1985).

For the purposes of dredged material assessment, detection levels in excess of the SL values is not requisite. In other words, exceeding the detection level values would not be a concern as long as the SL value was not exceeded. However, use of standard protocols is mandatory to ensure data comparability. These protocols, to some extent, imply certain detection limits for metals.

The recommended sample digestion techniques were 1) strong acid and APDC/MIBK extraction for saltwater, 2) hydrofluoric acid/aqua regia total acid for sediment, and 3) nitric acid/perchloric acid for tissue. Use of the hydrofluoric acid/aqua regia total acid digest is still being discussed by EPWG. It is important that the future metals data be comparable to that currently entered into the Puget Sound sediment quality data base, to ensure that application of the related screening and maximum levels is technically sound. If ongoing review suggests that future data may not be adequately comparable, an alternative digestion technique may be recommended.

The choice of recommended instrumental methods was based upon 1) the existence of an agency-approved protocol, 2) the ability to achieve recommended detection limits (see section 7.6.1), and 3) ready availability of equipment and prevalence of use. Because no one instrumental technique satisfied all of the requirements for all matrices, inductively coupled plasma emission (ICP), graphite furnace atomic absorption (GFSS), and cold vapor atomic absorption (CVAA) were recommended. The EPA hydride generation technique (HYDAA), the use of matrix modifiers in GFAA, and x-ray fluorescence (XRF) were allowed as long as accuracy and precision could be demonstrated to the levels specified in the QA/QC section of the report.

7.5.2 Organics. In addition to the compounds routinely analyzed by EPA and other agencies (e.g., the "priority pollutant organic compounds"), a large number of unidentified compounds may be present in sediment extracts. The reconstructed ion chromatogram [for gas chromatography/mass spectroscopy analyses (GC/MS)] or chromatograms for other detection systems be included in the chemical data reports. The purpose of these data is to at least document the composition of the sample extract for future reference.

The organics testing protocols were the subject of the PSEP report "Recommended Protocols for Measuring Organic Compounds in Puget Sound Sediment and Tissue Samples" (Tetra Tech 1986i). The report is summarized in exhibit E.14 and appears in full in "Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound" developed for PSEP (Tetra Tech 19861).

The organics protocols were synthesized from written sources (e.g., EPA standard methods) and from discussions at three workshops of regional experts. Because no agency-approved procedures exist for analyses at the low concentrations required (see section 7.6.2), multiple procedures for the different compound classes (e.g., volatiles, PCBs) are currently in use. Because these different procedures could all yield equivalent results, no one procedure was recommended. Instead, comprehensive QA/QC guidelines were developed that would enable the assessment of the comparability of data generated by the different procedures (Tetra Tech 1986i).

For the analysis of volatiles in sediments, two methods were recognized as acceptable for analysis at Puget Sound reference area concentrations: the EPA CLP heated purge-and-trap technique and the vacuum extraction/purge-and-trap technique. For the analysis of semivolatiles in sediments, the EPA CLP GC/MS and GC/ECD methods (with capillary column options for GC/ECD) were accepted for analyses at 50 ug/kg dry weight detection limits. Depending upon the ultimate use of the data, GC/flame ionization detection (FID) with confirmation was also accepted. To obtain detection limits acceptable for Puget Sound reference areas, multiple extract cleanup steps are required. A variety of procedures are in common use for each step, and methods were accepted that have been successfully used by regulatory and independent laboratories.

For the analysis of volatiles in tissue, the EPA CLP heated purge-and-trap technique and the vacuum extraction/purge-and-trap technique were accepted. No alternative procedure was recommended because higher detection limits may prevent chemical detection at concentrations considered to be significant human health risks. For the analysis of semivolatiles in tissue, multiple extract cleanup steps are required. A variety of procedures are in common use for each step, and methods were accepted that have been successfully used by regulatory and independent laboratories.

Frequencies, compound applicabilities, limitations, warning and control limits, and corrective actions were detailed for nine separate QC procedures: surrogate spikes, injection internal standards, method blanks, standard reference materials, matrix spikes, method spikes, analytical replicates, field replicates, and initial and continuing calibration. Data reporting requirements were similar to those of the EPA CLP.

7.5.3 Conventional Parameter Testing Protocols. Protocols for analysis of most conventional sediment parameters used under PSDDA will be those recommended by PSEP for analysis of Puget Sound sediments (Tetra Tech, 1986). Analysis of ammonia should be conducted according to standard Corps/EPA procedures (Plumb, 1981).

7.6 Detection Limits.

7.6.1 Metals and Metalloids. Limits of detection were recommended for the APA priority pollutant metals and metalloids after a consideration of attainable method detection limits for each matrix type, EPA water quality criteria (water), and expected background levels in the environment (sediment and tissue). The detection limits are summarized in table II.7-2.

7.6.2 Organics. Limits of detection were recommended for volatiles, semi-volatiles, and pesticides and PCB's that would allow quantification down to concentrations in Puget Sound reference areas. The detection limits are summarized in table II.7-3.

7.7 Conventional Chemical Tests. Conventional chemical variables (e.g., total volatile solids, total organic carbon, sulfides, ammonia) are not considered as chemicals of concern. These parameters do not have interpretation guidelines and will not generally have a direct bearing on a disposal decision for a management unit. However, collection of data on the following variables will be necessary further characterize the sediment and interpret chemical and biological tests:

- o Total volatile solids.
- o Grain size distribution (i.e., percent rocks, gravel, sand, silt, clay).
- o Total organic carbon (TOC).
- o Percent solids.
- o Total sulfides.
- o Ammonia.

The primary use of these variables will be as indicators of potential chemical concentrations, and in some cases, as normalizing variables for chemical concentrations in dredged material. Data for the following conventional analyses will not be required for dredged material chemical testing:

- o Oil and grease, or oil sheen test (these variables are indicators of some forms of hydrocarbon chemical concentrations; direct measurement of polynuclear aromatic hydrocarbons are already required). Considerable discussions concerning the need to analyze dredged material for oil and grease led to the decision to refine the historic practice of measuring oil and grease concentrations in dredged material by substituting direct measurement of those chemical compounds of concern found in petroleum and combustion products. Consequently, the PSDDA list of chemicals of concern includes 16 polynuclear aromatic hydrocarbons (PAHs). Measurement of oil and grease does not identify the presence, or quantify the concentration, of these priority pollutant chemicals. Oil and grease measurement will not distinguish between products of petroleum origin and oils from other, natural sources. In addition, the fraction of oil and grease that is available to be released to the water column and the sea surface cannot be predicted from a total oil and grease analysis. Oil and grease found in bottom sediments is considered to be substantively in a form that is not readily available

TABLE II.7-2. RECOMMENDED METALS LIMITS OF DETECTION FOR WATER, SEDIMENT, AND TISSUE MATRICES

	Water(a)	Sediment(a)	Tissue(c)
Antimony	3	0.1	0.02
Arsenic	1	0.1	0.02
Cadmium	0.1	0.1	0.01
Copper	1	0.1	0.01
Lead	1	0.1	0.03
Mercury	0.2	0.01	0.01
Nickel	1	0.1	0.02
Silver	0.2	0.1	0.01
Zinc	1	0.2	0.2
Manganese	NA(d)	2.0	NA

(a) ug/L.

(b) mg/kg dry weight.

(c) ug/g wet weight.

(d) NA = Not applicable

TABLE II.7-3 RECOMMENDED ORGANICS LIMITS OF DETECTION FOR SEDIMENT AND TISSUE MATRICES

Compound Type	Sediment(a)	Tissue(a)	Comments
Volatile	10-20	5-10	All analyses
Semivolatiles	1-50	10-20	Low-level analysis
Pesticides/PCB's	0.1-15	0.1-20	Low-level analysis

(a) ug/kg dry weight.

(b) ug/kg wet weight.

for dispersal. It is often associated with particles that will settle, and it has been processed to some degree during settling. Mechanically dredged material, released in a single dumping action from a bottom-release barge will also minimize the disturbance of the material and the release of oil fractions. For these reasons, the measurement of oil and grease in material to be dredged is considered to be a relatively general indicator that does not directly contribute to an assessment of the potential effects of dredged material disposal. Though the analysis of PAHs is considerably more expensive, the information can be related to possible adverse biological effects of material disposal.)

- Total nitrogen [useful in conjunction with total organic carbon measurements as a general indicator of chemical concentrations by carbon-rich materials (e.g., paper products and coals) total organic carbon and total volatile solids are considered adequate].

- Chemical oxygen demand (used as an indicator of the potential oxygen consumption by dredged material during dredging operations; low flows and low ambient dissolved oxygen are considered as more useful indicators).

8. TEST INTERPRETATION: ALTERNATIVE BIOLOGICAL EFFECTS CONDITIONS FOR SITE MANAGEMENT

8.1 Overview. The purpose of this section is to identify alternative biological effects conditions for site management (hereinafter referred to as "site management conditions" or "site conditions") that were considered for the unconfined, openwater disposal sites in the Phase I area.

Five steps were taken by EPWG in selecting a preferred site management condition for the Phase I area unconfined, open-water disposal sites. These steps are as follows:

Step 1. Selection of the general management approach to dredged material evaluation (see section I.5).

Step 2. Definition of various degrees of adverse biological effects that might occur at the sites (referred to as "biological effects conditions for site management" or "site conditions") (addressed in this section).

Step 3. Development of dredged material evaluation procedures as a means to avoid exceeding the site condition by:

(a) specifying chemical and biological testing requirements (see section II.6 and II.7), and

(b) defining disposal guidelines (test interpretation), including biological response guidelines (for biological tests) and sediment quality values (for chemical tests) (addressed in this section).

Step 4. Assessment of the environmental and economic consequences of the different alternative site conditions (see sections II.9 and II.10).

Step 5. Identification of the preferred biological effects condition for site management in the Phase I area of PSDDA (see section II.11).

A number of different definitions of possible biological effects condition for site management were considered (see table II.8.1). At each end of the range of possible biological effects due to chemicals, extreme site management conditions were defined. At the low end of the range, one possible site management condition would be to allow only dredged material that does not contain measurable levels of any chemical of concern (referred to as Site Condition 0). Virtually all sediments expected to be dredged in Puget Sound will have

some measurable levels of chemicals of concern (especially naturally occuring levels of heavy metals). As a result, use of this condition would result in no disposal of dredged material at the unconfined, open-water disposal sites. Although this option would comply with the CWA and State Water Quality Standards, (no unacceptable adverse biological effects at the unconfined, open-water disposal sites, by having virtually no discharge at the sites), it may not comply with the Federal guidelines when the consequences of disposal at wetlands and intertidal nearshore confined disposal sites are considered. This option places all environmental risk at nearshore and upland disposal sites and is considered environmentally, economically, and politically unacceptable.

At the high end of the biological effects range, Site Condition V would allow all highly contaminated dredged material, up to and including dangerous waste classified sediments by State of Washington Standards, to be present at the unconfined, open-water disposal sites.

The "Site Condition IV" definition, described as "major adverse effects due to sediment contamination" and encompassing material up to, but not including, material defined as "dangerous waste" per State hazardous waste laws, is similar to Site Condition V in that almost all Puget Sound dredged material would be allowed for disposal at the unconfined, open-water sites (i.e., very little material contains this degree of chemical concentrations).

Neither Site Conditions IV nor V were considered as acceptable biological effects conditions at the disposal sites. These conditions do not "preserve, maintain, or enhance" the integrity of the aquatic ecosystem (per the CWA). Accordingly, neither condition was recommended for detailed planning within PSDDA. Although these site conditions would provide the least expensive options for the dredger, all the environmental risk associated with dredging and disposal would be allocated to the aquatic environment. These conditions would not be permissible under current Federal or State law.

The remaining "gray area" was divided into three different "alternative biological effects conditions for site management," each describing a different degree of adverse enviromental effects on biological resources at the sites. The various conditions differ by having increasing degrees of effects on resources at the disposal site, from "no adverse effects due to sediment chemicals" to "moderate adverse effects due to sediment chemicals" (Site Conditions I-III, table II.8-1).

Site Condition I (no adverse chemical effects on biological resources), Site Condition II (minor adverse chemical effects), and Site Condition III (moderate adverse chemical effects) all define site conditions which, depending upon interpretation, could comply with the Section 404(b)(1) Guidelines. As a matter of comparison, each of these options were carried forward for detailed investigation.

TABLE II.8-1

ALTERNATIVE DEFINITIONS OF POSSIBLE BIOLOGICAL EFFECTS CONDITIONS FOR MANAGEMENT OF THE UNCONFINED, OPEN-WATER DISPOSAL SITES IN PHASE I AREA

Site Condition 0: No Chemically-Related Effects on Biological Resources Due to the Absence of Measurable Chemicals of Concern.

Onsite sediments do not contain chemicals at concentrations above analytical detection limits.

Site Condition I: No Adverse Effects on Biological Resources Due to Sediment Chemicals

No species will be affected due to sediment chemicals within the site in the short (acute) or long (chronic) term.

Site Condition II: Minor Adverse Effects on Biological Resources Due to Sediment Chemicals

Some species may be affected within the site from long-term exposure to sediment chemicals (only sublethal effects are anticipated).

Site Condition III: Moderate Adverse Effects on Biological Resources Due to Sediment Chemicals

Many species may be affected within the site from both short-term and long-term exposure to sediment chemicals (both lethal and sublethal effects are possible).

Site Condition IV: Major Adverse Effects on Biological Resources Due to Sediment Chemicals

Most species within the site may be affected by even short-term exposure to sediment chemicals (with substantial lethal effects likely). (This level includes onsite sediment chemical concentrations up to, but not including, "Dangerous Waste" material per State hazardous waste laws.)

Site Condition V: Severe Adverse Effects on Biological Resources Due to Highly Contaminated Sediments

All dredged material, including "Dangerous Waste" material, could be discharged at unconfined, open-water disposal sites. Species onsite are likely to experience severe lethal effects due to short-term exposure to material at this level.

Dredged material evaluation procedures (sampling requirements, chemical and biological tests, and disposal guidelines), promulgated pursuant to the CWA authorities of the Corps, EPA, and Ecology are used as the primary means of ensuring that the preferred biological effects site management condition is not violated. The evaluation procedures can assist regulatory agencies in assessing whether disposal of a dredged material from a given project would result in unacceptable adverse impacts to the water column or benthic environment and, as such, would or would not be compatible with the preferred disposal site condition.

The maximum degree of potential biological effects (section II-8.2) and of chemicals of concern (section II-8.3) were defined for each of the three site conditions. Chemical "trigger" levels for the initiation of bioaccumulation tests in the characterization of dredged material were also defined (section II-8.4). The alternative site management conditions were defined in "laboratory terms," such that alternative test interpretations (disposal guidelines) could be developed for the biological and chemical tests. Chemical guidelines for the first three effects conditions were set based on sediment quality values developed for Puget Sound that relate chemical concentrations to potential biological effects.

8.2 Options for Biological Effects Conditions for Site Management. The options considered for the upper level of biological effects for Site Conditions I, II, and III focused on the use of acute bioassay results as summarized in table II.8-2. The "laboratory" definition of the alternative site management conditions was developed by EPWG as follows:

- Site Condition I: "No significant sublethal, chronic toxicity"
- Site Condition II: "No significant acute toxicity"
- Site Condition III: "No severe acute toxicity"

The determination of a significant toxicity response is by comparison of test results for organisms maintained in samples of material to be dredged to test results for organisms maintained under reference sediment conditions. The primary function of "control" is to indicate acceptable conditions for maintenance of healthy test species in the laboratory during biological testing, and to provide a measure of mortality to test organisms held under laboratory conditions. Furthermore, the performance standards for "control" conditions (no more than 10 percent mortality) and for "reference" conditions (no more than 20 percent absolute mortality over control) (e.g., figure II.8-1) enable a test response to be interpreted in a meaningful way.

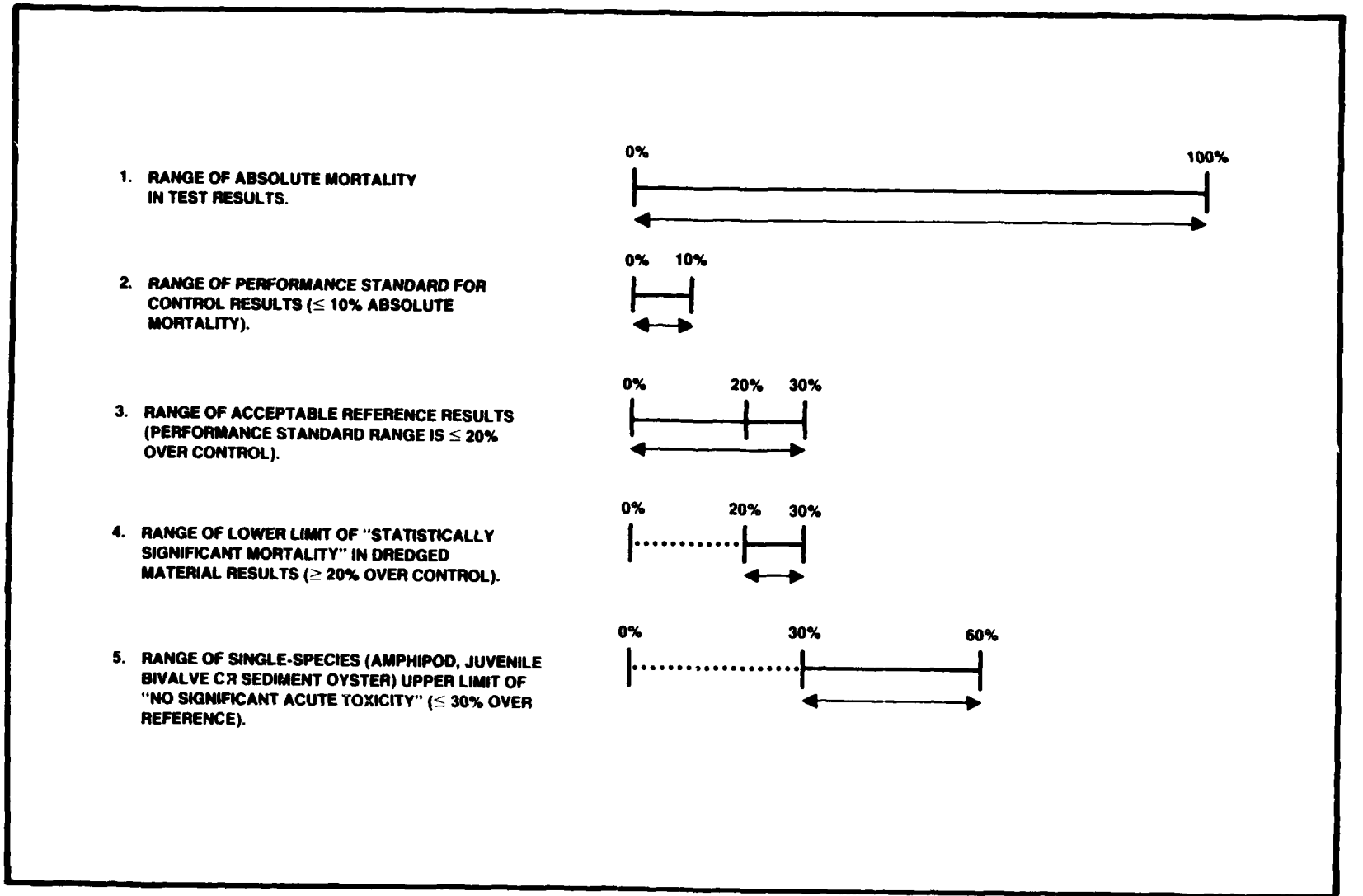


Figure II.8-1. Relationship of control, reference, and test treatment bioassay results in determining significant acute toxicity in sediment toxicity tests for dredged material.

TABLE II.8-2. BIOLOGICAL DISPOSAL GUIDELINES FOR ALTERNATIVE SITE MANAGEMENT CONDITIONS

o	Site Condition I -	"No sublethal or acute toxicity" is defined as: no one acute sediment toxicity bioassay(a) exhibiting a statistically significant (P less than 0.05) response over reference conditions and exceeding 20 percent absolute mortality over control; water column larval response does not exceed 0.01 of the LC50 after 4 hours of mixing; and no bioaccumulation levels exceeding a human health tissue guideline value.
o	Site Condition II -	No "significant acute toxicity" is defined as: no two acute sediment toxicity bioassays exhibiting the above conditions; and no one acute sediment toxicity bioassay response greater than or equal to 30 percent(b) over reference conditions and statistically significant with respect to reference conditions; water column larval response does not exceed 0.01 of the LC50 after 4 hours of mixing; and no bioaccumulation levels exceeding a human health tissue guideline value.
o	Site Condition III -	No "severe acute toxicity" is defined as: no two acute sediment toxicity bioassay responses greater than or equal to 30 percent(b) over reference and statistically significant with respect to reference conditions; and no more than one acute sediment toxicity bioassay response greater than or equal to 70 percent over reference and statistically significant with respect to reference conditions; water column larval response does not exceed 0.01 of the LC50 after 4 hours of mixing; and no bioaccumulation levels exceeding human health tissue guideline value.

(a) Biological tests that are used in the disposal guidelines are discussed in section II-6.
(b) Greater than 30 percent (absolute) over reference: e.g., if reference mortality is 12 percent, test mortality cannot exceed 42 percent.

In the absence of a acceptable sublethal test, the upper limit for Site Condition I biological response is established at "no species showing acute toxicity."

For Site Condition II, "significant acute toxicity" is defined table II.8-2. The 30 percent value shown in the Site Condition II biological guidelines was selected primarily because of historical precedence in interpretation of bioassays. When only one species of the three tested indicates a statistically significant response relative to reference, the 30 percent guideline is used to determine when sediment toxicity in the single species is sufficient to indicate a "significantly acute" condition in the lab.

For the acute sediment toxicity tests using Site Condition II, the amphipod, juvenile bivalve, or sediment toxicity larval (or embryo) mortality response alone may serve to indicate material unacceptability. If the dredged material total mortality in any one of these tests is significantly greater than the total mortality in the reference (more than 30 percent absolute), and if the test material is "statistically significant" relative to reference, the material is considered unacceptable for unconfined, open-water disposal. The definition of "statistically significant" acute response requires both a statistical difference from reference, and a total mortality in the dredged material test results that is greater than 20 percent (absolute) over the control results (i.e., exceeds the "performance standard" for reference test results). Also, if any two of the amphipod, juvenile bivalve, sediment toxicity larval and Microtox tests show a "statistically significant" acute response relative to reference, the material is considered unacceptable for unconfined, open-water disposal.

Though a useful indicator of relative sediment toxicity, the results of the Microtox test are more difficult to relate to adverse effects at the disposal site than are the results of the other recommended acute tests. For this reason, the requirement to conduct the Microtox test is solely for the assessment needs of Section 401 water quality certification reviews. The Microtox test result alone is not used to judge material acceptability. However, it may be used in combination with the other acute sediment toxicity tests to determine acceptability for unconfined, open-water disposal. For purposes of corroborating other test results, a significant response for saline-extract microtox is defined as a dredged material extract concentration decrease of 20 percent or more below reference extract (15 min. EC 50) (also statistically different from reference). For example, the following data would be indicative of an unacceptable (per Section 401) dredged material:

Microtox tests results	amphipod mortality
(ul/l, 15 min. EC50)	(percent, absolute)
control: 100 ± 2	control: 0 (mean) ± 0%
reference: 90 ± 5	reference: 5 (mean) ± 5%
dredged material: 45 ± 10	dredged material: 25 (mean) ± 7%

In this case, the dredged material test results are 25 percent (absolute) over control for the amphipod, (exceeding the "20 percent over control" guideline) and are 45 percent below the reference value for Microtox (exceeding the "20 percent below" guideline). Both tests are statistically different from reference.

Interpretation of the water column larval test (for Section 404 evaluations) requires an assessment of the possibility of unacceptable adverse effects occurring in the water column. The appropriate assessment is described in the EPA/Corps implementation manual for ecological evaluation of dredged material disposal in ocean waters (appendixes B, D, and H). The assessment is done by statistically comparing the larval survival after 96 hours in the seawater control to survival in the dredged material suspended phase exposures, including the consideration of initial mixing that might occur at the disposal site. As described in the implementation manual, the dredged material will be considered acceptable for unconfined, open-water disposal only if the test results and initial mixing calculations (after 4 hours) indicate that the "limiting permissible" concentration (LPC) would not be exceeded. The LPC is the concentration of the dredged material suspended phase which, after allowance for initial mixing, will not exceed a toxicity threshold defined as 0.01 of a concentration shown to be acutely toxic (LC50) to the larvae. In other words, the larval test will indicate that the material is acceptable for unconfined, open-water disposal if one one-hundreth (0.01) of the concentration resulting in 50 percent mortality of the larvae (LC50) is not expected to be exceeded after 4 hours of mixing at the disposal site. Appendixes D and H of the EPA/Corps manual for implementation of Section 103 of the Marine Protection, Research and Sanctuaries Act of 1972 (EPA/Corps, 1977) provide further details on data analysis and interpretation to be used with the water column larval test.

Site Condition III, "severe acute toxicity", is defined in table II.8-2 and represents a higher degree of confidence required to demonstrate toxicity relative to the Site Condition II guideline. The recommended site condition for the unconfined, open-water disposal sites in the Phase I area is discussed in section II-11.2.

8.3 Options for Setting Maximum Chemical Concentrations for Site Management Conditions. The range of options considered for maximum allowable levels of chemicals of concern for the four site conditions included (in order of increasing concentration for a chemical):

1. The lower confidence limit for the lowest AET (see Section II-7.2) determined for a range of biological indicators

2. The lowest AET determined for a range of biological indicators

3. The average AET determined for a range of biological indicators

4. The highest AET determined for a range of biological indicators

5. The upper confidence limit for the highest AET

6. A factor times the highest AET

7. Ecology regulations for Dangerous Waste.

The option used for maximum chemical levels for each of the three site conditions is summarized in table II.8-3; numerical values are given in table II.8-4. Maximum levels have not yet been assigned for some chemicals (e.g., pentachlorophenol) for the reasons cited in table II.8-4 (see footnote 'a').

The final maximum chemical level acceptable for unconfined, openwater disposal is discussed in section II-11.2. The rationale for selecting each maximum level in relation to the alternative biological effects conditions is discussed in the following sections.

8.3.1 Maximum Chemical Level for Site Condition I. Three options were proposed for setting a maximum chemical level for Site Condition I (ML1; i.e., the chemical concentration above which dredged material has reason to believe that it would be unacceptable according to Site Condition I disposal guidelines for unconfined, open-water disposal):

1. The lowest AET for a range of biological indicators

2. The lower 95 percent confidence limit of the lowest AET for a range of biological indicators

3. Twenty-five percent of the ML2 value (see section 8.2.2.2; the adjustment represents a safety factor for ML1).

Option 1 was selected for ML1. The lowest AET represents the chemical concentration above which an unacceptable adverse effect is always expected by one biological indicator. This level of effects corresponds to Site Condition I (section II-8.2).

8.3.2 Maximum Chemical Level for Site Condition II. Three options were considered for setting a maximum chemical level for Site Condition II (i.e., ML2):

1. The lowest AET for a range of biological indicators
2. The median AET for a range of biological indicators
3. The highest AET for a range of biological indicators.

Option 3 was selected. The highest AET represents the chemical concentration above which all of the biological indicators are expected to exhibit significant effects. Hence, by selecting this value for ML2, the material would provide a reason to believe that Site Condition II (section II-8.2.1) was reached (i.e., the dredged material is expected to be unacceptable according to Site Condition II guidelines without biological testing).

8.3.3 Maximum Chemical Level for Site Condition III. Three options were considered for setting a maximum chemical level for Site Condition III (i.e., ML3):

1. The upper confidence limit of the highest AET
2. The arithmetic average of the ML4 and ML2 values
3. The ML2 value times a factor.

Option 3 was selected; the ML3 values were defined based on an interpretation of the difference between "significant acute toxicity" (greater than 30 percent response) and "severe acute toxicity" (greater than 70 percent response). This higher level of effects addresses the intent of Site Condition III (section 8.2.1) at which toxicity in the range of 30 to 70 percent mortality is expected among bioassay indicators. Many dose-response toxicity curves are steep. Once a response is seen in 30 percent of the test population, a 70 percent response is typically observed with only a small increment in chemical concentration. Consequently, the ML3 values were arbitrarily set at twice the ML2 values. As sediment quality values are refined to better indicate "severe adverse effects", these revised values may be used to supplant the ML3 values, if needed.

TABLE II.8-3. CHEMICAL DISPOSAL GUIDELINES FOR ALTERNATIVE SITE MANAGEMENT CONDITIONS

o	Site Condition I -	"No sublethal or acute toxicity": chemically defined as ML1(a), where ML1 is the lowest AET(b) for a series of biological indicators (i.e., higher concentrations are expected to result in effects measured by at least one biological indicator)
o	Site Condition II -	No "significant acute toxicity": chemically defined as ML2, where ML2 is the highest AET for a series of biological indiators (i.e., higher concentrations are expected to result in effects measured by each of the biological indicators)
o	Site Condition III -	No "severe acute toxicity": chemically defined as ML3, where ML3 is twice ML2; although somewhat arbitrary, this higher concentration of contaminants is expected to result in more severe effects than at ML2 (i.e., similar to the observation that toxicity curves continue to increase sharply above the level that toxicity becomes statistically significant)

(a) ML = maximum chemical levels established for Site Conditions I, II, III, and IV are discussed in section II-8.2; numerical values for each maximum level are given in table II.8-4. Dredger option to conduct biological testing exists (see section II-2.5).

(b) AET = Apparent Effects Threshold; see section II.7-2.

June 1988 rev.

TABLE II.8-4. SCREENING AND MAXIMUM LEVEL CHEMISTRY VALUES

Chemical	SL*	ML1*	ML2*	ML3*
METALS (mg/kg dry weight; ppm)				
Antimony	2.6	3.2	26	52
Arsenic	70	85	700	1400
Cadmium	0.96	5.8	9.6	19.2
Copper	80	310	800	1600
Lead	70	300	700	1400
Mercury	0.21	0.41	2.1	4.2
Nickel	28	28	49(a)	98
Silver	1.2	1.2	5.2	10.4
Zinc	160	260	1600	3200
ORGANICS (ug/kg dry weight; ppb)				
Low molecular weight PAH	610	5200	6100	12200
Naphthalene	210	2100	2100	4200
Acenaphthylene	64	560	640	1280
Acenaphthene	63	500	630	1260
Fluorene	64	540	640	1280
Phenanthrene	320	1500	3200	6400
Anthracene	130	960	1300	2600
2-Methylnapthalene	67	670	670	1340
High molecular weight PAH	1800	12000	18000(a)	36000
Fluoranthene	630	1700	6300	12600
Pyrene	430	2600	4300(a)	8600
Benz(a)anthracene	450	1300	4500	9000
Chrysene	670	1400	6700	13400
Benzofluoranthenes	800	3200	8000	16000
Benzo(a)pyrene	680	1600	6800	13600
Indeno(1,2,3,-c,d)pyrene	69	600	690(a)	1380
Dibenzo(a,h)anthracene	120	230	1200	2400
Benzo(g,h,i)perylene	540	670	5400	10800

TABLE II.8-4. (Continued)

CHLORINATED HYDROCARBONS				
1,3-Dichlorobenzene	170	b	b	b
1,4-Dichlorobenzene	26	110	260	520
1,2-Dichlorobenzene	19c	35	50a	100
1,2,4-Trichlorobenzene	6.4	31	64	128
Hexachlorobenzene	23	70	230	460
PHTHALATES(c)				
Dimethyl phthalate	160	d	d	d
Diethyl phthalate	97	d	d	d
Di-n-butyl phthalate	1400(a)	d	d	d
Butyl benzyl phthalate	470	d	d	d
Bis(2-ethylhexyl)phthalate	1900(a)	d	d	d
Di-n-octyl phthalate	68000	d	d	d
PHENOLS				
Phenol	120	420	1200	2400
2-Methylphenol	6.3	63	63(a)	126
4-Methylphenol	120	670	1200	2400
2,4-Dimethyl phenol	10c	29	29	58
Pentachlorophenol	140	b	b	b
MISCELLANEOUS EXTRACTABLES				
Benzyl alcohol	10c	57	73	146
Benzoic acid	216c	650	650(a)	1300
Dibenzofuran	54	540	540	1080
Hexachloroethane(e,f)	1400	14000	14000	28000
Hexachlorobutadiene	29	120	290	580
N-Nitrosodiphenylamine	22	40	220	440
VOLATILE ORGANICS				
Trichloroethene(e,f)	160	1600	1600	3200
Tetrachloroethene	14	140	140(a)	280
Ethylbenzene	3.7	33	37(a)	74
Total xylenes	12	100	120(a)	240

TABLE II.8-4. (Continued)

PESTICIDES				
Total DDT	6.9	14.9	69	138
Aldrin	5	g	g	g
Chlordane	5	g	g	g
Dieldrin	5	g	g	g
Heptachlor	5	g	g	g
Lindane	5	g	g	g
TOTAL PCBs	130	130	2500	5000

* The following procedures were used to develop SL, ML1, ML2, and"ML3:

SL = 10% of ML2 or reference area concentration, whichever is higher, but no greater than the lowest AET for a range of biological indicators.
ML1 = Lowest Apparent Effects Threshold Value (LAET) for a range of biological indicators.
ML2 = Highest Apparent Effects Threshold Value (HAET) for a range of biological indicators.
ML3 = (ML2) x (2).

SL and ML values shown in this table are those originally derived during the Phase I study. As a result of information received during public review of the Phase I documents, several of the values have been updated (see table in section II-11 for current values). The older values are left here to reflect the historical decision process.

(a) The ML set for this chemical is based on a biological indicator with a definitive AET. These values may be adjusted upward based on another biological indicator which is currently represented by a "greater than" value for the AET (see the Sediment Quality Values report; exhibit E-21). For such biological indicators, the "greater than value is the highest concentration of a chemical above which there has yet to be a bioassay that met disposal guidelines, and indicates that there were no impacted stations with chemical concentrations above this value (a requirement for setting definitive AET). During review of actual testing data, it was determined that these "greater than" values are useful estimates of the maximum level until more definitive data are available.

TABLE II.8-4. (Continued)

(b) No ML was originally set for these chemicals because definitive AET could not be set for any biological indicator (see discussion on "greater than" values in footnote a). ML values may be assigned for several of these chemicals based on the highest "greater than" value presented in the Sediment Quality Values report (exhibit E-21).

(c) For these compounds, the reference concentration was higher than the calculated value of SL so SL was set at the reference value.

(d) Biological testing should not be triggered solely by the presence of phthalates. Because these compounds are often present as laboratory chemicals of concern, the highest AET was used as the screening level and no maximum levels were set.

(e) These ML2 values were set using the Equilibrium Partitioning approach (Tetra Tech 1986j) because no AET values were available.

(f) For chemicals with ML2 values set by the Equilibrium Partitioning approach, ML1 was set equal to ML2, and SL and ML3 values were calculated from ML2 according to the formulas given above.

(g) SL for these pesticides was set to 5 times an assumed analytical detection limit of 1 ug/kg dry weight sediment. No sediment quality values were available for setting maximum levels.

8.4 Procedure for Defining Human Health Bioaccumulation Levels. Bioaccumulation values for those chemicals that are a human health concern because of fish consumption were calculated by estimating daily consumption rates of fish that could have been exposed at the disposal site, calculating the target tissue concentration values, and comparing the target values to data on bioaccumulation for species from Puget Sound. These target values will be used to interpret laboratory bioaccumulation tests on proposed dredged material relative to human health concerns. The Puget Sound bioaccumulation data used in this study included laboratory and field data for species (mostly bivalves) from sediments that are representative of both reference and non-reference areas throughout Puget Sound.

8.4.1 Assumptions Made in Calculating Adjusted Health Indicators. Adjusted health indicators were developed by EPWG to approximate tissue concentrations of concern. The following simplifying assumptions were made concerning the relationship between tissue concentrations of chemicals of concern in aquatic species and potential human health concerns:

- o Human exposure route is primarily through consumption of fish that could be directly exposed to bottom sediments at the disposal site (i.e., flatfish)
- o All human exposure (consumption of flatfish) comes from a single population of fish having a home range that includes the disposal site
- o Exposure of the flatfish population is directly proportional to the area of the home range covered by the disposal site
- o Tissue concentrations of flatfish are directly proportional to exposure at the site (assumes 100 percent assimilation of chemicals of concern)
- o Both flatfish and human exposure factors can be expressed as reduced consumption rate (i.e., that all fish in the home range are equally available to be caught).

8.4.2 Target Tissue Concentration Calculation Models. To calculate target tissue concentration of chemicals that might pose a human health problem if the tissue was ingested, the following models were used:

For chemicals posing a carcinogen risk: $C = (R)(W)/(B)(I)$

where:

C = target tissue concentration
R = reference risk level
W = reference human weight
B = potency factor for the chemical in question
I = average seafood ingestion rate per human.

For noncarcinogens posing a human health risk: $C = (RFD)(W)/I$

where:

C = target tissue concentration
RFD = reference Risk Dose (Acceptable Daily Intake) Values
W = reference human weight
I = average seafood ingestion rate per human.

Of the variables given in the above models, several have established values that are set by EPA documents (see Tetra Tech 1986a). These include values for B, RFD, and W. The values for B and RFD are established based on toxicity data for the chemical in question and W is set at 70 kg, which represents the weight of a "reference man." Two variables that are subject to policy decisions are the reference risk level (R) and the seafood ingestion rate (I). In a previous EPWG meeting, the decision was made to set (R) at a value of 10-5.

8.4.3 Seafood Ingestion Rate Estimate. Seafood ingestion rates that estimate the amount of fish caught and eaten that could have been exposed to dredged material at the unconfined, open-water, disposal sites were calculated based on the following assumptions and available data. The ingestion estimates are calculated for bottom fish caught by recreational anglers only:

- Baseline seafood consumption rates for seafood caught in urban bays by recreational anglers were based on the data of Landolt et al. (1985). According to their report, the average daily fish ingestion rate for seafood from the urban bays is 11 g/day (table 62d, p. 65 in Landolt et al. 1985).

- The above value was adjusted to reflect the percentage of seafood caught that was represented by flatfish (which are the primary finfish that would be exposed to the open-water dredged material mound). According to Landolt et al. 1985, bottom flatfish represent 2.5 percent (by weight) of the total amount caught. Therefore the amount of seafood eaten that is composed of flatfish = 11 g/day x (2.5 percent) = 0.28 g/day.

- The food ingestion rate was further adjusted to reflect the amount of consumed flatfish that could have been exposed to dredged material at the disposal mound. This was accomplished by estimating the percent of the individual home range for bottom fish that was covered by the disposal site. This value is then applied to the daily ingestion rate to provide an estimate of the dietary contribution of fish eaten that might have been exposed to the disposal mound.

Studies on the nonrandom occurrence and stable percent incidence of fish liver tumors and tagging-recapture studies indicate that flatfish exhibit a home range in which juveniles and adults spend most of their lives within a given area. Bottom fish have also been shown to exhibit seasonal migrations perpendicular to the shoreline in an area approximately bounded by the 600-foot depth contour (Tetra Tech 1986; Bargmann, G., 1986, personal communication). The longshore extent of the home range is not known, but it has been approximated by the distance between West Point and Terminal 90/91 (approximately 3.2 mi). It is important to note that estimating the areal extent of a fish's home range is a very uncertain exercise and such estimates should be understood to be very rough.

Based on these data and assumptions, the final steps leading to the estimated seafood ingestion rate were:

1. Home range area estimate = 2,334 ac

TABLE II.8-5. RESULTING TARGET TISSUE CONCENTRATION VALUES (HI) FOR CHEMICALS OF CONCERN TO HUMAN HEALTH

Chemical	HI (ppm)(a)	Max. Ref. Value	Max. Non-Ref. Value
Antimony	5,600.0	---	---
Arsenic	10.1(d)	32	17.7
Mercury	300.0	0.21	0.20
Nickel	20,000.00	UD(b)	0.33
Silver	200.0	0.14	0.36
Benzo(a)anthracene	1.2	0.005	0.23
Fluoranthene	8,400.0	---	---
1,2-Dichlorobenzene	300.0	ND	ND
1,3-Dichlorobenzene	300.0	ND	ND
1,4-Dichlorobenzene	300.0	ND	ND
Dimethyl phthalate	300,000.0	UD	0.20
Di-n-butyl phthalate	30,000.0	UD	1.7
Bis(2-ethylhexyl) phthalate	18,000.0	0.13	0.25
Hexachloroethane	198.0	ND	ND
Hexachlorobutadiene	180.0	ND	ND
Phenol	3,000.0	ND	ND
Pentachlorophenol	900.00	ND	ND
Ethylbenzene	600.0	ND	ND
N-nitrosodiphenylamine	2,845.0	ND	ND
Hexachlorobenzene	180.0	0.003	0.07
Trichloroethene	127.0	ND(c)	ND
Tetrachloroethene	27.0	ND	ND
Total DDT's	41.0	0.007	0.06
Aldrin	1.2	0.001	0.004
Chlordane	8.7	0.004	0.02
Dieldrin	0.46	0.002	0.08
Heptachlor	4.2	UD	0.007
PCBs	.2	0.10	4.9

(a) Tissue concentration values result from an exposure analysis that calculates potential transfer of chemicals from the disposal site to humans via seafood consumption. The estimated low potential for this transfer results in relatively high tissue values for interpretation of lab tests.
(b) UD = Undetected. Chemical was analyzed for but was not detected.
(c) ND = No data. Chemical was not analyzed for in Puget Sound species.
(d) Adjusted based on reported ratio of inorganic to organic As (Tetra Tech 1986a).

2. Disposal site area estimate = 395 ac (Elliott Bay site; the largest Phase I site)

3. Percentage of home range covered by disposal site = $\frac{395 \text{ ac}}{2{,}334 \text{ ac}} \times 100 = 17$ percent

4. Amount of seafood caught and ingested in an urban bay that would have been in contact with the disposal mound (sediments or benthic infauna) = (0.28 g/day) x (0.17) = 0.05 g/day

5. The seafood ingestion rate of 0.05 g/day was substituted for the parameter (I) in the models presented in section 6.5.2.

The calculated target concentrations for chemicals of concern to human health (HI) are listed in table II.8-5.

8.4.4 Analysis of Adjusted Human Health Indicator Values. The HI presented above should not be considered firm, predictive, or definitive. They represent an application of the EPA carcinogen risk and RFD models for estimating acceptable tissue concentrations for certain chemicals. The models themselves are not proven. However, they offer the best direction that EPA has for determining the relationship between dietary intake and human health. Also, the ingestion rates applied to the models are a very rough (and conservative) approximation of the amount of fish tissue from an urban bay consumed by anglers that comes from fish that either spent their life on the disposal mound or at least feed at the mound.

Review of the HI table indicates that, based on data for bioaccumulation levels found in Puget Sound species, only arsenic and PCB's are likely to indicate a human health problem. In both cases, the bioaccumulation values for at least the nonreference areas exceed the HI value. These values are not likely to be exceeded in dredged material bioaccumulation tests because the values reported for bioaccumulation represent maximum values for urban bays and are probably not representative of levels expected for organisms exposed to moderately containing chemicals of concern dredged material (e.g., less than the maximum level allowed for open-water disposal; see section 7.3). Although uncertainty is high and data are insufficient to prove or disprove concern, it is not expected that bioaccumulation values for bivalves will exceed the HI values following the 30-day test exposure period.

Arsenic is unique in that both reference and nonreference tissue levels in Puget Sound exceed the indicator value. Arsenic is high in reference tissues primarily because arsenic is naturally elevated in seawater in the northeastern Pacific (including Puget Sound) and is bioaccumulated by organisms.

This condition implies that the indicator value would not be useful in interpreting bioaccumulation tests on dredged material because control, reference, and test tissues are likely to exceed the HI. Consequently, arsenic tissue concentrations should be interpreted by the use of statistically significant elevations above reference (EAR) tissue concentrations as a measure of pollutant effects that are of concern for human health. That is, if tissue concentrations for test organisms are significantly above tissue concentrations for reference organisms, the dredged material would be considered unacceptable for unconfined, open-water disposal.

For PCB's, the allowable tissue concentration is higher than that currently set by U.S. Food and Drug Administration (FDA). To be protective, the PCB tissue concentration level will be reduced to the FDA concentration of 2 ppm. If tissue concentrations in organisms from the test sediment are higher than 2 ppm, the dredged material would be considered unacceptable for unconfined, open-water disposal.

The bioaccumulation test will be conducted on those proposed dredge materials in which the sediment bulk chemistry levels are below the maximum level values and above the bulk sediment bioaccumulation trigger values (see table II.6-2). If the 30-day bioaccumulation test results in bioaccumulation levels greater than the HI (table II.8-5), the sediment will not be allowed for unconfined, open-water disposal. It is anticipated that over the next few years these bioaccumulation tests will provide sufficient data to determine if this concern warrants continued bioaccumulation testing.

Although dredged material data are insufficient to provide definitive conclusions, there are few indications of potential problems (see table II.8-5) deriving from bioaccumulation of chemicals for which tissue data are not available. Bioaccumulation from dredged material should not represent a major risk to human health. However, additional data are necessary to support (or refute) this perspective. Consequently, bioaccumulation tests would only be performed for dredged material with relatively elevated chemical concentrations. Additionally, the extent of bioaccumulation testing required for any one project should also be limited.

The subject of what constituted "elevated chemistry" that warranted bioaccumulation testing was debated. Bioaccumulation testing would be required for sediments containing chemicals of concern for human health at concentrations in the upper 30th percentile of the concentration allowable for unconfined, open-water disposal (i.e. 70 percent of the difference between the SL and ML concentration). This value was an arbitrary expression of the EPWG consensus concern for bioaccumulation. Analysis of bioaccumulation test tissues will be performed after other biological tests (bioassays) have been conducted.

In limiting the bioaccumulation testing for a given project, no more than one-half of the management units being analyzed would be required to undertake bioaccumulation testing. This limitation is based on the general premise that most dredged material would not result in tissue concentrations of concern (see section II-8.4 introduction).

Because of the ongoing development of additional bioaccumulation data and the expected reduction of the list of chemicals of concern to human health, bioaccumulation testing may be eliminated altogether in future revisions to the evaluation procedures.

9. EFFECTS ANALYSIS OF ALTERNATIVES

9.1 Introduction. The following analysis assesses the potential environmental impacts of establishing a biological effects condition for site management at unconfined, open-water disposal sites. A detailed environmental effects analysis of the alternative site management conditions considered by PSDDA is contained in the draft EIS. The EPWG selection of a site management condition constituted a recommendation to the overall PSDDA study regarding the preferred alternative to be addressed in the PSDDA draft EIS.

When assessing the potential effects of each alternative site condition, an evaluation of impacts those associated with unconfined, open-water disposal, and the consequences of disposal of material not acceptable for unconfined, open-water disposal. An analysis of the impacts to both open-water and land environments serves to highlight the fact that environmental tradeoffs exist regardless of where dredged material is disposed.

The smaller the quantity of dredged material placed at the unconfined, open-water site, the greater the quantity of material containing chemicals of concern requiring land or shore disposal (and vice versa). As such, the risk associated with chemicals of concern in dredged material will shift between aquatic and land sites. Site conditions that result in the least amount of chemicals in material to be placed at open-water sites would place most of the environmental (terrestrial species, freshwater species) and human health (exposure, drinking water) risks associated with chemicals of concern at the confined sites. Conversely, selection of an alternative that allows for the placement of dredged material with high levels of chemicals at the open-water sites would place most of the environmental (benthic species, marine fish) and human (chemicals in seafood) risks at those sites.

The following key assumptions are made concerning the prediction of future conditions at the disposal sites. First, the assessment assumes that most dredged material found to be acceptable for unconfined, open-water disposal will be discharged at the PSDDA identified disposal sites. Though some material will likely be placed at upland or near shore sites as part of occasionally approved fill projects, the relatively inexpensive and available unconfined, open-water sites are likely to be preferred by most dredgers with acceptable dredged material.

A second key assumption is that most material found unacceptable for unconfined, open-water disposal is expected to be dredged, not left in place. Although the cost of confined disposal will likely render some projects economically infeasible, the number of projects that will opt to not dredge cannot be easily ascertained for this analysis. Consequently, the analysis assumes that comparable volumes of dredging will be conducted regardless of the site management condition considered.

A third key assumption is that the site management condition, once selected, will be maintained throughout the 15-year analysis period. The alternatives analysis assumes that the preferred site condition will be maintained without exception to facilitate a clearer picture of the possible environmental effects.

9.2 Dredging Site Environmental Analyses. An analysis of the environmental effects of dredging includes effects at the dredging site as well as those of the disposal site. Only a brief review of environmental effects at the dredging site is given in this section because most dredging will occur (if the project is economically feasible and environmentally acceptable) regardless of the chosen site condition. Project-specific review will be required to determine if the dredged material will go to unconfined or confined disposal, based on where the specific project is located, when the dredging is scheduled to take place, and how the dredging will be accomplished.

Environmental concerns at the dredging site are associated primarily with the release of particle-bound and soluble-phase chemicals of concern due to sediment disturbance. Release of sediment-bound ammonia and local reductions in dissolved oxygen (from increased chemical oxygen demand of anoxic sediments disturbed during dredging) may be environmental concerns in certain areas. Available knowledge and experience can be considered in decisionmaking for these variables.

Potential adverse environmental effects at the dredging site are not significant when removing material that is acceptable according to Site Condition I or II guidelines. Chemical concentrations in such material are relatively low, dilution levels are relatively high during dredging operations, and water column release of chemicals of concern are expected to be negligible. The primary concern in dredging this material is localized changes in water quality resulting from lowered dissolved oxygen, increased water column particulate levels, and the release of ammonia. Current control technologies (e.g., providing mixing zones, restricting dredging to "windows" when adverse effects would be reduced) are considered sufficient to prevent significant adverse effects at the dredging site.

Concerns over adverse environmental effects during dredging operations is greater with material that is unacceptable for unconfined, open-water disposal under Site Condition II. Such material poses potential problems with the

resuspension of containing chemicals of concern sediment and the possible release of chemicals of concern into the water column. Additional testing of other contaminant pathways (see section II-2 and section IV) and possible restrictive measures may be necessary before material of this type can be dredged. Though PSDDA is conducting additional studies that will assist in evaluating dredging and disposal of containing chemicals of concern sediments, the decision on testing and needed restrictions ultimately is made on a project-specific basis by the appropriate permitting agencies.

9.3 Disposal Site Environmental Analysis. Potential effects at the disposal site are the focus of the environmental effects analysis of the alternative site conditions. Such effects are of greatest concern because dredged material will often have different physicochemical properties than the native sediment at the disposal site. The magnitude of these differences can affect chemical mobility in dredged material (U.S. Corps of Engineers 1983). More importantly, the disposal sites represent biologically active environments. Disposal of material will have at least an adverse physical effect on existing benthic communities.

9.3.1 Factors Affecting the Fate of Dredged Material Contaminants. The properties of dredged material, and the shortand long-term physical and chemical environment at the disposal site influence the fate and environmental consequences of chemicals of concern. The major variables that influence contaminant behavior in dredged material are the amount and type of clay; organic matter content; amount and type of cations and anions associated with the sediment; the amount of potentially reactive iron and manganese; and the oxidation reduction, pH, and salinity conditions of the sediment. The most important factors are percent clay and organic matter content, initial and final pH, and oxidation-reduction conditions. Dredged material from industrial/urban areas frequently contain relatively high concentrations of organic matter and clay and are biologically and chemically active. These sediment conditions favor effective retention of many chemicals of concern, provided the dredged materials are not subject to mixing, resuspension, or changes to their chemical environment. Sandy sediments, in contrast, are typically low in organic matter content and less effective in retaining metal and organic chemicals of concern. Sandy sediments tend not to accumulate chemicals of concern unless a contaminant discharge is located nearby. Should chemical concentrations of sandy sediments occur, potentially toxic substances may be readily released upon mixing in the water column or by leaching.

Disposed into an aquatic environment, dredged material remains water-saturated, anoxic, reduced, and near-neutral in pH. In contrast, when sediment is taken out of the water and allowed to dry in an upland site, it becomes oxic and the pH may drop. Nearshore disposal sites can have a combination of anoxic, reduced conditions in the dredged material placed below tidal elevation, and oxic conditions in dredged material placed above the tidal elevation.

9.3.2 Review of Available Information on Disposal Impacts. Much of the current knowledge concerning the impacts of dredged material disposal is derived from a series of studies conducted by the Corps' WES. Since 1970, when the Dredged Material Research Program (DMRP) was authorized under the Rivers and Harbor Act, several research and applied programs have been instituted by WES. These include the DMRP, the Long-Term Effects of Dredging Operations Program (LEDO), and the Field Verification Program (FVP). Together these programs have addressed a wide array of topics concerning the dredging and disposal of dredged material including the effects of dredging operations on water column and benthic environments, description of dredged material behavior during and following disposal, design and operation of confined disposal sites, and field investigations of the effects of disposal operations. This work has also addressed beneficial uses of dredged material (e.g., use of dredged material for habitat development). In addition to the work directed by WES, information on dredging impacts can be found in symposium proceedings such as the International Ocean Disposal Symposium, Symposium on Coastal and Ocean Management, and Dredging and Dredged Material Disposal Symposium (sponsored by American Society of Civil Engineers). In addition, major dredging studies have been undertaken in the Northwest and Puget Sound region. These studies included the Anacortes Dredging Study (1970), Northwest Dredging Effects Study (1974), the Budd Inlet, Olympia Study (1975), the Grays harbor Dredging Effects Study (1976-1977), and the Duwamish River Sediment Study (1976-1980). The following brief review discusses work that addressed the impacts of dredged material disposal on the aquatic environment.

For most dredged material nationwide, environmental effects of disposal in open waters are largely the result of physical impacts associated with disposal. Physical impacts include complete burial of benthic communities existing in the disposal zone. Recolonization of a disposal site can be rapid, providing the material is of similar grain size as the native sediments. More persistent physical impacts to benthic organisms can occur where dredged material is placed on substrates of dissimilar grain size, with impacts greatest when dredged material containing a high percentage of sand is placed on mud substrate and covers mud-dwelling organisms unsuited for living in sandy sediments (Maurer et al. 1978).

The level of chemical concentrations of exposed sediments may also affect rates and the general success of recolonization at the disposal sites. Work at the Black Rock Harbor research disposal site using a very highly contaminated dredged material (via FVP research of the Corps and EPA) indicates that the rate of recolonization is slower than would be expected based on field work with freshly deposited sediment that is relatively clean but similar in grain size to Black Rock Harbor material. The Black Rock Harbor material was disposed in aquatic, confined upland, and newly-created confined wetland disposal sites. A thorough evaluation of lab assessments and tests was performed, and a comparison was made of effects among disposal sites.

Interpretation of the recolonization data for material disposal at the Black Rock Harbor aquatic site is confounded by the fact that grain size changes occurred at the disposal site due to winnowing of the fines to the mound flanks. A hurricane event also perturbed the site during the recolonization studies.

Chemical concentrations in the Black Rock Harbor material are considerably higher than the level that would be acceptable in Puget Sound waters under PSDDA. Although results similar to those seen with Black Rock Harbor material are not expected at the Phase I disposal sites, the information obtained from the FVP is useful in identifying potential adverse effects that warrant consideration in dredged material assessment.

Impacts to the water column have been found to be generally of short-term duration and typically are the result of increases in turbidity and release of chemical constituents such as ammonium, manganese, iron, and orthophosphates (Blom, et al. 1976; Chem, et al. 1976; Jones and Lee 1978). Changes in water column properties brought about by the release of dredged material into the aquatic environment are are not considered to be sources of significant impact to aquatic organisms. Baumgartner et al. (1978), in monitoring physical and chemical parameters in the water column during and following disposal of material at the Duwamish waterway disposal site, concluded that no long-term effects resulted from the disposal operations. Parameters measured during their field investigations included suspended solids, pH, ammonium, nitrates, nitrites, and several heavy metals.

Increases in turbidity (e.g., increases in suspended particles) due to dredged material disposal do not apparently cause significant or long-term impacts to aquatic species. Turbidity studies of Peddicord et al. (1975), Peddicord and McFarland (1978), and McFarland and Peddicord (1980) have shown lethal concentrations of suspended dredged material to be at least an order of magnitude higher than maximum water column concentrations observed during dredging operations. Gentile, et al. (1985), however, found that the crustaceans decreases as the concentration of chemicals associated with the suspended particles increases. Both mysids and amphipods exhibited lethality to contaminated suspended sediments at concentrations significantly lower than that required when the same species were exposed to clean sediments having similar grain size distribution to the material containing chemicals of concern. The significance of the findings of Gentile, et al. (1985) to benthic populations near a dredged material disposal site are unknown. Baumgartner, et al. (1978), reported small, though persistent increases in suspended particles levels near the bottom during long-term monitoring of a Duwamish River waterway disposal site. The laboratory work of Gentile, et al. (1985) suggests that disposal of dredged material containing chemicals of concern could result in some impacts to benthic species if the material were to result in persistent increases in suspended particles in and around the disposal site.

Impacts of chemicals, especially chronic impacts, are generally thought to be due to the uptake, accumulation, and (as in the case with some chemicals) metabolic transformation of the compound into toxic forms (e.g., benzo(a)pyrene). The biological availability of chemical compounds associated with some dredged materials will greatly influence the rate at which these compounds will be accumulated. Early work under the DMRP by Neff et al. (1978) on metal availability and accumulation in aquatic species indicated that metals were not generally taken up by the test organisms. When accumulation did occur, the levels to which the metals were concentrated often varied from one sampling period to another and were quantitatively marginal.

Recent research on bioaccumulation from dredged material indicate that organics, as a general class of compounds, are more biologically available to aquatic organisms than are metals (Lake, et al. 1985). Lipophilic organic compounds (those that have affinity for fats and oils) appear to be readily bioaccumulated from sediments to which they are associated. In both laboratory experiments and field evaluations, bivalves and burrowing polychaetes have been found to accumulate significant concentrations of organic compounds that had been associated with dredged material.

In conclusion, past laboratory and field research efforts have largely indicated that the disposal of most dredged material will not result in unacceptable adverse effects to the receiving environment. This is especially true if the material being dredged is coarse-grained and without measurable levels of chemicals of concern. Much of the material dredged in the central portion of Puget Sound, however, has just the opposite characteristics. Sediment dredged from the urban waterways near major metropolitan areas in Puget Sound is typically fine-grained with high clay and organic content, and contains significant concentrations of chemicals of concern discharged by nearby urban sources.

Understanding the interaction between chemicals of concern, dredged material properties, and physical, chemical, and biological conditions at a proposed disposal site will aid in selection of disposal methods that will minimize potential contaminant release and transport. The following sections present a discussion of how these potential biological effects and pathways differ for each of the disposal options.

9.3.3 Unconfined, Open-Water Disposal. The pathways of exposure that might be expected at an open-water disposal site where unconfined dredged material is placed are depicted in figure II.2-2 (section II-2). During disposal operations, fine particles and organic matter can be released into and accumulate in the sea-surface microlayer. Once in the sea-surface microlayer, chemicals of concern associated with these particles and organic matter can adversely affect marine eggs and larvae and can be carried to nearby beaches. In the past, visible "slicks" and occasional "sheens" have been reported during

dredging in the Elliott Bay area. Although most of these solids will settle to the bottom, dredged material normally will contain some material that could be released to the surface.

As the discharged dredged material descends through the water column, a portion of the dredged material will entrain water and particles can be "stripped away." The net effect is that the material can be transported by ambient currents away from the designated disposal site. Such material usually consists of the finer silt and clay particles and any neutrally buoyant particles. The magnitude of this effect will depend upon hydrologic forces at the disposal site.

Of the disposed material that does affect bottom communities, some may become resuspended by current action or through biological activity and be transported off the disposal site. Material releases that do occur can be minimized by proper siting of the disposal site in environments that are physically nondispersive (low or weak currents), and at depths below the influence of surface wave action. The environmental effect of material that is lost during and after disposal is not known.

Of the material that does settle within the disposal site, the primary routes of exposure depend on the direct interaction of organisms with the bedded dredged material. Larval and adult forms of the benthic species that settle on the newly deposited material come into contact with particle-bound contaminants and with dissolved chemicals of concern within the sediment pore water. Accumulation of these chemicals of concern will depend largely on the concentration of the chemicals of concern and their relative biological availability. The effects of biological accumulation of chemicals of concern are not understood, although it is generally accepted that chronic effects result from chemicals of concern that are biologically available, accumulated, and, in some instances, metabolically modified. Transport of chemicals of concern from the disposal site, other than through material release of suspended particles and soluble diffusion, can occur when benthic organisms emigrate from the site or when epibenthic predators feed on benthic species inhabiting the disposal area.

9.3.4 Confined Aquatic Disposal. Confined aquatic disposal is the placement of contaminated dredged material at an aquatic site followed by capping with cleaner material over the contaminated sediment. As long as the cap remains in place, the major pathways of concern for contaminant loss are diffusion (of soluble components) and convection. The pathways of concern for unconfined, open-water disposal (e.g., bioturbation and resuspension) are effectively eliminated, providing the cap is thicker than the depth of expected biological activity. At water depths unaffected by wave action, and in locations that have low current velocities, movement of interstitial water is substantially absent and contaminant movement through the sediment is consequently a minor pathway.

A confined aquatic disposal site must meet certain physical requirements to prevent contaminant losses. The area must have relatively low current velocities, must not be located on a steep slope, and must be below the depth at which wave action is a factor. During disposal operations, exposure pathways are similar to those outlined in the section II-9.3.3 for unconfined, open-water disposal. These pathways include potential release to the sea-surface microlayer, particle loss due to water entrainment, and loss of material on impact with the bottom.

9.3.5 Upland Disposal (Conventional and/or Confined). Upland disposal involves the placement of dredged material on land, typically above upper tide levels. Upland disposal sites are normally diked areas that retain the dredged solids while allowing the carrier and/or consolidation water to be released. Upland sites can also accept dredged material that has been dewatered elsewhere and transported in by truck or rail. Such sites may be located immediately adjacent to, or removed great distances from, the dredging site. The major pathways of chemical exposure are discussed in section III.

When dredged material dries in an upland environment, drastic physicochemical changes occur. During the drying process, organic complexes oxidize and decompose. As the sediments dry, volatile contaminant losses to the air may occur due to changes in atmospheric pressure that can "barometrically pump" air through the sediment mass. In addition, oxidation of iron complexes and other metal complexes also occur. These chemical transformations could release chemicals of concern to surface runoff, soil pore water, and leachate through the material. Upland disposal can result in leaching of chemicals of concern to the ground water or back to surface waters (seeps).

After most of the solids have settled in the disposal site (for hydraulic dredging) and sediment consolidation extrudes pore water (for hydraulic and mechanical dredging), the return water will be discharged back into the environment. This effluent and site runoff water can carry dissolved and particulate-bound chemicals of concern. Floatable chemical concentrations could also be contributed to the sea-surface microlayer.

Proper site design and, if needed, treatment of the effluent, can significantly reduce contaminant losses via the effluent. Unlike the effluent, longer-term geochemical changes due to oxidation in the upland site can mobilize additional chemical concentrations which would be available for transport by ground water or surface water. If a cap is not present, plants and animals that colonize the upland site could take up and bioaccumulate released contaminants, as well as pass them farther up the food chain and/or offsite.

9.3.6 Nearshore Disposal (Conventional and/or Confined). Nearshore disposal combines open-water and upland disposal methods at a single site by placement of dredged material in an aquatic environment. The final surface elevation after filling is above water (normally marine or tidal). Nearshore disposal sites for contaminated sediments are diked, confined areas that are often capped with cleaner material. The routes of contaminant exposure that are a concern with shore disposal sites are discussed in section III.

Several pathways exist for soluble convection and diffusion of chemicals of concern from a diked nearshore disposal site. Depending upon the degree of ground water seepage that occurs at the site, production of leachate into the sediment below the disposal mound and seepage under or through the dike can be important pathways of contaminant release. The geochemistry at nearshore sites varies above and below the saturation level established by tidal action. Contaminants in dredged material will behave differently in each of these environments.

As with confined aquatic disposal, the cap provides an effective barrier against the release of chemicals of concern, providing the cap integrity is not destroyed. If a cap is not present, pathways of exposure would include contact and uptake of chemicals of concern by plant and animal life, as well as transport of chemicals of concern from the site through surface runoff.

9.4 Availability of Alternative Disposal Options. When evaluating the environmental effects of dredging, consideration must be to (1) the environmental consequences of maintaining a particular site management condition at unconfined, open-water sites, and (2) the adverse effects of disposing material unacceptable for unconfined, open-water disposal at alternative disposal sites. As presented in section I-3, three disposal options are available for such material. These options include confined aquatic disposal (CAD), the capping of dredged material deposited in water with "clean" material, and disposal in shore or land areas.

Confined aquatic disposal is not currently available throughout Puget Sound, and may not be used routinely for a variety of reasons. Historically, there has been avoidance of, and protective treatment given to, the aquatic environment when considering disposal sites for contaminated materials. Additionally, there is a public perception in the Puget Sound area that aquatic capping of dredged material is not entirely reliable or technically feasible in the deep waters of Puget Sound. This perception has also limited the application of the confined aquatic disposal option. Furthermore, siting and monitoring requirements for confined aquatic sites are likely to limit use of this disposal option to a few larger projects in the near term. Confined aquatic disposal may become a more preferred option in the future after projects have been undertaken to develop and demonstrate technical feasibility of capping material at available deepwater sites in Puget Sound. Technology does exist to dispose of and sufficiently cap containing chemicals of concern material in aquatic sites (Morton 1983). Monitoring of existing confined aquatic disposal sites also indicates that the cap is effective in isolating and sequestering chemicals of concern (Morton et al. 1983).

9.5 Comparison of the Preferred Phase I Disposal Sites. DSWG evaluated potential disposal sites within Puget Sound by using a variety of site selection factors. The selection factors were applied to all sites evaluated and the preferred sites identified by DSWG are the ones that most closely fit the selection factors. For the purposes of this analysis, all unconfined, open-water disposal sites being considered by PSDDA (one each at Commencement Bay, Elliott Bay, and Port Gardner) will be treated as environmentally similar. Although some differences do occur between the sites (table II.9-1), the factors that normally affect exposure pathways are similar among the preferred sites. Where appropriate, differences between the sites that would affect the conclusions drawn from the environmental analysis will be highlighted.

All three sites are located in low-energy environments (less than 0.5 knots current speed) that are relatively nondispersive with respect to resuspension of dredged material. In addition, all three preferred sites have similar physical and biological characteristics (i.e., a similar granulometry and approximate levels of benthic biomass and benthic infauna speciation). Differences that do occur between the preferred sites include depth and the number and kinds of amenities (resources) that are found in areas around the disposal site. The most obvious amenity difference is that the Port Gardner area contains higher concentrations of Cancer magister in shallower waters of the bay than does Elliott Bay or Commencement Bay. Assessment of the environmental effects of disposal at the Port Gardner site will include an evaluation of the proximity of, and possible adverse effects of containing chemicals of concern sediments to, this crab population. The effects of sediment chemical concentrations on Dungeness crabs have not been extensively studied. Some previous research with gravid female crabs exposed for up to 60 days and larvae exposed for up to 10 days to containing chemicals of concern sediments indicated no adverse reproductive effects (Chan, S.L., 1986, personnel communication).

Based on a review of major pathways presented in section 9.3.3 for unconfined, open-water disposal sites, similar modes of chemical exposure can be envisioned for all three of the preferred disposal sites. The potential for fine material and organic matter to remain and concentrate in the sea surface microlayer will be more dependent upon the kinds of material rather than on the physical characteristics of the disposal site. Different amounts of material may be lost during disposal at the three sites (due to water entrainment) because of differences in the depth of the disposal sites. Data resulting from the DFID model (Trawle and Johnson 1986) indicate that differences in depth existing among the preferred disposal sites do not play a significant role in increasing release of material from similar kinds of dredged material. Because of the similar low current velocities and general nondispersive nature of the preferred disposal sites, resuspension and transport of bedded dredged material off the disposal site are expected to be similar for all three sites.

TABLE II.9-1. COMPARISON OF PHYSICAL AND BIOLOGICAL PARAMETERS OF THE PREFERRED OPEN-WATER DISPOSAL SITES IN THE PHASE I STUDY AREA

	Port Gardner	Elliott Bay	Commencement Bay
Depth (m)	135	169	178
Current speed (kn)	0.5	0.5	0.5
Sediment type	silty-clay	silty-clay	silty-clay
Taxonomic composites	primarily annelids and molluscs	primarily annelids and molluscs	primarily annelids and molluscs
Biomass (g/m2)	40-50	40-50	40-50

Once the material has settled at the disposal site, the primary route of exposure (except for resuspension) will be through direct contact between the organisms and the bedded dredged material. Since similar species occur at all three sites, the kinds of organisms that recolonize the mound will be the same and effects from chemical concentrations should be the same, provided that approximately the same kinds and mass loadings of chemicals of concern occur at all sites.

9.6 Adverse Effects of Alternative Site Management Conditions. Adverse environmental effects expected at the preferred unconfined, open-water sites from alternative site management conditions are evaluated in the following sections. For this evaluation, individual treatment will be given to individual disposal sites only where differences among sites exist.

9.6.1 Assumptions Used in Alternative Site Condition Analysis. Because scientific knowledge and understanding of population and community level effects associated with the disposal of containing chemicals of concern material is not sufficient, predictions of effects must be based on chemical and biological tests of the dredged material performed in the laboratory. Where possible, specific biological tests were recommended based on relationships established in previous Puget Sound investigations between sediment chemical concentrations and biological effects (field or laboratory).

Environmental monitoring at the disposal site is important for verifying laboratory predictions about field effects and will allow any needed site remedial work. Details of the monitoring plan are discussed in the MPTA. The following laboratory tests were addressed by evaluating the potential for environmental effects at the disposal sites:

- Sediment Chemical Analysis--a model for protectively estimating the potential amount of contaminant available to organisms. Under PSDDA, sediment chemical analyses establish upper and lower bounds of chemical chemical concentrations that must be biologically tested to further evaluate environmental effects (sections II-7.3 and 7.4).

- Acute Toxicity Bioassays--a model for estimating potential biological effects at the disposal site. Although the tests are short-term (10 days), and the endpoint measured (mortality) is a severe indicator of biological effects, these acute toxicity tests indicate potential environmental effects (section II-6.3).

- Sublethal Bioassays--a better model of the potential long-term environmental effects that might be found at the disposal site. Measurements of endpoints such as growth rate or reproduction provide an integration of the effects of chemicals of concern on the whole organism (section II-6.4).

- Bioaccumulation--a model of the potential for chemicals of concern in the dredged material to be a human health hazard (Section II-6.4.1). Chemical analysis will be for those chemicals that present a carcinogen risk or are noncarcinogenic but still pose a human health risk (section II-8.4).

9.6.2 Tradeoffs Between Alternative Site Management Conditions. The analysis of alternative site conditions results in a qualitative prediction of trends in biological effects summarized in table II.9-2. A quantitative analysis of the expected trends is not possible. In assessing the environmental effects, both land resources and aquatic resources need to be considered, because dredged material not acceptable for unconfined, open-water disposal will be placed at an upland/nearshore confined site (provided the project is economically feasible). If confined aquatic disposal becomes an acceptable option in Puget Sound, the trends in environmental tradeoffs noted in table II.9-2 between land and water resources will be altered.

The relative potential for effects on water and land resources changes depending on the alternative site management conditions chosen for unconfined, aquatic disposal sites. Selection of Site Condition III for unconfined, open-

water disposal sites results in the highest potential for adverse environmental effects in the aquatic environment, but the lowest potential for similar effects on land resources. Alternatively, selection of Site Condition I for unconfined, open-water disposal would place the highest potential for adverse environmental effects at the nearshore/upland sites.

9.6.3 Adverse Effects of Alternative Site Management Conditions.

9.6.3.1 Site Condition I Effects. Overall, Condition I is the most chemically conservative of the alternative site conditions examined in detail by PSDDA. Of the three alternative site conditions considered, it provides the lowest level of chemical concentrations that would be allowed at the open-water disposal sites.

Maximum chemical concentrations associated with Site Condition I are defined by the ML1 chemistry values presented in table II.8-4 and represent the contaminant concentration associated with the lowest AET value determined for a range of biological indicators. Concentrations of chemicals of concern in the sediment are low enough that no biological effects are expected on or off the disposal site. Because the laboratory tests that constituted three of the four biological indicators used to develop AET are also some of the tests that will be applied in biologically evaluating sediments proposed for dredging, the ML1 values for Site Condition I represent the chemical concentration at which only the most sensitive of the bioassay species are expected to respond.

The dominant species found at the preferred disposal sites (annelids and molluscs) are generally not found to be acutely sensitive to chemicals of concern at environmental levels of chemicals of concern represented by the ML1 chemistry values, and therefore are not expected to be adversely affected. Crustaceans, which are typically the most sensitive species to sediment-bound chemicals of concern, are not present in great abundance (less than 10 percent of the total biomass of benthic infaunal species) at the preferred open-water disposal sites (Clarke 1986). Hence, the cumulative effects represented by Site Condition I at open-water sites are not expected to be significant.

Another potential source of cumulative effects is from the physical effects of sediment disposal at the site. Direct physical disturbance will occur in the zone of active deposition and will continue as long as the disposal site is in active use. Specific project evaluations, as required under specific Federal and State authorities, would establish actual dredged material volumes that can be placed in unconfined, open-water disposal sites. However, based on the proposed site management condition I, and using best-available assumptions and sediment chemistry data, an estimated 6.7 million c.y. of future dredged material could be found technically acceptable for unconfined, open-water disposal through the year 2000 (34 percent of the 19.4 million c.y. that might be considered for disposal at the Phase I area PSDDA sites). This compares with

TABLE II.9-2. TRENDS ASSOCIATED WITH ALLOWING ALTERNATIVE SITE CONDITIONS FOR UNCONFINED, OPEN-WATER DISPOSAL

Site Condition I(a)		Site Condition III
	Impacts to Puget Sound water quality(b)	→
	Impacts to benthic species	→
	Risk to fisheries	→
←	Risk to humans	
←	Impacts to ground water	
←	Impacts to air quality	
←	Pressure to use limited uplands	
←	Loss of intertidal areas and wetlands	
	Loss of technological control	→
	Difficulty to remediate	→

(a) Site Condition I results in less material (and effects) at unconfined, open water sites, and more material (and effects) at land/shore sites, than Site Condition III.

(b) Direction of the arrows indicates the relative increase in the environmental impact as the alternative site condition changes.

6.8 million c.y. of dredged material actually placed in Phase I waters over the past 15 years. In the past not all acceptable material was placed at public disposal sites. Some was used for landfill or other beneficial purposes. This would be expected to be true in the future too. Further discussion of the consequences of the proposed site management condition is contained in the DEIS. Detailed assumptions and calculations, shown elsewhere in EPTA, are based on present conditions. It is anticipated that as source control improves and project-specific experience and data become available, the portion of future dredged material that is acceptable for unconfined, open-water disposal would go up.

Physical disturbance is expected to reduce the value of the biological resources of the site for the time that the site is being used. The preferred sites were initially chosen, however, to minimize potential effects on important aquatic resources by avoiding high use areas and important food habitats. Clarke (1986) found that the locations of all three preferred disposal sites meet this criterion in that all sites had reduced biological resources compared with surrounding areas. The effect of dredged material disposal on food habitat for epibenthic predators is expected to be minimal because of the relatively low initial food habitat potential that presently exists in the areas of the preferred disposal sites.

9.6.3.2 Site Condition II Effects. Dredged material having a sediment chemical concentration below the ML2 level and meeting the biological disposal guidelines (or dredger option) is proposed to be allowed for unconfined, open-water disposal. Chemical guidelines at Site Condition II represent the highest AET determined for a range of biological indicators. Effects represented by Site Condition II at open-water sites are expected to consist of some chronic effects on-site but no significant effects offsite. Specific project evaluations, as required under specific Federal and State authorities, will establish actual dredged material volumes that can be placed in unconfined, open-water disposal sites. However, based on the proposed site management condition II, and using best-available assumptions and sediment chemistry data, an estimated 11.2 million c.y. of future dredged material could be found technically acceptable for unconfined, open-water disposal through the year 2000 (58 percent of the 19.4 million c.y. that might be considered for disposal at the Phase I area PSDDA sites). This compares with 6.8 million c.y. of dredged material actually placed in Phase I waters over the past 15 years. In the past not all acceptable material was placed at public disposal sites. Some was used for landfill or other beneficial purposes. This is expected to be true in the future too. Further discussion of the consequences of the proposed site management condition is contained in the DEIS. Detailed assumptions and calculations, shown elsewhere in EPTA, are based on present conditions. It is anticipated that as source control improves and project-specific experience and data become available, the portion of future dredged material that is acceptable for unconfined, open-water disposal would go up.

The biological testing guidelines for Site Condition II, which allow for minor significant effects in the laboratory tests, suggest that some biological effects may be expected at the disposal site. The severity and extent of biological effects are not expected to be great because the majority of the species found at the preferred disposal sites are not known to be acutely sensitive to chemicals of concern. Effects associated with Site Condition II will include sublethal effects and, potentially, an increase in the mortality of the more sensitive but less abundant crustacean species. Cumulative effects are expected to consist of a reduction in population and community biomass and an increase in the tissue concentration levels of chemicals of concern.

Measurable tissue contaminant levels may result at Site Condition II, but these levels are not expected to present a human health problem. Predators that include the disposal site as part of their home range will also exhibit increases in tissue contaminant concentration from contact with sediments and ingestion of infaunal species. These increases are not expected to pose a human health problem.

Direct physical disturbance will occur in the zone of active deposition and will continue as long as the disposal site is being actively used. Physical disturbance will reduce the recruitment of settling larvae, which in turn, will contribute to a reduction in population numbers and biomass.

9.6.3.3 Site Condition III Effects. By definition, Site Condition III would allow for moderate effects at the disposal site. Material that is acceptable for unconfined, open-water disposal according to Site Condition III guidelines could produce highly significant responses in bioassays (e.g., greater than 30 percent mortality relative to control mortality) but not "severe" effects (greater then 70 percent mortality). In addition, bioaccumulation levels for chemicals of concern could exceed the human health indicators and the material still be considered for unconfined, open-water disposal. The likelihood that disposal of material under Site Condition III guidelines would result in toxicity to marine organisms at the disposal site is greater than that under Site Condition I or II guidelines. Actual biological effects will be a function of the organisms exposed to the material and the specific organism chemical interactions.

Specific project evaluations, as required under specific Federal and State authorities, will establish actual dredged material volumes that can be placed in unconfined, open-water disposal sites. However, based on the proposed site management condition III, and using best-available assumptions and sediment chemistry data, an estimated 14.9 million c.y. of future dredged material could be found technically acceptable for unconfined, open-water disposal through the year 2000 (77 percent of the 19.4 million c.y. that might be considered for disposal at the Phase I area PSDDA sites). This compares with 6.8 million c.y. of dredged material actually placed in Phase I waters over the past 15 years.

The cumulative effects of this incremental volume could be severe because of the chemical concentrations associated with the material and the physical effects associated with disposing of such a large volume of material. Effects on organisms in and around the disposal site would be anticipated for all expected pathways of contaminant exposure to this material.

10. COST ANALYSIS

10.1 Overview and Calculation of Dredged Material Volumes. Two important factors considered in developing the evaluation procedures for Phase I of PSDDA are:

1. The costs of chemical and biological testing to determine acceptability for unconfined, open-water disposal.

2. The overall program costs resulting from the selection of different biological effects site conditions for management of the unconfined, open-water disposal sites.

Sediment chemistry guidelines for various levels of sediment chemical concentrations were defined in section II-8.2 for the alternative site conditions. Based on these maximum levels for three of the site conditions, a cost analysis was performed to:

- Estimate costs for sampling, chemical testing, biological testing, and data quality assurance (QA) evaluation in the PSDDA Phase I study (see sections II-4, II-6, and II-7), and to compare those costs to the testing costs for current dredged material management procedures.

- Estimate costs for dredged material management scenarios based upon three alternative site conditions for management of the unconfined, open-water disposal sites. Selection of each site conditions results in allocation of a different portion of the dredged material volume between unconfined, open-water disposal and confined disposal.

- Estimate costs for the long-haul transport of dredged material for disposal in the Strait of Juan de Fuca and the Pacific Ocean, and to compare those costs with costs of unconfined and confined disposal technologies.

The test procedures proposed in sections II-6 and II-7 require analysis for greater numbers of chemicals and a greater number of aquatic biological tests than required under the PSIC guidelines. (This is not true, however, for land biological testing.) The nature and extent of testing should be based on project size, quality of sediments to be dredged (as determined from historical information), and depth of sediments to be dredged (see section II-4.5). A projection of testing costs under PSDDA and a comparison of these projected costs with those estimated for testing programs under the PSIC guidelines is included in section 10.2.

The analysis also provides comparative cost estimates for dredging, transport of dredged material, and disposal by different methods. Prediction of costs for the three sediment management scenarios depends on estimates of both the

nature and the volume of sediments to be dredged. Sediment volumes were projected by the Corps for a 15-year operating period (1986-2000) in the Phase I area. Available sediment chemistry data for proposed and existing dredged areas in the three Phase I dredging areas were used to characterize the sediment chemicals of concern. Classification of these sediments by degree of contamination enabled allocation of total volumes to be dredged in each area into subvolumes that were either acceptable or unacceptable for unconfined, open-water disposal. The derivation of these volumes and subvolumes is the subject of section 10.1.3.

For this cost analysis, the management of dredged materials was divided into three sequential operations: dredging, transport of dredged material, and disposal. Though many combinations of disposal technology and types of disposal sites are possible, the primary emphasis was placed on comparing the total costs of unconfined and confined disposal for each of the alternative site conditions. Consequently, only the following disposal options and technology assumptions were considered:

Unconfined Disposal

- Unconfined, open-water

Confined Disposal

- Aquatic, capped
- Nearshore
- Upland, intermediate secure
- Upland, secure,

The technology assumptions for each of these five options is described further below (see section II-10.3.1).

Chemicals of concern may be isolated from the surrounding environment with increasing effectiveness from the top to the bottom of this list of disposal options. The cost of each option may also increase from top to bottom, as do engineering and maintenance requirements (and associated costs) that are necessary to construct and monitor these sites and ensure their integrity. Transport costs may similarly increase because of the distance of most upland sites from the marine environment.

The cost per unit volume of sediment handled according to each disposal option is estimated in section 10.3. The volume allocations projected in section 10.1.3 and the unit disposal costs in section 10.3 were used to estimate total disposal costs for each of the technologies in the Phase I areas included in

this analysis. In section 10.4, the overall costs for Puget Sound-based sediment management options are compared to costs for the additional disposal alternative of hauling dredged materials to hypothetical disposal locations in the Strait of Juan de Fuca and the Pacific Ocean. Section 10.5 contains a summary of the cost analysis.A summary of the individual analyses of the volume and chemical composition of sediment and the corresponding analyses of costs that were performed are provided in figure II.10-1.

Other, equally valid cost assumptions could have been used in the analysis. However, small differences in unit costs assumed here would not measurably alter the conclusions regarding the selected site management alternative (see section II-11). Volume of material required to use confined disposal is the key factor driving the compiled costs of the alternatives.

10.1.1 Sources of Data. Sources of data for the cost information presented in this analysis include the following:

- Literature describing dredging and chemical testing of dredged materials
- Dredging permit applications
- Cost estimates for coring, sampling, chemical and biological testing, and dredging provided by contractors
- Discussions with dredge operators, barge owners, port representatives, engineers, and scientists involved in testing and disposal program designs
- The Dredged Material Inventory (Envirosphere 1986; exhibit E.5)
- The data base used to derive sediment quality values for Puget Sound (Tetra Tech 1986j) (see exhibit E.9).

The Corps derived the initial volume estimates (by dredging areas and subareas) from the Dredged Material Inventory (Envirosphere 1986) and other projections for major dredging projects in Puget Sound.

10.1.2 Cost Assumptions. Specific cost assumptions for the testing, dredging, and ocean-dumping cost analyses are described in detail in Sections 10.2, 10.3, and 10.4, respectively. Major assumptions of the cost analyses include the following:

- Disposal technology costs were developed as costs per cubic yard of dredged sediment as a function of volumes of sediment (ranging from 10,000 to 1,000,000 c.y.).

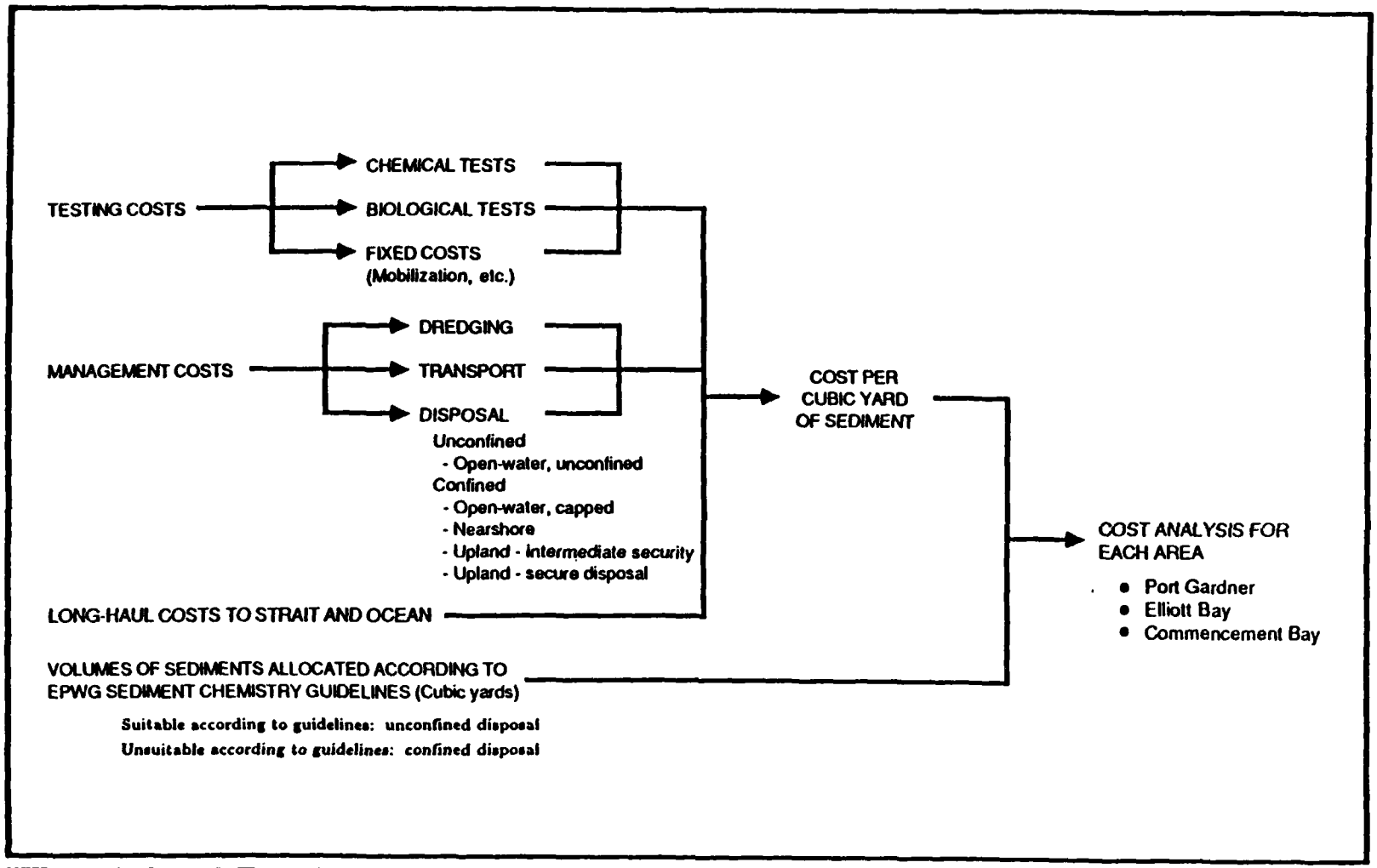


Figure II.10-1. Relationship of testing and dredged material management analyses to the overall cost analysis for dredging areas.

- o All costs were adjusted to mid-1986 costs based on a 6 percent annual inflation rate.

- o All program-level costs are expressed in terms of present unit costs (by unit volume) multiplied by projected 15-year dredged volumes. No attempt was made to forecast trends in the dredging industry that might cause variations in future unit costs. Program costs include compliance and user fees.

- o Estimates of sediment volumes provided by the Corps were based on past dredging activities and projected volumes for major planned projects. These estimates do not include the Navy Homeport project planned for the Port Gardner area. The Navy project will not use the PSDDA disposal site.

- o Estimates of sediment volumes provided by the Corps include the Duwamish and the Blair-Sitcum large-volume navigation improvement projects which, if undertaken, could use PSDDA sites for open-water disposal.

- o The assessment of dredging volumes, sediment testing requirements, and disposal technologies did not include a survey of existing and future capacities of dredging, laboratory, and transport industries. An assessment of the feasibility of implementing testing/disposal requirements or developing additional capacities was not a part of this cost assessment.

- o The cost analysis for sediment testing is protective; i.e., it assumes that all sediment will be subjected to the PSDDA requirements. No attempt was made to estimate the quantity of material that may already be adequately characterized and would not require additional testing.

10.1.3 Dredged Material Volume Estimates. The estimation of dredged material volumes that are acceptable or unacceptable for unconfined, open-water disposal according to each level of sediment chemistry guidelines is a prerequisite for estimating program-level costs. The method for allocating sediment volumes to unconfined or confined disposal shown in figure II.10-2 is based on area/subarea volume estimates by the Corps, estimated chemical concentrations in sediments [from the data base used to develop sediment quality values (Tetra Tech 1986j)], and the maximum levels for the three alternative site conditions (section II-8.2).

Area Volume Estimate. For the purpose of this cost analysis, three major dredging areas were defined for the Phase I area (Everett to Tacoma): Port Gardner, Elliott Bay, and Commencement Bay. These dredging areas are shown in figure II.10-3. Projections for dredged material volumes were made for the three dredging areas in the Phase I area for the 15-year period 1986 to 2000

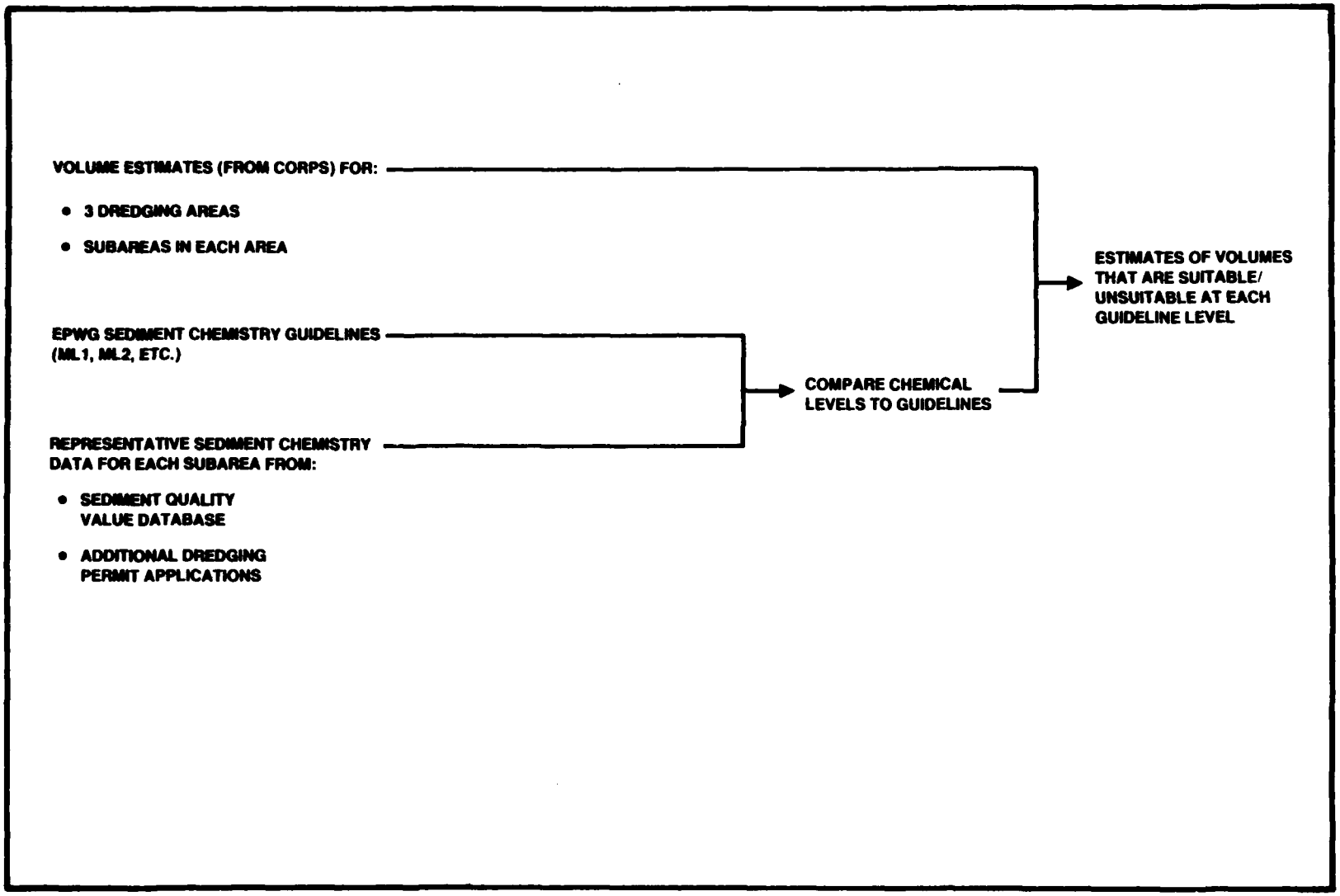


Figure II.10-2. Methods for quantifying dredged material volumes according to each EPWG site condition.

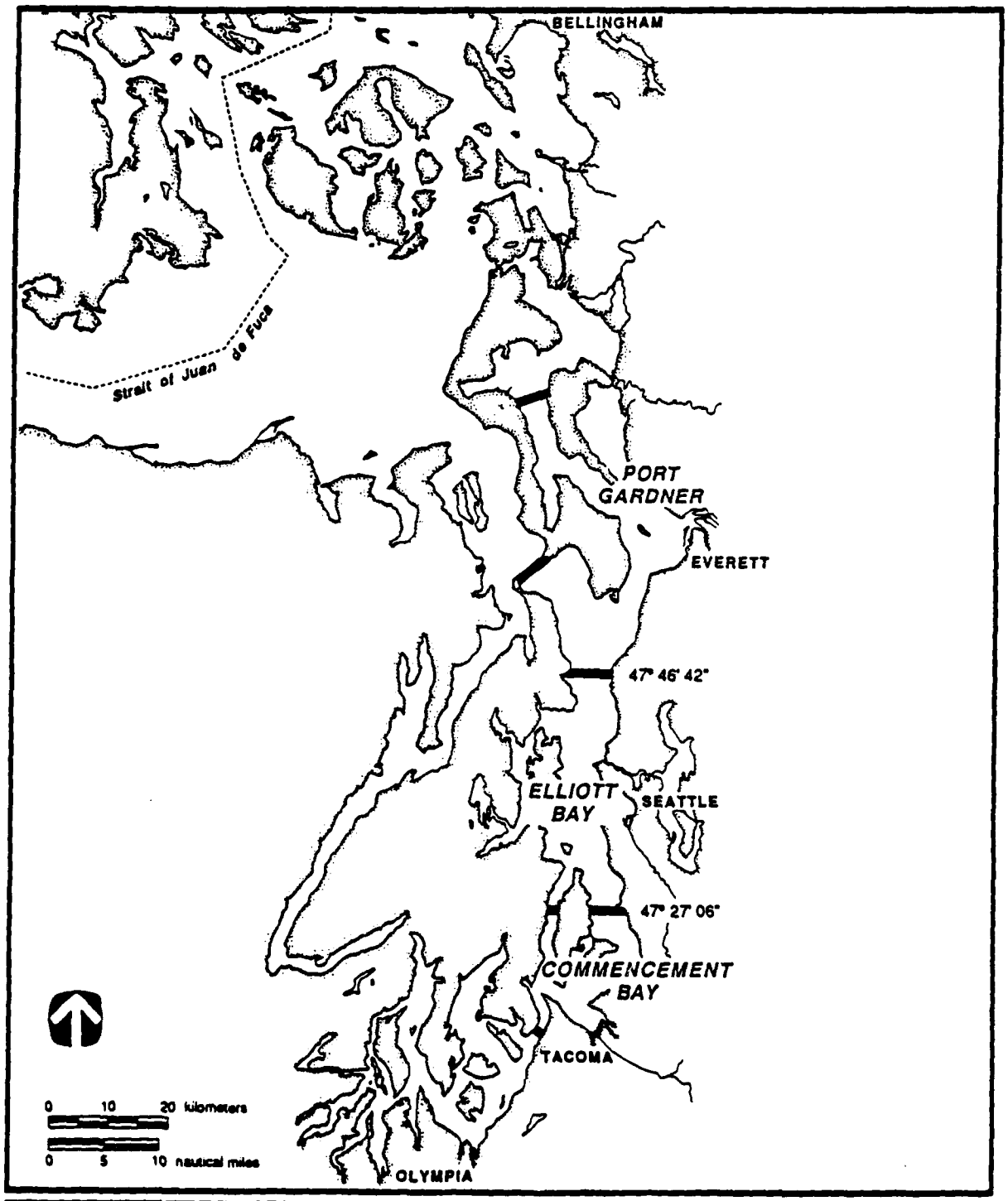


Figure II.10-3. Locations of the three Phase I dredging areas in central Puget Sound.

(table II.10-1). These projections were further categorized by dredging subareas within each of the three areas (table II.10-2). The total projected volume for all areas for the period is 19,397,000 c.y.

Sediment Chemistry Data. Average chemical concentrations in sediments were determined from available data from each of the dredging subareas listed in table II.10-2. Only the concentrations of detected chemicals were used when calculating mean values. A detailed description of the chemicals included and the data used from each region is given in exhibit E.9. In the Port Gardner area, chemical analysis data were available for the East Waterway (10 samples) and Lower Snohomish River (4 samples). In the Elliott Bay region, data were available for the Lower Duwamish River (31 samples), Upper Duwamish River (4 samples), Turning Basin No. 3 (3 samples), Sinclair Inlet (8 samples), Eagle Harbor (24 samples), Kenmore Navigation Channel (7 samples), and Lake Union (2 samples, plus 28 PCB samples). Data from the Commencement Bay area were available for Hylebos Waterway (45 samples), Blair Waterway (25 samples), Sitcum Waterway (5 samples), and other waterways (31 samples).

Comparison of Sediment Concentration with Screening Level and Maximum Levels. Once estimates for chemical concentrations were derived for the various subareas in each area, they were compared to the screening and maximum sediment chemistry levels for dredged material (table II.10-3). For PSDDA guidelines at the maximum levels (ML) 1, 2, or 3, when the mean concentrations of any two chemicals in sediments from a subarea precluded unconfined, open-water disposal of those sediments according to the guidelines in table II.10-3, then the sediment volume for that subarea was included in the sediment volume sum exceeding that particular ML. Otherwise the volume for that particular subarea was added to the volume that is acceptable for unconfined, open-water disposal according to that guideline. An exception to this "single chemical allowance rule" occurs when a single chemical exceeds the maximum level value in table II.10-3 by more than 100 percent. The screening level (SL) does not include a single chemical allowance; i.e., exceedance by any one chemical will require biological testing to determine its acceptability for unconfined, open-water disposal according to the guideline.

Thallium has been removed from consideration in this analysis and chromium has been placed on the list of chemicals of concern in limited areas only. However, chromium will continue to be measured routinely in most areas to build a data base for refining its sediment quality value (see section II-7.1.3).

Sediment Volume Allocations for Unconfined and Confined Disposal. The sediment volume allocations for each dredging area and alternative chemical disposal guidelines are shown in table II.10-4. A bar-chart depicting the relative volumes of sediments exceeding and meeting the alternative unconfined, open-water disposal guidelines is shown in figure II.10-4. The volumes of dredged materials that would be acceptable at multiuser public, unconfined, open-water sites under PSDDA are the volumes whose sediment chemistry does not exceed a particular chemistry guideline. These volumes are viewed as a range:

TABLE II.10-1. FORECAST DREDGING VOLUMES
(c.y. x 1,000) FOR PHASE I AREA, 1985-2000a

Activity	Port Gardner and Vicinity	Elliott Bay and Vicinity	Commencement Bay and Vicinity	Total
Corps(b)	3,000(c)	4,112(d)	2,690(e)	9,802
Ports(f)	300	2,000	700	3,000
Other(g)	1,643(h)	4,413	539	6,595
TOTAL	4,943	10,525	3,929	19,397

(a) See figure I.1-1 for Phase I subareas used for purposes of dredging and disposal analysis.

(b) Forecasts by the Corps (in c.y. x 1,000) include the following:
Upper Snohomish - 2,000
Lower Snohomish - 1,000
Upper Duwamish and upper turning basin - 1,530
Duwamish widening and deepening - 2,500
Kenmore - 70
Hylebos Waterway - 50
Blair/Sitcum navigation improvement project - 2,500

(c) Volume includes 2,000,000 c.y. of material (primarily sand) to be dredged from upper Snohomish River basin and maintenance project. Adjacent upland disposal is preferred for economic reasons.

(d) Includes 2,512,000 c.y. for Duwamish widening and deepening project which has been authorized but is not expected to be undertaken in the short term (1986-1990).

(e) Includes 2,500,000 c.y. for Blair/Sitcum navigation improvement project which has been authorized but is not expected to be undertaken in the short term (1986-1990).

TABLE II.10-1. (Continued)

(f) Forecasts by Ports of Everett, Seattle, and Tacoma, as follows (in c.y. x 1,000):

Everett
Port construction - 300

Seattle
T-91 shortfill - 400
Kellogg Island - 800
Port share of Duwamish widening and deepening - 800

Tacoma
Third SeaLand Berth - 100
New Pier 5 area wharf - 150
Blair terminal berth - 100
Hylebos maintenance - 150
Berth and waterway maintenance - 80

(g) All other project activities, including private parties, state, and municipalities. For Elliott Bay and vicinity and Commencement Bay and vicinity, volume to be dredged is based on extrapolation of past 15 year dredging by this activity. Extrapolation was based on simple mean of yearly dredging volume from 1970 to 1985. This yearly average was brought foward for the 15-year forecast. For Port Gardner and vicinity, the same procedure was followed except that estimated volume of material to be dredged for the Navy Homeport project (3,300,000 c.y.) was not included.

(h) Does not include Navy Homeport project (3,300,000 c.y.).

TABLE II.10-2. 15-YEAR PROJECTIONS (1985-2000) OF TOTAL DREDGING VOLUMES (c.y. x 1,000) BY SPECIFIC DREDGING SUBAREAS WITHIN EACH DREDGING AREA

Area	Subarea	Projected Volumes (c.y. x 1,000)
Port Gardner and vicinity	East Waterway	553
	Lower Snohomish	2,021
	Upper Snohomish	2,175
	All other subareas	194
	Total	4,943
Elliott Bay and vicinity	Lower Duwamish	4,812
	Upper Duwamish	2,021
	Duwamish turning basin	612
	Lakes: Kenmore/Sammamish River	114
	Lakes: Lake Washington	1,368
	Lakes: Lake Union	5
	Lakes: Lake Washington Ship Canal	80
	Sinclair Inlet	200
	Eagle Harbor	115
	All other subareas	1,198
	Total	10,525
Commencement Bay and vicinity	Hylebos Waterway	200
	Blair Waterway	2,560
	Sitcum Waterway	550
	Other waterways	80
	All other subareas	539
	Total	3,929
	Grand Total	19,397

Reference: 15-year projected volumes provided by Corps. See footnotes on table II.10-1.

TABLE II.10-3. SEDIMENT CHEMISTRY GUIDELINES (a)

Chemical	PSIC Guidelinesa	PSDDA Chemistry Guidelines SL	ML1	ML2	ML3
METALS (mg/kg dry weight; ppm)					
Antimony		2.6	3.2	26	52
Arsenic	12.5	70	85	700	1400
Cadmium	0.7	0.96	5.8	9.6	19.2
Copper	68	80	310	800	1600
Lead	33	70	300	700	1400
Mercury	0.15	0.21	0.41	2.1	4.2
Nickel		28	28	49	98
Silver		1.2	1.2	5.2	10.4
Zinc	105	160	260	1600	3200
ORGANICS (ug/kg dry weight; ppb)					
LPAH	680	610	5200	6100	12200
Naphthalene		210	2100	2100	4200
Acenaphthylene		64	560	640	1280
Acenaphthene		63	500	630	1260
Fluorene		64	540	640	1280
Phenanthrene		320	1500	3200	6400
Anthracene		130	960	1300	2600
2-Methylnapthalene		67	670	670	1340
HPAH	2690	1800	12000	18000	36000
Fluoranthene		630	9700	6300	12600
Pyrene		430	2600	4300	8600
Benz(a)anthracene		450	1300	4500	9000
Chrysene		670	1400	6700	13400
Benzofluoranthenes		450	3200	8000	16000
Benzo(a)pyrene		680	1600	6600	13600
Indeno(1,2,3,c,d)pyrene		69	600	690	1380
Dibenzo(a,h)anthracene		120	230	1200	2400
Benzo(g,h,i)perylene		540	670	5400	10800

TABLE II.10-3. (Continued)

CHLORINATED HYDROCARBONS				
1,3-Dichlorobenzene	170	b	b	b
1,4-Dichlorobenzene	26	110	260	520
1,2-Dichlorobenzene	19	35	50	100
1,2,4-Trichlorobenzene	6.4	31	64	128
Hexachlorobenzene	23	70	230	460
PHTHALATES				
Dimethyl phthalate	160	b	b	b
Diethyl phthalate	97	b	b	b
Di-n-butyl phthalate	1400	b	b	b
Butyl benzyl phthalate	470	b	b	b
Bis(2-ethylhexyl)phthalate	1900	b	b	b
Di-n-octyl phthalate	68000	b	b	b
PHENOLS				
Phenol	120	420	1200	2400
2-Methylphenol	6.3	63	63	126
4-Methylphenol	120	670	1200	2400
2,4-Dimethyl phenol	10	29	29	58
Pentachlorophenol	140	b	b	b
MISCELLANEOUS EXTRACTABLES				
Benzyl alcohol	10	57	73	146
Benzoic acid	216	650	650	1300
Dibenzofuran	54	540	540	1080
Hexachloroethane	1,400	14,000	14,000	28,800
Hexachlorobutadiene	29	120	290	580
Trichlorobutadiene	5.4	54	54	108
Tetrachlorobutadiene	8.4	84	84	168
Pentachlorobutadiene	4.6	46	46	92
N-Nitrosodiphenylamine	22	40	220	440
VOLATILE ORGANICS				
Trichloroethene	160	1600	1600	3200
Tetrachloroethene	14	140	140	280
Ethylbenzene	3.7	33	37	74
Total xylenes	12	100	120	240

TABLE II.10-3. (Continued)

PESTICIDES				
Total DDT	6.9	14.9	69	138
Aldrin	5	b	b	b
Chlordane	5	b	b	b
Dieldrin	5	b	b	b
Heptachlor	5	b	b	b
Lindane	5	b	b	b
TOTAL PCB's	130	130	2500	5000

(a) SL and ML values shown in this table are those originally derived using the Phase I study. As a result of information received during public review of the Phase I documents, several of the values have been updated (see table in section II-11 for current values). The older values are left here to reflect the historical decision process.

(b) PSIC = Puget Sound Interim Criteria (125% values; single exceedance).

(c) No ML available (see table II.8-3).

at one extreme, sediment that meets the screening level will be considered acceptable for unconfined, open-water disposal. At the other extreme, sediment that exceeds the maximum level is extremely likely to be unacceptable for unconfined, open-water disposal. Within this SL to ML range, there is presently no certain method for estimating the volumes of sediment that would be acceptable or unacceptable for unconfined, open-water disposal according to biological tests based on sediment chemistry data. Therefore, for purposes of this cost analysis, the volume of additional material that would not meet biological guidelines (and hence go to confined disposal) is assumed to range from none (all sediment meets biological guidelines) to all (all sediment does not meet biological guidelines).

For example, for site condition II, the actual sediment volume allocations are contained within the range bounded by ML1 and ML2. In order to identify an acceptable volume for condition II, the arithmetic mean of the volume range is calculated and carried through this analysis (e.g., volume at ML 1, plus volume at ML 2, divided by 2). As a result, the mean dredged material volumes expected to be allowed at multiuser, public, unconfined, open-water disposal sites is estimated based on the chemistry-based allocations (table II.10-5). These estimates are based on the mean of volumes meeting the particular guideline level and the next lower guideline level.

Testing costs vary substantially among different projects and testing facilities. There are many factors that affect cost, typically resulting in a range of possible costs. It was not the objective of the PSDDA cost analysis to fully explore this range, but rather to identify "representative costs" that would allow a fair comparison of the alternative site management conditions. While for some projects the costs for chemical and biological tests are expected to exceed the values in the PSDDA reports, other projects are expected to incur lesser costs. Recent (1988) bid advertisements for conducting PSDDA baseline studies have shown current chemical and biological test costs to be reasonably close to those values used in the Phase I cost analysis, when adjusted for price level changes.

10.2 Cost of Testing. Cost estimates for sampling and for chemical and biological testing are needed to compare the costs of tests for each site condition for dredged material, and to compare PSDDA and PSIC testing costs. Costs of obtaining sediment cores and performing and assessing proposed chemical and biological tests on sediment samples are estimated in this section.

Proposed sampling and chemical and biological testing requirements for dredged material disposal assessments are described in sections II-4.5, II-6, and II-7. The number of required sediment cores and resulting samples for projects of differing area ranks and depths of sediment to be dredged are shown in table II.3-1. The program-level testing costs presented in this section were calculated for three area ranking levels (low, moderate, and high) and two depths listed in the sampling and analysis RAD (exhibit B). The present

TABLE II.10-4. DISPOSAL VOLUME ALLOCATIONS (1985-2000) (cy x 1,000)

Area	PSIC Guidelines[a]				PSDDA Chemistry Guidelines[b]					
	PSIC		SL		ML1		ML2		ML3	
	E[c]	M[d]	E	M	E	M	E	M	E	M
Port Gardner	4,268	675	4,943	0	518	4,425	0	4,943	0	4,943
Elliott Bay	9,175	1,350	7,413	3,112	7,413	3,112	6,888	3,637	1,837	8,688
Commencement Bay	3,704	225	3,929	0	1,234	2,695	215	3,714	0	3,929
TOTAL	17,147	2,250	16,285	3,112	9,165	10,232	7,103	12,294	1,837	17,560

[a] Values in the "M" column (i.e., volume that might meet PSIC guidelines) based on professional judgment and expertise of Ecology personnel.

[b] Allocations based on comparison of representative bulk chemistry data from the dredging areas to PSDDA chemical guideline values.

[c] E = Material associated with chemical concentrations in the sediment quality value database that exceeds chemistry guidelines values.

[d] M = Material associated with chemical concentrations in the sediment quality value database that meets chemistry guideline values.

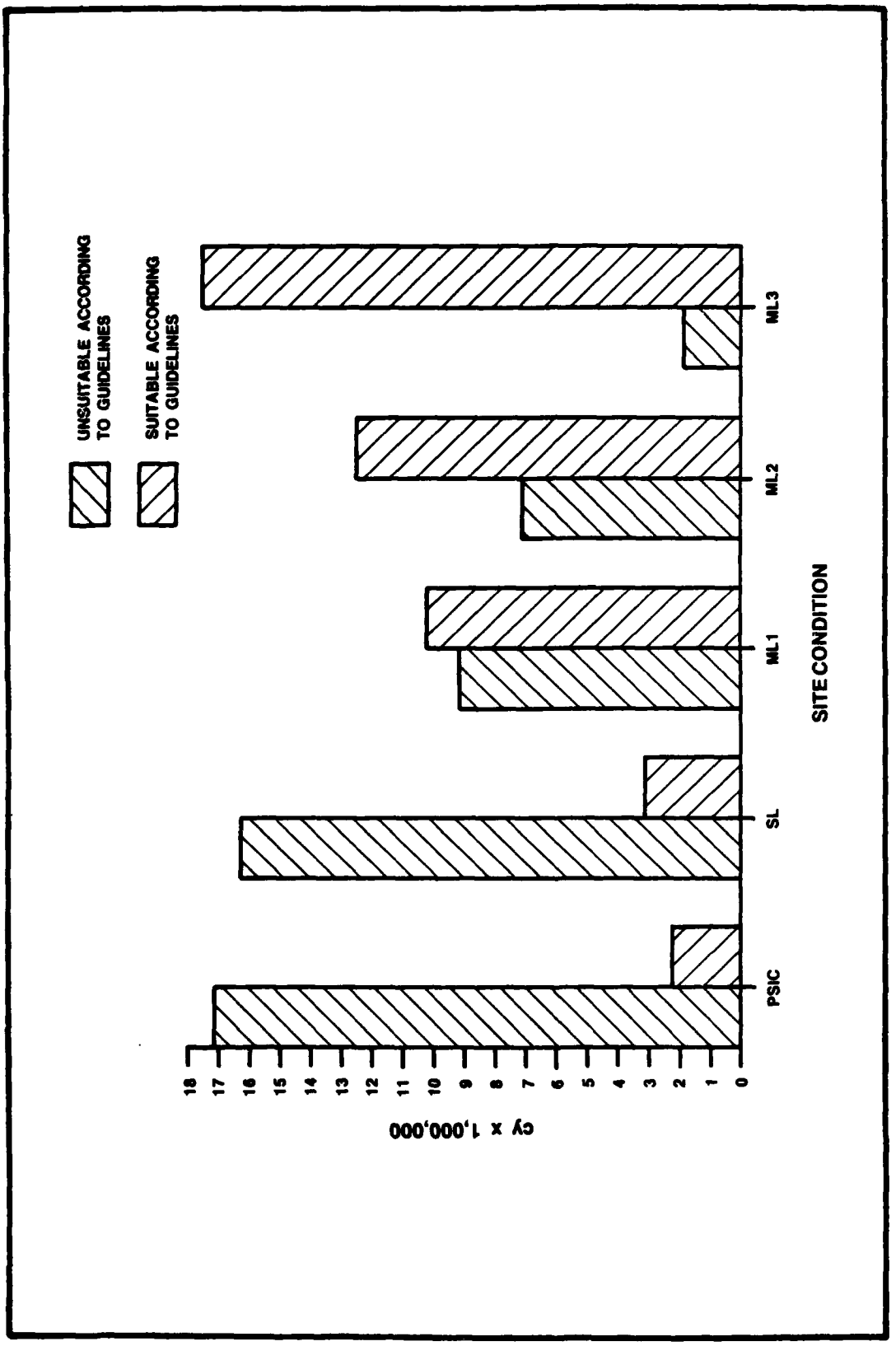


Figure II.10-4. Total sediment allocation for each sediment chemistry guideline level (see Table II.10-4).

TABLE II.10-5. MEAN DREDGED MATERIAL VOLUMES (c.y. X 1,000) EXPECTED TO BE SUITABLE AT MULTIUSER PUBLIC UNCONFINED, OPEN-WATER DISPOSAL SITES

Area	PSIC Guidelines	PSDDA Guidelines(a)		
		I(b)	II	III
Port Gardner	675	2,212	4,684	4,943
Elliott Bay	1,350	3,113	3,374	6,162
Commencement Bay	225	1,348	3,160	3,776
Total	2,250	6,673	11,218	14,881

(a) Volumes determined as the mean of volumes not exceeding the level in question and the next lower level. For example, for PSDDA guideline II, the volume equals (volume not exceeding ML2 + volume not exceeding ML1)/2.

(b) Allowable dredged material volumes under PSDDA guideline I were calculated as the mean of the volume not exceeding ML1 chemistry guidelines and the volume not exceeding chemistry values represented by the following equation:

$$(SL + ML1)/2$$

The volumes (c.y. x 1,000) represented by the chemistry values for (SL + ML1)/2 for the areas are as follows:

Area	(SL + ML1)/2
Port Gardner	0
Elliott Bay	3,113
Commencement Bay	0
Total	3,113

and future rankings estimated by the Corps for each area and subarea are listed in table II.10-6. Also shown are the corresponding number of sediment cores and analyses required under the PSDDA program for each dredging area.

10.2.1 Testing Requirements. For this cost analysis, it was assumed that a full analysis of the chemicals of concern for dredged material (table II.10-3) is required for characterization of the sediment as described in section II-7.4. If the concentrations of chemicals of concern exceed the screening level for those chemicals, then additional biological testing is required (see section II-5). If the test results do not meet the chemical guidelines, then the dredged materials may or may not be managed according to the prescribed methods for that particular site condition depending on the outcome of the biological testing. These issues are addressed in section 10.3. For the program-level analysis of testing costs, it was assumed that all sediment expected to be allowed at multiuser, public, unconfined, open-water disposal sites will be subjected to the biological tests. The volumes for this analysis are listed in table II.10-5.

Chemical Tests. The following are brief descriptions of the EPWG-prescribed chemical tests that were included in the cost analysis. More details are provided in section II-7.4. Quality assurance techniques described in Tetra Tech (1986b) are assumed for each of the four kinds of analyses:

1. Metals are extracted using a hydrofluoric/aqua regia total acid digestion with analysis by spectrophotometry as described in Tetra Tech (1986f).

2. Pesticides and PCB's are solvent extracted and quantified by gas chromatography coupled with a choice of detectors. Extract cleanup and instrumentation must be sufficient to achieve detection limits of 1 to 20 ppb dry weight.

3. Acid, base, and neutral organic compounds are solvent extracted and analyzed using gas chromatography coupled with a choice of detectors (e.g., mass spectrometer, flame ionization detector). Extract cleanup must be sufficient to achieve detection limits of 50 ppb dry weight.

4. Volatile organic compounds are analyzed using heated purge-and-trap or vacuum extraction/purge-and-trap coupled with a mass spectrometer or several specific detectors.

Biological Tests. Proposed biological tests for sediment quality include acute (lethal and sublethal) tests and a bioaccumulation test. The acute tests include two specified bioassay tests (amphipod and Microtox) and two tests that have several options (juvenile bivalve bioassay and larval bioassay). The bioaccumulation test uses an adult clam (Macoma spp.). Costs for the bioaccumulation test include the tissue analysis for chemicals listed as

TABLE II.10-6. AREA RANKINGS, NUMBER OF CORES, AND NUMBER OF ANALYSES ESTIMATED FOR EACH SUBAREA

Area	Rank(a) Now/Future	Number of Cores(b)	Number of Analyses(c)
Port Gardner			
Lower Snohomish	High/Moderate	500	100
Upper Snohomish	Moderate/Low	272	38
East Waterway	High/High	138	92
All other subareas	Moderate/Moderate	49	10
		959	240
Elliott Bay			
Lower Duwamish	High/High	1,203	802
Upper Duwamish	High/Moderate	505	101
Duwamish Turning Basin	Moderate/Low	77	11
Lakes: Kenmore/Sammamish River	High/Moderate	29	6
Lakes: Lake Washington	Moderate/Moderate	342	68
Lakes: Lake Union	High/High	1	1
Lakes: Lake Washington Ship Canal	High/High	20	13
Sinclair Inlet	High/High	50	33
Eagle Harbor	Low Moderate/Low(d)	14	2
All other subareas	Moderate/Moderate	300	60
		2,541	1,097
Commencement Bay			
Hylebos Waterway	High/High	50	33
Blair Waterway	High/Low	370	51
Sitcum Waterway	High/High	38	25
Other waterways	High/Moderate	20	4
All other subareas	Moderate/Moderate	135	27
		613	140
PSIC			
Port Gardner		1,236	412
Elliott Bay		2,631	877
Commencement Bay		982	327

TABLE II.10-6. (Continued)

(a) The ranking system is based on two factors: the number of contaminant sources (existing or historic) and the available information on chemical and biological-response characteristics of the sediments. The present rank for an area is presented under the "now" column, while the expected rank in the near future (once initial sampling is undertaken in the area) is presented under "future." The number of cores and analyses were calculated using the "future" rank.

(b) The cubic yardage associated with each core taken under PSDDA will depend upon the area rank as follows:

Rank	Cubic Yardage
Low	8,000 c.y.
Moderate	4,000 c.y.
High	4,000 c.y.

(c) By assumption, the cubic yardage associated with each analysis under PSDDA will depend upon the area rank as follows:

Rank	Cubic Yardage
Low	58,000 c.y.
Moderate	20,000 c.y.
High	6,000 c.y.

(d) The "low" rank for Eagle Harbor is for areas west of the Wyckoff creosote plant. All dredging activity is expected from this area. Areas east of the plant are ranked "high" and would be expected to maintain that rank.

potential human health problems in section II-6.5. Biological testing requirements for upland/nearshore disposal were not specifically determined during the evaluation. For purposes of this cost analysis, the costs for such tests were assumed to be at least equal to the cost of aquatic biological testing under PSDDA.

10.2.2 Costs. To assess the costs to the dredging industry posed by testing requirements under the proposed PSDDA program, it is necessary to evaluate them using different chemistry disposal guidelines for sediment characterization and to compare PSIC with PSDDA costs. Unit costs are representative of mid-1986 rates and are for quantity analyses (i.e., greater than one sample). Single tests may cost as much as twice the given bulk rates.

PSIC Costs. Requirements of PSIC (see section II-1.4.3) include analysis for metals (As, Cd, Cu, Pb, Hg, Zn), priority pollutant acid-base chemicals, total low molecular weight polynuclear aromatic hydrocarbons (LPAH), total high molecular weight polynuclear aromatic hydrocarbons (HPAH), pesticides and PCB's, total solids, oil and grease, grain size, sulfides, and total volatile solids. Biological testing requirements are assumed to include the amphipod bioassay. Average per-analysis costs for these tests are listed in table II.10-7.

PSDDA Costs. The projected testing requirements under PSDDA and estimated per-analysis costs for the chemical and biological tests are shown in table II.10-8.

Costs for conducting sediment test protocols have also been estimated by Lee et al. (1985). Where protocols similar to those discussed here are specified, the costs are comparable when updated to mid-1986 values.

With the volume estimates for each area presented in section 10.1.3, program-level testing cost estimates were developed for each of the three PSDDA chemical guidelines and the PSIC guidelines (table II.10-9). For dredged material, using the disposal guidelines for condition II, the total sampling and testing cost for all areas is $7 million (present value) over the 15-year projection period, or approximately $466,000/year.

A graphical comparison of sampling and testing costs for the above guidelines is shown in figure II.10-5. Testing costs for projects are projected to be only 2 percent higher under the Phase I program than under the PSIC program.

10.3 Costs of Disposal. The cost analysis of alternative management options for dredged material disposal must address all stages of the dredging process:

- o Dredging and placement of sediments in a conveyance (barge or pipeline)
- o Transport of the sediment from the project site to the disposal site
- o Disposal of the sediment in 1) unconfined, open-water sites, or 2) confined sites at open-water, nearshore, or upland locations.

10.3.1 Assumptions. The objective of this assessment is to evaluate the change in costs resulting from application of the alternative Phase I disposal requirements and resulting volumes of sediments presented in section 10.1.3. It is assumed that the primary variable in the analysis is the selection of disposal option because disposal technologies vary substantially in cost and also strongly influence transport requirements. The major engineering and design attributes of each type of disposal technology considered in this

TABLE II.10-7.

COSTS FOR PRESENT (INTERIM CRITERIA) SEDIMENT TESTING REQUIREMENTS

Variable	Average Per-Analysis Testing Cost ($)
Chemical	
Total solids	$10
Oil and grease	35
Grain size	75
Sulfides	20
Total volatile solids (TVS)	15
Metals (As, Cd, Pb, Hg, Zn)	150
Total LPAH and Total HPAH	175
Pesticides and PCB's	210
Priority pollutant acid/base/neutrals (organic compounds)	600
Total Chemical	$1,290
Biological	
Amphipod bioassay	$450
Total Biological	450
Total Cost	$1,740

TABLE II.10-8.

COSTS FOR PROJECTED SEDIMENT TESTING REQUIREMENTS

Variable	Average Per-Analysis Testing Cost ($)
Chemical	
Grain size	$75
Sulfides and ammonia	40
Percent solids	10
Total volatile solids	15
Total organic carbon	35
Priority pollutant metals (plus Mn)	160
Pesticides and PCB's	200
Priority pollutant acid/ base/neutrals (organic compounds)	600
Purgeables	210
Total Chemical	$1,345

TABLE II.10-8. (con.)

Variable	Average Per-Analysis Testing Cost ($)
Biological	
Bioaccumulation	$1,000 (a)
Juvenile bivalve	500
Amphipod bioassay	450
Larval bioassay (b)	675 (c)
Microtox	175
Total Biological	$2,800

(a) Bioaccumulation costs are estimated at $2,000 per analysis. Per section II-6 above, bioaccumulation testing will only be required when chemicals of human health concern are elevated. Further, no more than one-half of the samples for any given project would be required to run this type of testing. For purposes of this cost analysis, it was assumed that one-half of all samples needing biological testing would also run bioaccumulation tests (one-half of $2,000 is applied to every sample).
(b) Costs shown for the larval test are the net effect of combining the Section 401 sediment toxicity larval test and the Section 404 water column larval test.
(c) Larval sediment toxicity ($450) and water column ($450) testing would total $900 for each analysis. For purposes of this cost analysis, it was assumed that water column tests would be needed on only 50 percent of biological samples ($675 = $450 plus one-half of $450).

TABLE II.10-9.

PROJECTED COSTS OF SEDIMENT SAMPLING AND TESTING
OVER THE NEXT 15 YR (1985-2000)

Area	Cost Category ($ x 1,000)	Cost ($ x 1,000) PSDDA Disposal Guidelines I	II	III	PSIC
Port Gardner	Program design/mgt(a)	19	19	19	20
	Coring(b)	191	191	191	247
	Chemistry(c)	323	323	323	531 (d)
	Aquatic biological(e)	414	656	672	185 (f)
	Land biological(g)	179	0	0	739
	QA/QC and reporting(h)	5	5	5	8
	Area Total	1,131	1,194	1,210	1,730
Elliott Bay	Program design/mgt	22	22	22	22
	Coring	508	508	508	526
	Chemistry	1,475	1,475	1,475	1,131
	Aquatic biological	482	574	1,216	395
	Land biological	2,563	2,382	635	1,585
	QA/QC and reporting	18	18	18	15
	Area Total	5,068	4,979	3,874	3,674
Commencement Bay	Program design/mgt	18	18	18	19
	Coring	123	123	123	196
	Chemistry	191	191	191	422
	Aquatic biological	218	380	391	147
	Land biological	427	105	0	639
	QA/QC and reporting	3	3	3	6
	Area Total	980	820	726	1,430
	PSDDA Total	7,179	6,993	5,810	
	PSIC Total				6,834

TABLE II.10-9 (con.)

(a) Design and management costs based on $5,000 for design of a medium-sized project (100 cores) and $8,000 for management and review. Total medium-sized project cost: $13,000. Small and large projects (10 and 1,000 cores) are estimated to cost approximately one-half and twice the amount of the medium-sized project. Cost model: cost = log(number of cores) x $6,500.

(b) Coring costs were estimated at $200 per core.

(c) Chemistry costs were estimated at $1,345 per analysis (table II.10-8).

(d) Chemical testing costs under PSIC were estimated at $1,290 per analysis (table II.10-7).

(e) For PSDDA, biological testing costs $2,800 per analysis (table II.10-7).

(f) Aquatic biological testing costs under PSIC were estimated at $450 per analysis (table II.10-7).

(g) Biological testing requirements and costs for upland/nearshore disposal were not determined during the Phase I study. For the purposes of this evaluation, they were assumed to at least equal the cost of aquatic biological testing under PSDDA ($2,075).

(h) QA/QC and reporting costs based on the following:

- o Additional QA coring costs: 2 percent of coring costs
- o Additional analytical costs: 5 percent of analytical costs
- o QA/QC analysis/reporting: based on assessment of all QA/QC analyses and 20 percent of other analyses at 2.5, 2, and 1.5 h per analysis for small, medium, and large projects, respectively. Cost model: cost = $(-0.5\log N+3) \times 11.25 \times N$; where N = number of analyses (excluding QA/QC analyses).

Figure II.10-6 depicts the overall structure of the cost model used for evaluating management alternatives. Each pathway through the model represents an individual alternative disposal method.

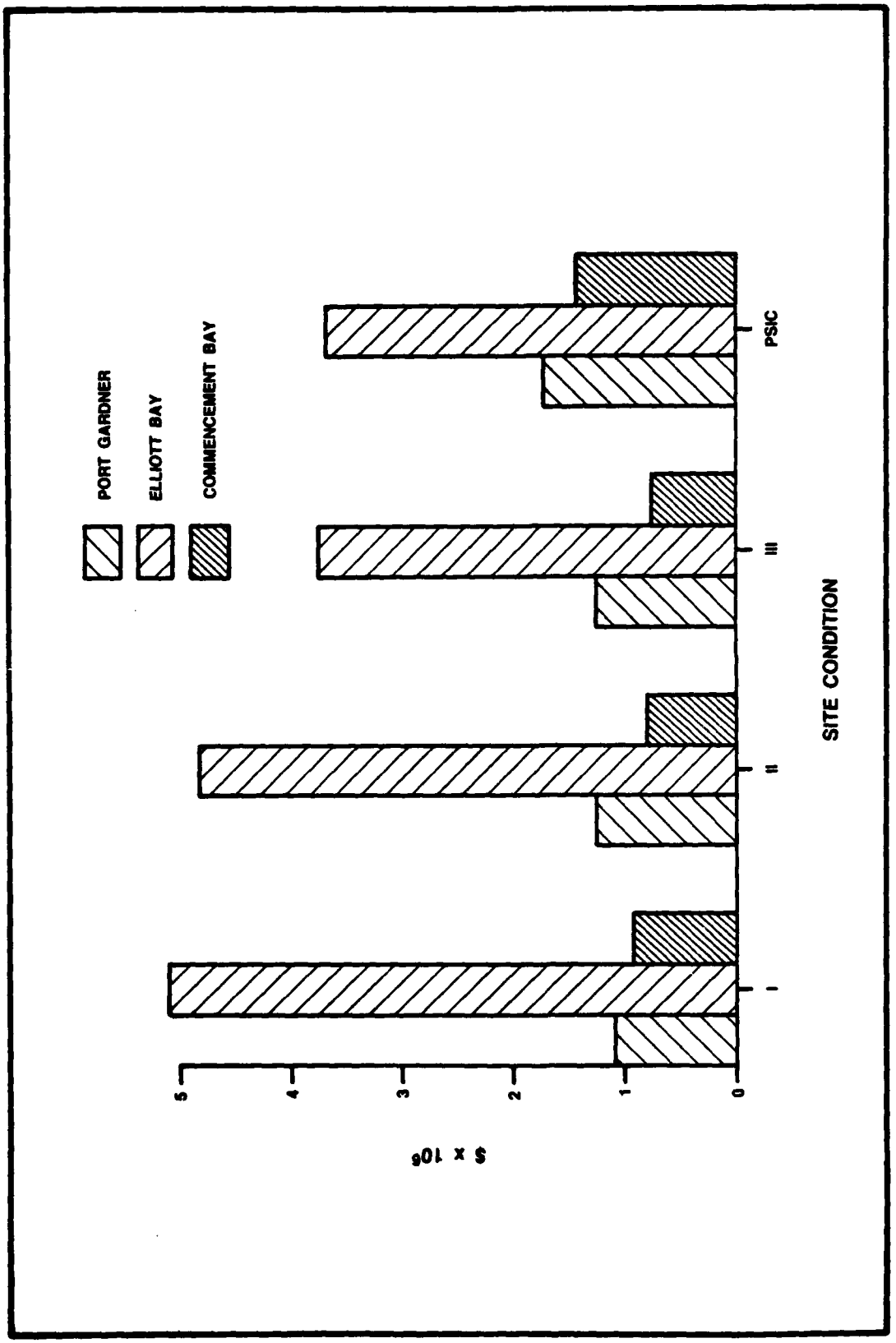


Figure II.10-5. Comparison of sampling and testing costs for each dredging area. (see Table II.10-9).

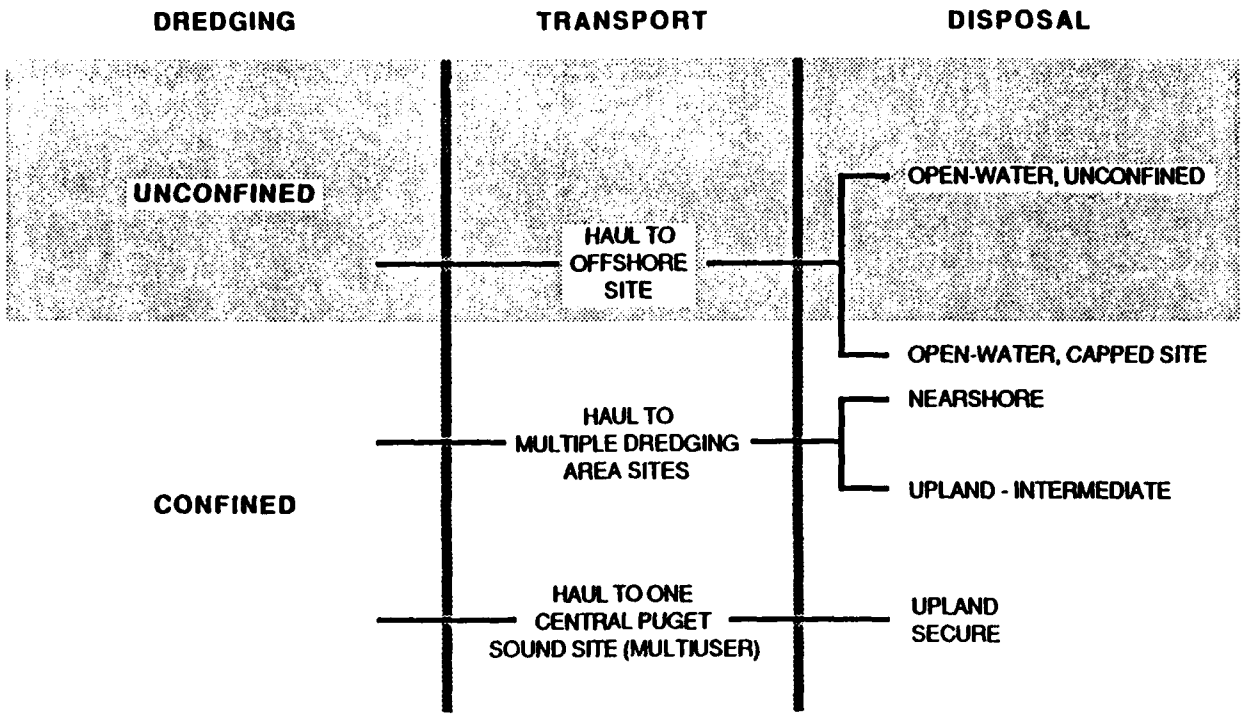


Figure II.10-6. Structure of the cost model for dredged material management, including costs of dredging, transport, and disposal.

analysis are shown in Table II.10-10. Assumptions for the use of each confined disposal technology for handling dredged material was developed by the Corps. According to these estimates, 40 percent of the material going to confined disposal will be disposed of by open-water capped technologies, 19 percent by nearshore technologies, 40 percent by upland-intermediate secure technologies, and 1 percent by upland-secure technologies.

A second variable of somewhat lesser importance (and largely dependent upon the selected disposal site) is transportation. Both the method of transport and the transport distance must be considered. It is assumed in this analysis that all water transport of sediment is via barge. Transport distance was accommodated in the model by defining the locations of existing and hypothetical disposal sites appropriate to each type of disposal technology and the distance (nmi) from each dredging subarea. Sediment transport costs were then based on a unit cost per loaded-haul-nmi. Because a bucket dredging operation was assumed, overland transport of sediment was assumed to be by truck.

Cutterhead, hopper, and clamshell-type dredges are all commonly used in Puget Sound waters (Phillips et al. 1985). In order to maintain a manageable number of cost scenarios, the following assumptions were made:

- A standard mechanical clam dredge (barge-mounted) is used for sediments qualifying for unconfined, open-water disposal
- A closed clam dredge is used for other sediments (confined disposal).

10.3.2 Dredging Costs. Costs for clamshell (bucket) dredging operations have been estimated by other researchers for the Puget Sound region (Phillips et al. 1985) and are updated here to mid-1986 costs:

Bucket Size (c.y.)	Production Rate (c.y./h)	Cost ($/c.y.) (1986)
5	200	$1.50
15	650	$0.46

For this analysis, it was assumed that the smaller bucket size is used in all projects (Parker, R., January 1987, personal communication). It was assumed that the cost of closed clamshell dredges is also represented by the above cost.

The dredging costs for the Port Gardner area are estimated to be $7.4 million, those for the Elliott Bay area are estimated to be $15.8 million, and those for the Commencement Bay area are estimated to be $5.9 million.

TABLE II.10-10.

DESCRIPTIONS OF SEDIMENT DISPOSAL TECHNOLOGY ASSUMPTIONS

Disposal Technology	Description	Key Comments
Open-water unconfined	Sediment discharge at designated open-water site.	o Open-water site
Open-water capped	Discharge to an underwater depression. Clean dredged material is placed over contaminated layer.	o Natural depression (no dike construction) o Vertical down-pipe (no diffuser) o Silt curtain
Nearshore	Disposal site in the area of influence of normal tidal fluctuations, i.e., diked waterways.	o Graded dike o Leachate monitoring wells o Clean dredged material cover
Upland-intermediate security	Terrestrial site removed from marine environment. Some contaminant controls.	o 3-ft soil liner o Leachate monitoring system o Clean dredged material cover
Upland-secure	Chemical waste landfill.	o All design requirements for hazardous waste disposal site in accordance with State and Federal regulations

10.3.3 Transport Costs.

a. Marine Transport. For this cost analysis, an estimate of $0.25/c.y. per loaded nmi (Phillips et al. 1985) is used for dredged sediment transport by barge. Haul distances for bulk transport from each subarea/waterway and projected dredging volumes for the 15-year analysis period are listed in table II.10-11. Transportation distances from the subareas within each ofthe three Puget Sound areas to potential dredged material disposal sites were measured from centralized points within each subarea. The coordinates of these points are included in table II.10-11. Four types of disposal site locations were chosen for each of the three Phase I dredging areas (table II.10-12):

- o An open-water disposal site (for the calculation of distances to both unconfined and capped sites)
- o A nearshore disposal area
- o A restricted upland disposal area (upland - intermediate security
- o A secure upland disposal area (assumed to be at Arlington, Oregon).

b. Overland Transport. Overland transport presupposes some requirement for transferring sediment from barge to truck. The cost for this transfer was assumed to be best represented by the cost per cubic yard ($1.50) for the lower dredging production rate (i.e., 5 c.y. bucket size). This estimate is comparable to that for shore-based dragline operations (King and Millison 1985).

Transport from shore to upland confined disposal sites can represent a significant added cost for these disposal technologies. This is particularly true in the Puget Sound basin, where steep shoreline relief and limited accessibility have a large influence on transfer to upland sites. Table II.10-11 includes the overland distances to each upland site. All overland transport was assumed to be by truck at an average unit cost of $0.25/c.y./mi for long distance hauling, and $0.35 for short distance (less than 10 mi) hauling.

Table II.10-13 is a summary of the transport costs for delivery of sediment to each type of site listed in tables II.10-11 and II.10-12. Based on the estimated percentage of total sediment that will go to each type of disposal site, table II.10-13 includes the prorated cost of sediment transport from each Phase I dredging area to the unconfined and confined sites assumed to be serving that particular area.

TABLE II.10 11. SUBAREA LOCATIONS AND THEIR TRANSPORT DISTANCES TO DREDGED MATERIAL DISPOSAL AREAS

Regional Service Areas and Subareas	Open Water Disposal Site Location and Distance from Source[a]	Nearshore Disposal Site Location and Distance from Source	Upland (Limited Disposal Site Location and Distance from Source	Secure Upland Disposal Site Location and Distance from Source[b]
PORT GARDNER, EVERETT	Lat: 47°58' Long: 122°15'15"	Lat: 47°59'40" Long: 122°14'	Lat: 47°40' an existing dredged material Long: 122°10'30" disposal site	Arlington, OR
East Waterway Lat: 47°59'10" Long: 122°13'13"	1.8 nmi	1.8 nmi	Option 1 - 0.3 nmi, 4.2 mi rail or truck Option 2 - 5.7 nmi (via Snohomish River)	50 mi
Upper Snohomish Lat: 48°50' Long: 122°10'50"	5.1 nmi	4.8 nmi	1.0 nmi	360 mi
Lower Snohomish (incl. delta) Lat: 48°1'30" Long: 122°16'	3.4 nmi	2.2 nmi	Option 1 - 3.3 nmi, 4.2 mi rail or truck Option 2 - 7.7 nmi (via Snohomish River)	360 mi
ELLIOTT BAY, ETC.	Fourmile Rock Lat: 47°37'30" Long: 122°25'	N. End Harbor Island Lat: 47°35'20" Long: 122°20'	Upland site on Harbor Island	
Lower Duwamish Lat: 47°31'50" Long: 122°21'45"	5.3 nmi	4.1 nmi	2.4 nmi plus 0.3 mi by truck	335 mi
Upper Duwamish Lat: 47°31'50" Long: 122°18'55"	7.8 nmi	6.7 nmi	5.0 nmi plus 0.3 mi by truck	335 mi
Duwamish Turning Basin Lat: 47°30'50" Long: 122°18'55"	9.0 nmi	7.8 nmi	6.1 nmi plus 0.3 mi by truck	335 mi
Eagle Harbor Lat: 47°37' Long: 122°30'	4.5 nmi	6.1 nmi	Use nearshore transport distance plus 0.3 mi by truck	335 mi
Sinclair Inlet Intersection with Bremerton	12.75 nmi	14.8 nmi	Use nearshore transport distance plus 0.3 mi by truck	335 mi

[a] Same for both capped and unconfined.

[b] Overland distance only.

TABLE II.10-11. (Continued)

Regional Service Areas and Subareas	Open-Water Disposal Site Location and Distance from Source (a)	Nearshore Disposal Site Location and Distance from Source	Upland (Limited Disposal Site Location and Distance from Source	Secure Upland Disposal Site Location and Distance from Source (b)
ELLIOTT BAY, ETC.	Fourmile Rock Lat: 47o37'30" Long: 122o25'	N. End Harbor Island Lat: 47o35'20" Long: 122o20'	Upland site on Harbor Island	
Lake Wash. Ship Canal Lat: 47o39'15" Long: 122o21'50"	6.9 nmi	10.4 nmi	Use nearshore transport distance plus 0.3 mi by truck	335 mi
Kenmore/Sammamish R. Intersection of Lake Wash./Kenmore	20.2 nmi	16.0 nmi	Use nearshore transport distance plus 0.3 mi by truck	350 mi
Lake Washington Mid-span I-90 bridge	15.0 nmi	5.4 nmi	Use nearshore transport distance plus 0.3 mi by truck	335 mi
Lake Union Lat: 47o38'30" Long: 122o20'	8.2 nmi	11.5 nmi	Use nearshore transport distance plus 0.3 mi by truck	340 mi
COMMENCEMENT BAY	Lat: 47o16'30" Long: 122o25'55"	Lat: 47o15'15" Long: 122o25'45"	To Port of Tacoma upland site "D"	
Hylebos Waterway Lat: 47o16'30" Long: 122o23'	2.5 nmi	3.1 nmi	Minimal water transport, 3.0 mi by truck	300 mi
Blair Waterway Lat: 47o16' Long: 122o23'50"	2.0 nmi	2.6 nmi	Minimal water transport, 1.75 mi by truck	300 mi
Sitcum Waterway Lat: 47o16'15" Long: 122o25'	0.87 nmi	1.4 nmi	Minimal water transport, 2.0 mi by truck	300 mi

(a) Same for both capped and unconfined.

(b) Overland distance only.

TABLE II.10-12. LOCATIONS CHOSEN FOR DISPOSAL SITES IN THE THREE PHASE I DREDGING AREAS

	Port Gardner	Elliott Bay, Etc.	Commencement Bay
Open-water disposal (both capped and unconfined)	Existing preferred site in the regional service area. Lat: 47°59'00" Long: 122°15'17"	Existing/preferred site in the regional service area. Lat: 47°37'36" Long: 122°22'00",	Existing/preferred si in the regional servic area. Lat: 47°16'17" Long: 122°25'28"
Nearshore disposal	Site is a large existing "spoil area" noted on the navigational chart of Port Gardner and vicinity. A point within this area was chosen for distance measurement purposes. Site is due west of the city of Everett in the southern portion of the Snohomish River Delta. Lat: 47°59'40" Long: 122°14'00"	The north end of Harbor Island was chosen arbitrarily as the location of a nearshore disposal facility for the purpose of calculating transport distances from the various subareas. Lat: 47°35'20" Long: 122°20'00"	Middle Waterway wa chosen as suggested b ACOE for the nearshor site in Commencemer Bay for transport dis tance caiculation pur poses. Lat: 47°15'15" Long: 122°25'45"
Upland (restricted) disposal	An existing dredged material disposal site is located on the east side of the Snohomish River just north of where I-5 crosses the river, so for transport distance calculations a point within this existing site was chosen. Lat: 47°40'00" Long: 122°10'30" Transportation of dredged material to this site would involve a combination of overwater and over-land means. Another option, shipping the material up the Snohomish River, would involve total water transport.	Harbor Island was chosen arbitrarily for the location of a restricted upland disposal site, primarily to enable the use of the nearshore transport distances already calculated. Lat: 47°35'20" Long: 122°20'00"	The Port of Tacoma upland site "D" wa suggested by ACOE calculate transpor distances.
Upland secure disposal	Chemical Waste Management Disposal Facility in Arlington, Oregon	Chemical Waste Management Facility in Arlington, Oregon	Chemical Waste Manag ment Disposal Facil in Arlington, Oregon

10.3.4 Disposal Costs. As shown in figure II.10-6, the two overall dredged material disposal options addressed in this analysis are unconfined and confined disposal. Unconfined disposal encompasses one disposal technology: unconfined, open-water disposal. Confined disposal encompasses a range of technologies from open-water capping to secure land-based landfilling.

10.3.4.1 Unconfined Disposal. Unconfined, open-water disposal of bucket-dredged sediments is usually accomplished by a barge or scow for transport to an open-water disposal area. Sediment discharge is accomplished by release through doors in the bottom of the vessel's hull ("split-hull" barge).

Unconfined, open-water disposal costs are normally low and consist primarily of barge and crew standby time during the actual disposal (sediment release) process. Assuming crew and equipment costs from Godfrey (1983) and Means (1984) construction cost data, the total equipment and labor cost is $300/h. A maximum discharge rate of 1,000 c.y./h yields a unit disposal cost of $0.30/c.y.

10.3.4.2 Confined Disposal. A relatively broad range of technologies is included in the confined disposal category. For this cost assessment, four technologies were modeled and evaluated for total cost: open-water, capped; nearshore; upland-intermediate secure; and upland-secure.

Open-Water Capped. The capped, open-water site was assumed to consist of a natural depression requiring no excavation or underwater dike construction. Materials were assumed to be deposited in a natural depression in the seafloor at a site between 60 and 500 feet deep (Phillips et al. 1985). Operational assumptions included sediment deposition through a vertical downpipe (tremie) with no diffuser. The deployment of a silt curtain to limit lateral dispersion during sediment discharge was assumed. [Examples of existing capped, open-water sites similar to this description have been evaluated for Puget Sound (Sumeri 1984) and elsewhere (Shields et al. 1984)].

The overlying cap materials were assumed to be available from dredging projects in the same vicinity as that generating the sediments requiring confined disposal. The volume of the cap was assumed to be twice the volume of the confined sediments (2:1 ratio).

Tripling the cost of unconfined, open-water disposal (to accommodate the additional cap volume) yields an estimated $0.90/c.y. disposal cost. Use of the downpipe system adds another $1.00/c.y. (Phillips et al. 1985). An additional cost of $0.05/c.y. for a silt curtain was estimated based on material costs of $2.75/c.y. of curtain (King and Millison 1985). Assuming a requirement of 10,000 ft^2 of curtain and 20 percent contingency. (e.g., anchors, ballast,

TABLE II.10-13. SEDIMENT TRANSPORT COSTS BY SPECIFIC DREDGING AREAS WITHIN PHASE I DREDGING AREAS

Area	Subarea	Projected Volumes (cy x 1,000)	Transport Costs ($ x 1,000) [a] (all sediment to each option) Haul to Open-Water Site	Haul to Nearshore Site	Haul to Upland Intermed. Site	Haul to Secure Site	Estimated Unit Costs ($/cy) Haul to Unconfined Disposal	Haul to Confined Disposal [b]
Port Gardner								
	East Waterway	618	$278	$278	$1,038	$56,593	$0.45	$1.85
	Lower Snohomish	2,086	$1,773	$1,147	$7,259	$192,590	$0.85	$2.76
	Upper Snohomish	2,239	$2,855	$2,687	$4,702	$205,428	$1.28	$2.50
	Total	4,943	$4,906	$4,112	$12,999	$454,611	(average) $0.86	(average) $2.37
Elliott Bay								
	Lower Duwamish	4,945	$2,596	$5,069	$14,538	$424,528	$0.53	$2.44
	Upper Duwamish	2,154	$2,477	$3,608	$9,693	$186,321	$1.15	$3.44
	Duwamish Turning Basin	745	$1,080	$1,453	$3,844	$64,647	$1.45	$3.88
	Lakes: Kenmore/Sammamish River	247	$1,433	$988	$2,742	$22,971	$5.80	$8.45
	Lakes: Lake Washington	1,501	$6,755	$2,026	$7,115	$129,987	$4.50	$4.82
	Lakes: Lake Union	138	$386	$397	$1,159	$12,334	$2.80	$5.92
	Lakes: Lake Washington Ship Canal	213	$527	$554	$1,649	$18,712	$2.48	$5.46
	Sinclair Inlet	334	$1,211	$1,236	$3,467	$29,709	$3.63	$7.19
	Eagle Harbor	248	$384	$378	$1,280	$21,520	$1.55	$3.84
	Total	10,525	$16,849	$15,708	$45,486	$910,729	(average) $2.65	(average) $5.05
Commencement Bay								
	Hylebos Waterway	335	$385	$260	$704	$25,711	$1.15	$2.21
	Blair Waterway	2695	$2,762	$1,752	$5,660	$206,841	$1.03	$2.14
	Sitcum Waterway	685	$514	$240	$1,439	$52,574	$0.75	$1.97
	Other Waterways	214	$214	$128	$449	$16,425	$1.00	$2.12
	Total	3,929	$3,875	$2,380	$8,252	$301,551	(average) $0.98	(average) $2.11
	Grand Total	$19,397	$25,630	$22,200	$66,737	$1,666,892		

[a] Cost for barging: $0.25/nmi
Shore transfer and trucking <10-mi transfer: $1.50/cy Trucking: $0.35/cy/mi
Shore transfer and trucking >10-mi transfer: $1.50/cy Trucking: $0.25/cy/mi

[b] Units costs for transport to confined site prorated based on following assumed allocation among disposal technologies:

Disposal Technology	Percent of Sediment Requiring Confined Disposal that is Going to Each Technology
Open-Water capped	40
Nearshore	19
Upland intermediate	40
Upland secure	1

fittings), yields a total estimated purchase cost of $3,667 for the curtain. Scaling in accordance with the $1.00/c.y. cost for the downpipe [manufacturing cost of approximately $75,000 (Phillips et al. 1985)] yields a unit cost of $0.05/c.y. Design and permitting costs for the model project size of 75,000 c.y. yields unit costs of $0.07 for each element. The total estimated unit cost for open-water, capped disposal (excluding transport) is $2.08/c.y. (table II.10-14). Monitoring is not included in the cost of confined aquatic disposal, in part due to the more rigorous technology assumptions for this disposal technique (see section II-10.3.4.2), in part to an assumption (for this cost analysis) that the material is not sufficiently contaminated to warrant intensive monitoring, and in part to insufficient information concerning potential monitoring requirements.

Nearshore. Nearshore disposal sites are confined disposal facilities located within the areas of influence of normal tidal fluctuations (Cullinane et al. 1986). Dredged material is added to the diked area until the final elevation is above the high tide elevation. Nearshore sites are normally used in conjunction with hydraulic dredges, but can also accommodate dredged material from bucket operations. Sites in Puget Sound can involve diking of waterways with sediment deposition behind the dike structure.

Unlike the underwater, capped facility, the nearshore disposal site includes the construction of facility structures (dike end weir) prior to site use. Site control and treatment requirements vary widely from site to site. It was assumed for this model that nearshore facility supernatant is not processed by physical or chemical treatment. Site control consists of run-on diversion and site completion with a surface cover of clean dredged material.

Cost estimates for development, operation, and completion of nearshore sites of various capacities are available in the literature (Phillips et al. 1985; Cullinane et al. 1986). Table II.10-15 lists the estimated capacity and preparation costs for previously assessed nearshore sites in Puget Sound. The mean value of the costs shown in table II.10-15 (updated to mid-1986) is $0.66/c.y. Assuming a final cover of 3 feet of clean, dredged material and an average site fill depth of 30 feet, an additional cost of $0.22/c.y. would be incurred. Adding the cost of installation of three monitoring wells per site ($7,500) and the cost of monitoring for a 30-year period ($36,000) yields an approximate additional unit cost of $0.05/c.y. for ground water monitoring (based on the average site capacity of the eight sites in table II.10-15. (Note: This level of monitoring effort assumes that routine monitoring has been established for nearshore sites. Nearshore disposal project undertaken in the near future are likely to experience higher monitoring costs pending demonstration of an appropriate site design.)

Land acquisition costs were based on Puget Sound port and financial institution estimates of $10.00/ft^2. (Site is assumed to accommodate an average fill depth of 30 feet.) Clearing and preparation costs are based on estimates from Cullinane et al. (1985). Design cost is assumed to be 5 percent of the construction cost for the average site size of 265,000 c.y. Permitting cost for the average sized facility is assumed to be $7,500. Habitat mitigation is based on purchase of undeveloped shoreline at $1,000/linear ft.

TABLE II.10-14.

DISPOSAL TECHNOLOGY
COST MODEL: OPEN-WATER CAPPED

Technology Element	Cost/c.y.
Dredged material disposal	$0.30
Cap placement	0.60
Downpipe placement	1.00
Silt curtain	0.05
Design (a)	0.07
Permitting (a)	0.07
TOTAL	$2.08/c.y.

(a) Assume $5,000 for design and $5,000 for permitting, based on model project size of 75,000 c.y.

TABLE II.10-15.

NEARSHORE DISPOSAL DIKE AND WEIR COSTS

Site	Capacity (c.y. x 1,000)	Dike and Weir Costs ($ x 1,000)	Preparation Cost ($/c.y.)
Middle Waterway	650	340	$0.52
Milwaukee Waterway	2,160	1,039	0.48
Blair Waterway outer slip	892	885	0.99
Blair Waterway middle slip	945	463	0.49
Blair Waterway inner slip	600	383	0.64
Blair graving dock	200	101	0.51
Hylebos Waterway No. 1	1,274	691	0.54
Hylebos Waterway No. 2	300	331	1.10
Average	878		$0.66

Reference: Phillips et al. (1985), updated to 1986.

Combining the above costs, the total estimated unit cost for nearshore disposal is $14.43/c.y. of sediment (table II.10-16).

Upland-Intermediate Secure. The cost of upland disposal of sediments will vary according to specific site characteristics (Phillips et al. 1985). Factors include ownership of the site, amount of site preparation necessary, and the amount of treatment and monitoring required both during and after sediment disposal and site capping.

Because upland, intermediate security sites share similar design components to those included in municipal refuse disposal sites, the best available model for this type of site and its additional complex structures is a municipal waste landfill. Costs associated with such facilities were therefore used in this analysis. A recent national survey of 1986 use (tipping fee) costs at landfills by the National Solid Waste Management Association (Johnson and Pettit 1987) indicated an average cost of $12.30/ton for the State of Washington. A conversion factor of 0.63 c.y./ton can be derived using sediment density measurements for three Commencement Bay samples (Sumeri 1984) and assuming a consolidation factor of 0.8. Using this conversion factor, tipping fees represent a cost of $19.52/c.y. This cost reflects the permitting, maintenance, monitoring, and other operational requirements that are built into the use fees through long-established municipal-sector accounting.

Upland-Secure. The closest upland site in the Pacific Northwest region currently accepting contaminated chemical wastes is the Chem Security, Inc. waste disposal site in Arlington, Oregon owned by Chemical Waste Management, Inc. Although it is likely that a secure site used solely for sediment disposal would differ somewhat in design, operation, and location, the Arlington site is believed to be the best representation of an active site capable of accepting highly contaminated materials.

The cost for disposal of sludge materials [not regulated by the Toxic Substances Control Act (TSCA) or other anticipated bans on solvent-bearing materials] at the Arlington facility is approximately $110-$120/ton [including a ctate tax of $10/ton (as of 31 July 1986)], depending on the quantity shipped. (The value was provided by Chem Security for planning purposes only and was not provided as a firm bid estimate.) This compares with a recent estimate of $90-$130/ton developed by the U.S. EPA (1985). A price of $110/ton is assumed for this analysis. Applying the previously calculated conversion factor of 0.63 to the above cost, this yields a unit cost of $175/c.y.

Summary of Costs for Confined Disposal. The costs of each of the confined disposal technologies are shown in table II.10-17, and are prorated in accordance with the sediment volumes anticipated to be transported to each type of site (Johns, D.M., 10 July 1986, memorandum for record). Assumptions for the percentage of material going to each kind of confined disposal were made by the Corps based on current trends in material management. Accordingly, 40 percent of the material is projected for open-water capped disposal and 19, 40, and 1 percent are projected for nearshore, upland intermediate, and upland secure disposal, respectively. The prorated average cost for confined disposal is $13.13.

TABLE II.10-16.

DISPOSAL TECHNOLOGY
COST MODEL: NEARSHORE

Technology Element	Cost/c.y.
Land acquisition	$9.00
Clearing/preparation	0.03
Dike and wier	0.66
Cover	0.22
Miscellaneous	0.09
Monitoring	0.05
Design	0.05
Permitting	0.03
Habitat mitigation	4.30
TOTAL	$14.43/c.y.

10.3.5 Costs of Alternative Disposal Management Options. Total management costs for dredged material for each Phase I dredging area were calculated using the sediment volume categories developed in section 10.1.3, together with the above-described cost estimates, according to the following relationship:

Total Management Cost	=	Unit Hauling Cost	+	Unit Disposal Cost	x	Sediment Volume	+	Total Dredging Cost

The results of these calculations are presented in table II.10-18 for the 15-year projection period. Summaries of these alternative total disposal costs are provided in figure II.10-7. These results show that the costs for transport and disposal of sediment under the PSDDA program will be significantly less, even at the Condition I level, than the costs for the present interim program (i.e., using Puget Sound Interim Criteria). The estimated costs at Condition I and for the interim program (excluding sediment sampling and testing) are approximately $259 and $324 million, respectively. The costs at Conditions II and III are $194 million and $139 million, respectively. Corresponding annual costs are also shown in table II.10-18.

10.4 Cost of Ocean Disposal.

10.4.1 Hauling Costs. The cost of hauling dredged material to the Strait of Juan De Fuca and the Pacific Ocean from the three Phase I Puget Sound dredging areas was estimated as a function of material volume (c.y.) and distance from a central location within each of the three areas.

For the first 40 nmi of absolute distance (i.e., haul distance) from a central location within each of the three areas to the hypothetical disposal site, a barge transport cost of $0.25/c.y./nmi was assumed (Phillips et al. 1985). For haul distances in excess of 40 nmi, the following cost equation provides a unit cost:

$$\$/c.y./nmi = \$0.25 + (nmi-40) \times \$0.00625$$

Transport distances were calculated by designating a central point in each of the three areas and measuring the distance from each to a point northwest of Admiralty Inlet (latitude: 48°15'00" N; longitude: 123°00'00" W). This shipping hub in Admiralty Inlet was assumed to be a point through which all dredged material en route to the strait or ocean must pass. The remaining distances from the hub to dredged material disposal sites in the strait and ocean are the same for each of the Phase I dredging areas. Two hypothetical disposal locations, one at the midpoint in the strait (40 nmi from the hub), and one 3 nmi offshore (73 nmi from the hub) were selected for the analysis (figure II.10-8). Transport distances from the three dredging areas to the hub and the hypothetical disposal locations are listed in table II.10-19.

TABLE II.10-17.

SUMMARY OF COSTS FOR CONFINED DISPOSAL

Disposal Technology	Cost ($/c.y.)	Including Secure Site: Percent of Sediment Going To Each Technology	Including Secure Site: Prorated Cost ($/c.y.)
Open-water capped	$2.08	40	$0.83
Nearshore	14.43	19	2.74
Upland (a)	19.52	40	7.81
Upland secure	175.00	1	1.75
Prorated Total:			$13.13

(a) Based on State of Washington tipping fee survey (Johnson and Pettit 1987). Actual local fees may be up to 100 percent higher.

TABLE II.10-18. COSTS OF DREDGING MATERIAL FROM THE PHASE I AREAS, HAULING IT TO THE APPROPRIATE SITE, AND DISPOSAL[a]

		PSDDA						PSIC	
		Site Condition I		Site Condition II		Site Condition III			
Area	Type (b)	Volume (cy x 1,000)	Cost ($ x 1,000)	Volume (cy x 1,000)	Cost ($ x 1,000)	Volume (cy x 1,000)	Cost ($ x 1,000)	Volume (cy x 1,000)	Cost (c) ($ x 1,000)
Port Gardner	UCOW	2,212	5,884	4,684	12,459	4,943	13,148	675	1,796
	CON	2,731	46,427	259	4,403	0	0	4,268	72,556
	Subtotal	4,943	52,311	4,943	16,862	4,943	13,148	4,943	74,352
Elliott Bay	UCOW	3,112	13,848	3,374	15,014	6,162	27,421	1,350	6,008
	CON	7,413	145,888	7,151	140,732	4,363	85,864	9,175	180,564
	Subtotal	10,525	159,736	10,525	155,746	10,525	113,285	10,525	186,572
Commencement Bay	UCOW	1,348	3,747	3,160	8,785	3,776	10,497	225	626
	CON	2,581	43,206	769	12,873	153	2,561	3,704	62,005
	Subtotal	3,929	46,953	3,929	21,658	3,929	13,059	3,929	62,630
	Total		259,001		194,266		139,492		323,553
	Annual Total		17,267		12,951		9,299		21,570

a Dredging was assumed to be by clam dredge. Hauling costs were estimated as the average cost to haul material either by water (for open-water disposal) or by truck (for confined disposal) to the nearest disposal site. Disposal costs for confined disposal are based on an average cost of upland/nearshore disposal. For this analysis, disposal sites were assumed to be available.

b UCOW = Unconfined, open-water disposal.
CON = Confined upland/nearshore disposal.

c PSDDA costs for unconfined and confined disposal applied to PSIC volumes.

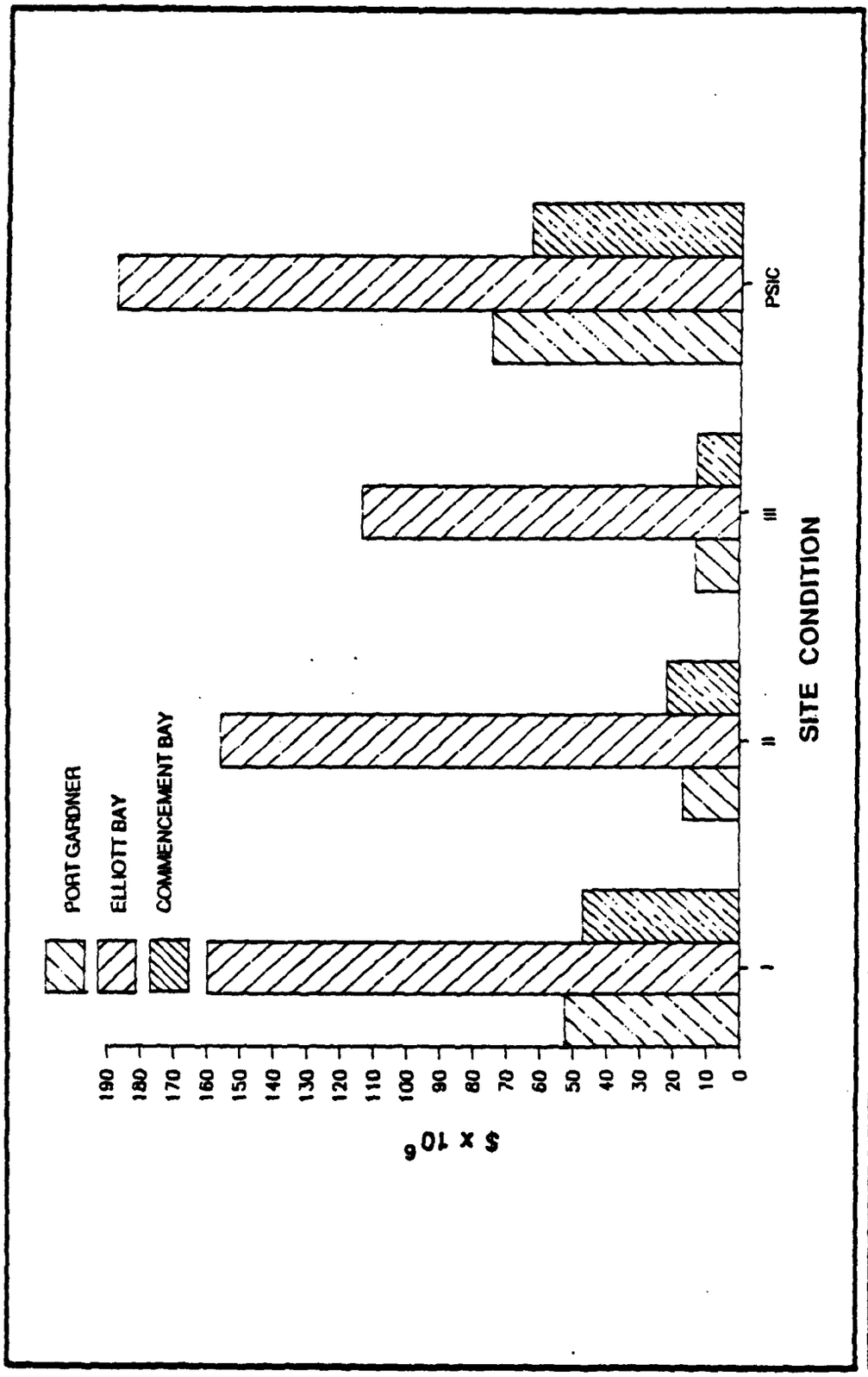


Figure II.10-7. Dredging, hauling, and disposal costs for each area.

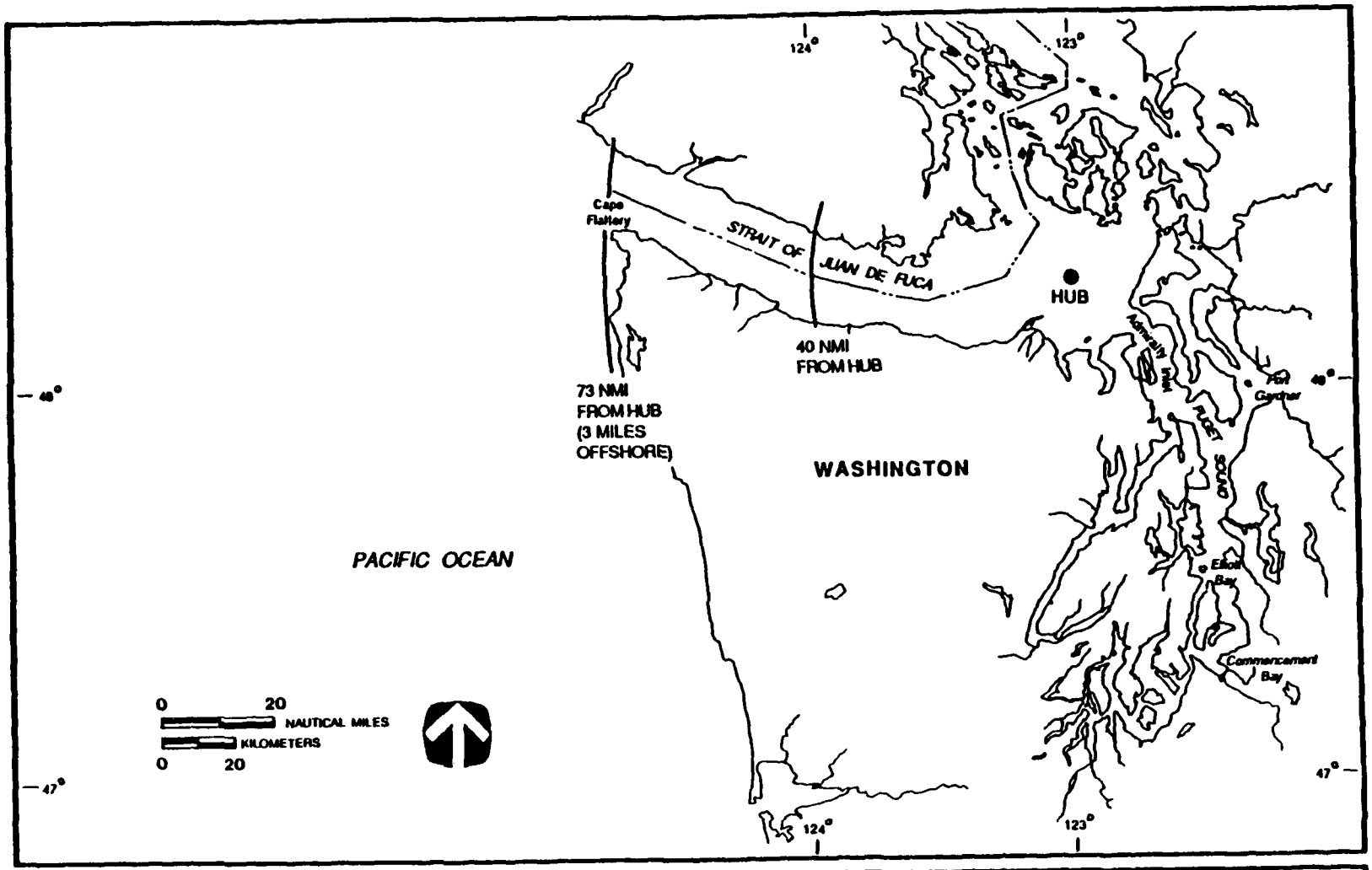


Figure II.10-8. General location of Puget Sound area dredged material sources and the material transport routes and distances to the Strait of Juan de Fuca and the Pacific Ocean. All material transported from the three Phase I dredging areas is assumed to pass through the point labeled HUB.

TABLE II.10-19

DREDGED MATERIAL HAUL DISTANCES FROM THE THREE
PHASE I DREDGING AREAS TO LOCATIONS IN THE STRAIT AND OCEAN

Destination	Total Haul Distances (in nmi)		
	Port Gardner	Elliott Bay	Commencement Bay
Hub	45	51	73
Strait location	85	91	113
Ocean location	118	124	146

(a) The following coordinates represent points within the dredging areas and at the Hub used for the transport distance calculations.

Coordinates:	Latitude	Longitude
Port Gardner	47°58'00"	122°15'15"
Elliott Bay	47o35'20"	122°20'00"
Commencement Bay	47°16'30"	122°25'55"
Hub	48°15'00"	123°00'00"

TABLE II.10-20

DREDGED MATERIAL DISPOSAL COSTS:
DISPOSAL IN THE STRAIT/OCEAN

Area	Destination	Distance (nmi)	Total Management Cost ($ x 1,000) (a) PSDDA Disposal Guidelines I	II	III	PSIC
Port Gardner	Strait	85	61,419	11,015	5,734	92,758
	Ocean	118	83,950	13,152	5,734	127,969
Elliott Bay	Strait	91	174,480	168,744	107,715	213,050
	Ocean	124	235,637	227,740	143,710	288,744
Commencement Bay	Strait	113	75,251	25,621	8,748	106,010
	Ocean	146	96,544	31,965	10,011	136,568

(a) Cost at each effects level based on the assumption that all acceptable sediments are disposed of at unconfined, open-water site, and that all unsuitable sediments are hauled to the strait/ocean. Hauling rates = $0.25/c.y./nmi. Unit cost used for unconfined, open-water is also used for disposal cost at sea ($0.30/c.y.).

TABLE II.10-21. COMPARISON OF DISPOSAL IN THE STRAIT/OCEAN TO TRANSPORT AND DISPOSAL UNIT COSTS FOR OTHER TECHNOLOGIES

Area	Destination	Long-Haul Transport and Disposal (Table II.10-20)	Transport and Unconfined Disposal (Table II.10-13)	Transport (Table II.10-13)[a] and: Open-Water Capped (Table II.10-17)	Nearshore (Table II.10-17)	Upland Intermed. Sec. (Table II.10-17)	Upland Secure (Table II.10-17)
Port Gardner	Strait	$46.75	$1.16	$2.94	$16.80	$21.89	$177.37
	Ocean	$64.90					
Elliott Bay	Strait	$50.05	$2.95	$4.73	$19.48	$24.57	$180.05
	Ocean	$68.20					
Commencement Bay	Strait	$62.15	$1.28	$3.06	$16.54	$21.63	$177.11
	Ocean	$80.30					

[a] Open-water capped transport costs assumed to equal costs for hauling to unconfined disposal sites. Transport costs for nearshore and upland disposal based on prorated average for confined disposal.

Sediment management costs using the strait and ocean disposal technology for each site condition are based on the assumption that all acceptable sediments according to each site condition are deposited at unconfined, open-water sites. The cost analysis for each ML level further assumed that all unacceptable sediment for unconfined, open-water disposal was hauled to the strait or ocean. The costs for this option for each site condition are shown in table II.10-20.

10.4.2 Comparison to Costs for Confined Disposal. The long-haul transport and disposal costs for strait and ocean disposal shown in table II.10-20 are compared to the transport and disposal costs for other disposal technologies in table II.10-21. The unit cost for the unconfined, open-water option is the sum of the unit transport cost to open-water sites in each area (table II.10-13) and the estimated cost of disposal ($0.30/c.y.). Unit transport costs for other disposal options shown in table II.10-13, togather with the estimated unit costs for disposal (table II.10-17), were used to estimate the unit costs for each disposal management option in each Phase I Puget Sound dredging area. This analysis demonstrates that ocean disposal is substantially more costly than unconfined and confined disposal technologies (due primarily to transport requirements), with the exception of disposal at the upland secure site.

10.5 Conclusions. In the Phase I area, 19.4 million c.y. of material is forecasted to be dredged over the next 15 years. Of this total, approximately 17 million c.y. of sediment are unacceptable for unconfined, open-water disposal (and 2 million c.y. are acceptable) at the level set by PSIC. The volume of sediment found to be acceptable for unconfined, open-water disposal with Site Condition I is 6.7 million c.y. Significantly more sediment was found to be acceptable for unconfined, open-water disposal with Site Condition II (11.3 million c.y.) and Site Condition III (14.9 million c.y.). The resulting volumes also provide an indication of the material management requirements that will be posed by the sediment quality guidelines during the projection period (1985-1999).

10.5.1 Costs of Testing. Analysis of the anticipated chemical and biological testing requirements under Phase I of PSDDA indicates that both the required number of sediment samples and types of tests will increase slightly over present (interim) levels. EPWG has proposed a schedule for the frequency of sediment coring and analyses based on known sediment quality (rank), project voltme, and other factors. Under this system, and assuming the present and future rankings assigned to each subarea within the three Phase I dredging areas (table II.10-6) and guidelines established at the site Condition II level, the 15-year period testing costs for the Port Gardner, Elliott Bay, and Commencement Bay areas would be approximately $1.2 million, $5 million, and $0.8 million, respectively, and $7 million total for the entire Phase I area.

TABLE II.10-22

TOTAL COSTS FOR THE MANAGEMENT OPTIONS
PRESENTED IN THE PSDDA EIS ($ x 1,000) (a)

Option	Testing (b)	Dredging Disposal (c)	Compliance Inspection (d,e)	Monitoring (f,g)	Total Costs
PSDDA					
Site Condition I	7,179	259,001	787	712	267,679
Site Condition II	6,993	194,266	1,324	1,475	204,058
Site Condition III	5,810	139,492	1,756	3,014	150,072
PSIC	6,834	323,553	375	0	330,762

(a) Options included three alternative guidelines under PSDDA and use of PSIC throughout the Phase I study area. Cost assumptions used to estimate these costs are representative, but do not display the full range of possible costs of dredging and dredged material disposal. Given the number of factors that can affect cost, increased costs above those shown can result for any particular project.

(b) Testing costs include cost of coring, chemical testing, and biological testing of sediment samples. These costs do not include the cost of biological testing that might be required for material that would be disposed of in upland/nearshore sites.

(c) Dredging costs include cost of dredging, hauling, and disposal of material going to unconfined, open-water and that going to upland/nearshore disposal sites. THE COSTS PRESENTED HERE ARE UNDERSTATED SINCE THEY DO NOT INCLUDE THE COST OF SITE ACQUISITION AND DEVELOPMENT THAT WOULD BE REQUIRED FOR ALL MATERIAL GOING TO UPLAND/NEARSHORE.

(d) Compliance inspection costs result from ensuring that dredging operators are complying with disposal site use requirements. Compliance inspection costs were estimated at a given fee per c.y. of material that would be disposed of at the open-water sites under each option. For each option, it was assumed that 60 percent of the volume would be for projects under 15,000 c.y. (the break-even volume to reach the minimum charge of $2,000), and inspection costs were assumed at $0.15 per c.y. For the remainder of the volume, the $0.07 per c.y. fee was used to estimate costs.

TABLE II.10-22

(e) Compliance inspection under PSIC is expected to be minimal. The cost of $375,000 is considered the minimum effort required to conduct compliance inspections over a 15-year period.

(f) Monitoring costs are those costs associated with monitoring the open-water disposal sites. No monitoring costs that would be associated with upland/ nearshore confined disposal sites were included in this analysis. Costs were based on those found in the PSDDA monitoring report. The costs shown for PSDDA Site Condition II are those shown in the monitoring report. Costs for PSDDA Site Condition I assume no full monitoring level of effort, only checking level of effort every 3 years. Costs for PSDDA Site Condition III assume full monitoring every 3 years. Details of the monitoring plan are presented in the Monitoring Plan Technical Appendix.

(g) Monitoring of unconfined, open-water disposal sites is not required under PSIC.

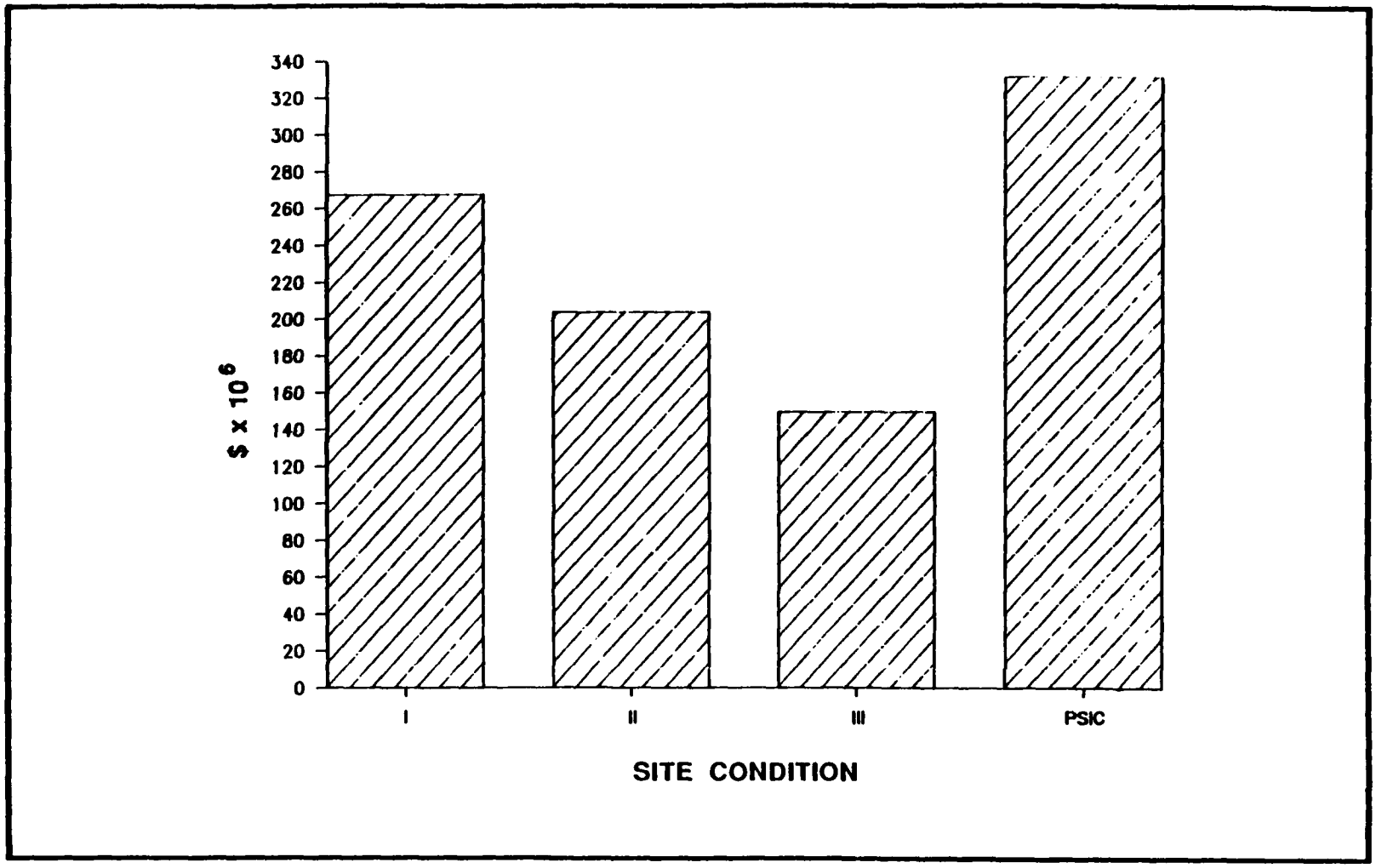


Figure II.10-9. Comparison of total costs for PSDDA and PSIC Program alternatives.

Over the 15-year period, this represents an approximate annual testing cost of $466,000. In comparison, the 15-year costs for the three areas at the site Condition I level are $1.1 million, $5 million, and $1 million, respectively. The incremental additional cost of testing at the Condition I instead of the Condition II level is only $0.2 million over the entire 15-year period. This amount is equivalent to an additional annual cost of $12,000.

On a per-analysis basis, it is anticipated that, when biological testing is required, Phase I program testing protocols will cost approximately 3-4 times the amount required under the PSIC program. However, on a programatic basis (table II.10-9), this cost is balanced by the additional chemistry and land biological testing for the PSIC program.

10.5.2 Sediment Management Costs. The total estimated sediment management costs are presented in table II.10-22 and figure II.10-9. These management costs include the costs of monitoring at the unconfined, open-water disposal sites. Details of the monitoring plan for this disposal option are presented in the MPTA. The high cost for upland-secure disposal relative to other confined sediment disposal technologies is an overriding factor in the disposal cost analysis. Because it is estimated that approximately 1 percent or less of contaminated sediments would be disposed of in this type of site, it does not severely impact the total costs for confined disposal.

The total estimated costs of accepting Site Condition I (the lowest of the four alternative site conditions) or the existing Puget Sound Interim Criteria for sediment from all three dredging areas is approximately $268 million and $331 million, respectively, over the 15-year period of analysis. Using the disposal guidelines represented by Site Condition II, the total estimated cost is approximately $204 million. The total estimated cost of accepting Site Condition III is approximately $150 million.

11. SELECTED DISPOSAL GUIDELINES FOR SITE MANAGEMENT June 1988 rev.

11.1 Basis for Selection. Of the three alternative site conditions, Site Condition II was selected as the upper level of potential adverse biological effects acceptable for unconfined, open-water disposal. The site condition was selected based primarily on the following factors:

- o Environmental Protection and Accountability - Material that is acceptable at Site Condition II is not expected to produce adverse effects outside of the disposal site due to relatively low concentrations of chemicals of concern and the use of relatively nondispersive sites. By definition, "no significant acute toxicity" would be allowed at the disposal site, and any long-term, sublethal adverse effects would be confined to the disposal site where they can be monitored, and managed as needed. Also, Site Condition II is consistent with State Water Quality Standards.

- o Costs - The total estimated dredged material disposal costs associated with Site Condition II are substantially lower than those estimated using Site Condition I; and are comparable to the costs associated with Site Condition III.

- o Precedents - Site Condition II reflects the way that 404(b)(1) Guidelines, have been historically applied, avoiding "significant acute toxicity" from material that was approved for unconfined, open-water disposal.

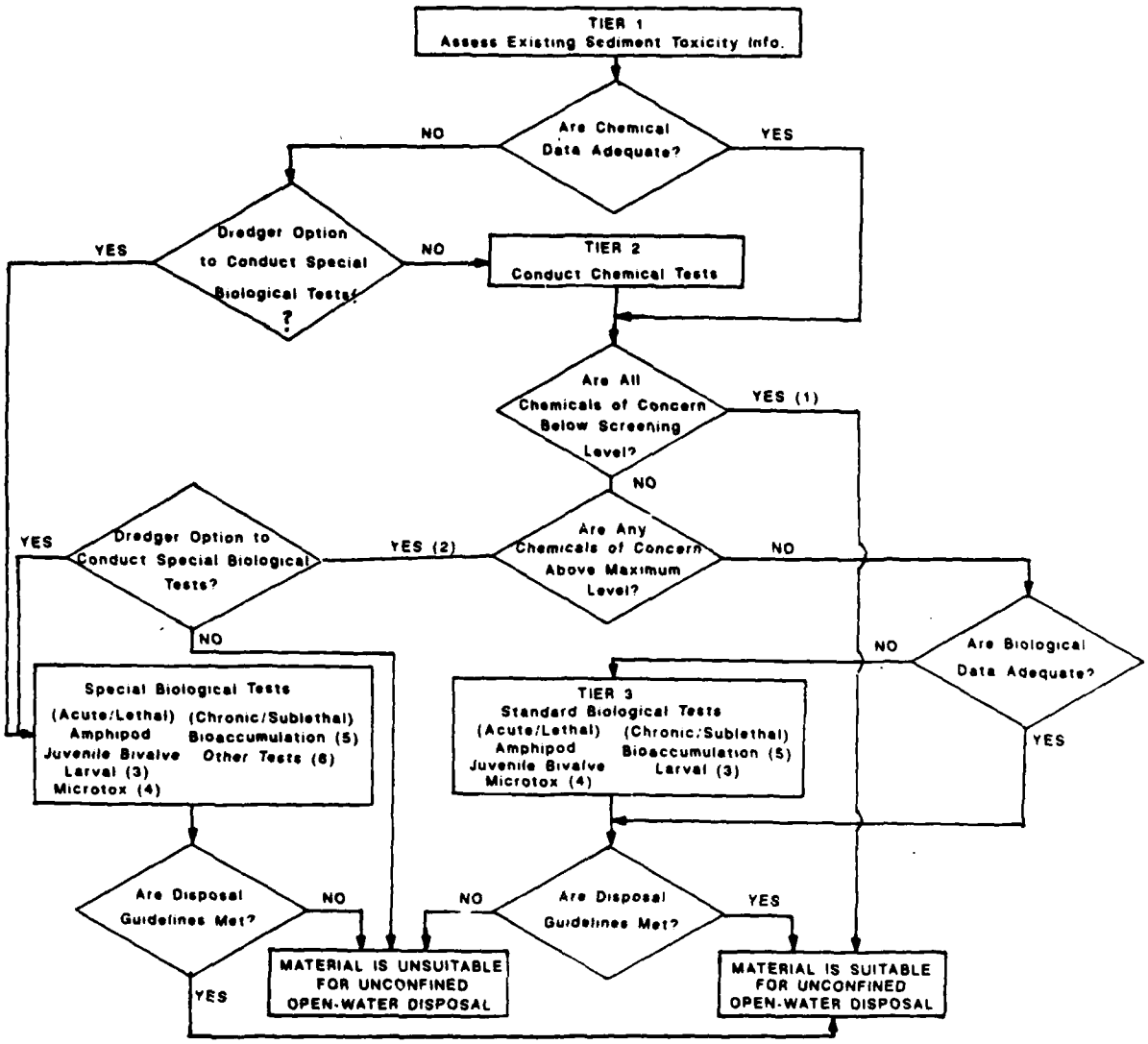
The expected volumes of dredged material acceptable under Site Condition II guidelines are expected to produce no more than minor effects at the disposal site. The total estimated management costs associated with Site Condition II allowable effects are lower than those estimated using existing Puget Sound Interim Criteria.

11.2 Selected Disposal Guidelines. Chemical and biological testing sequence is shown in figure II.11-1 and disposal guidelines for Site Condition II allowable effects are summarized in table II.11-1. Screening level and maximum level chemical concentrations for this site condition are summarized in table II.11-2. Dredged material with chemical concentrations above the maximum level listed in table II.11-2 presents a reason to believe that the material is likely to be unacceptable for unconfined, open-water disposal. The dredger may stop here with no further biological testing required, or may conduct additional biological testing (see section II-2.5) to show that discharge of the dredged material would not cause "unacceptable adverse effects." Dredged material with chemical concentrations below the screening level (Table II.11-2) are acceptable for unconfined, open-water disposal without biological testing unless considered anomalous (see section II-7.7). At chemical concentrations between the screening and maximum levels, the dredged material is only considered acceptable if the biological guidelines are not exceeded. The disposal guidelines to be used in conducting Section 401 and Section 404 evaluations are shown on figure II.11-2. The "net effect" of combining the 401

and 404 procedures is shown in the disposal guidelines outlined on figure II.11-3. Such material is defined as producing minor effects of sediment contamination on biological resources (see section II-8.2.2). Definitions of what constitutes a "significant" response in biological tests specified by EPWG are summarized in figure II.11-4.

An illustrated comparison of the PSDDA screening and maximum levels to the existing Fourmile Rock and Puget Sound interim criteria is provided in figures II.11-5 through II.11-7. Through the pattern differs for each chemical in common (there are many other PSDDA chemicals of concern which are not addressed by the interim criteria), often the screen level is below the interim criteria, while the maximum level is above.

11.3 Dredger Option to Conduct Biological Testing. When dredged material chemicals of concern exceed the ML values, the dredger will have two options. He may accept the indications of the ML that the material is unacceptable for unconfined, open-water disposal. He may also puruse another option to conduct biological testing. His testing program must be coordinated and aproved by the PSDDA agencies prior to initiation. Details regarding the dredger option are specified in section II.2.5



(1) Biological testing may still be required if there is reason to believe that the sediment is highly anomalous and may represent a significant environmental risk even though all chemicals of concern are below screening levels for unconfined open-water disposal.

(2) Standard tier 3 biological testing can still be conducted when only a single chemical of concern exceeds the maximum level by < 100% Biological testing of material with chemical levels above maximum level is allowed as an option of the dredger(see footnote 6)

(3) The larval species can be used in either a sediment toxicity bioassy (for Section 401) and/or in a water column bioassy (for Section 404) The sediment larval test is required whenever biological testing is necessary, the water column larval test is only required when water column effects are of concern.

(4) Microtox testing is required only for Section 401 reviews; it is not required for Section 404 evaluations.

(5) The chemical screening level that determines when bioaccumulaton testing is required is higher than for other biological testing.

(6) Special biological testing under the "Dredger Option" will include additional, more sensitive sublethal biological tests (see EPTA).

Figure II.11-1 PSDDA testing sequence.

TABLE II.11-1

BIOLOGICAL AND CHEMICAL DISPOSAL GUIDELINES
FOR THE SELECTED SITE CONDITION

o Biological Site Condition (a)--
No two acute sediment toxicity bioassays exhibiting a statistically significant (P less than 0.05) response over reference conditions; or
No one acute sediment toxicity bioassay response is greater than 30 percent over, and statistically significant with respect to, reference conditions; or
If tested, the water column larval response does not exceed 0.01 of the LC50 concentration after 4 hours initial mixing; and
If tested, adult bivalve bioaccumulation levels do not exceed human health tissue guidelines.
o Maximum Chemical Level (b)--
No sediment chemical concentrations higher than the highest AET for a series of biological indicators (ML2 values).

(a) Condition II; biological tests that comprise the determination of Site Condition II are discussed in section II-7.

(b) Condition II; maximum chemical level (ML2) established for Site Condition II is discussed in section II-8.2; numerical values for ML2 are given in table II.8-3; the dredger option is discussed in section II-11.3.

TABLE II.11-2

SCREENING AND MAXIMUM LEVEL CHEMISTRY VALUES
FOR THE SELECTED SITE CONDITION

Chemical	SL*	ML*
METALS (mg/kg dry weight; ppm)		
Antimony	2.6	26
Arsenic	70	700
Cadmium	0.96	9.6
Copper	81	810
Lead	66	660
Mercury	0.21	2.1
Nickel	28	120a
Silver	1.2	5.2
Zinc	160	1600
ORGANICS (ug/kg dry weight; ppb)		
Low molecular weight PAH	610	6100
Naphthalene	210	2100
Acenaphthylene	64	640
Acenaphthene	63	630
Fluorene	64	640
Phenanthrene	320	3200
Anthracene	130	1300
2-Methylnaphthalene	67	670

TABLE II.11-2 (con.)

Chemical	SL*	ML*
High molecular weight PAH	1800	51000
Fluoranthene	630	6300
Pyrene	430	7300 (a)
Benzo(a)anthracene	450	4500
Chrysene	670	6700
Benzofluoranthenes	800	8000
Benzo(a)pyrene	680	6800
Indeno(1,2,3,-c,d)pyrene	69	5250 (a)
Dibenzo(a,h)anthracene	120	1200
Benzo(g,h,i)perylene	540	5400
CHLORINATED HYDROCARBONS		
1,3-Dichlorobenzene	170	(b)
1,4-Dichlorobenzene	26	260
1,2-Dichlorobenzene	19	350 (a)
1,2,4-Trichlorobenzene	6.4	64
Hexachlorobenzene	23	230
PHTHALATESc		
Dimethyl phthalate	160	(d)
Diethyl phthalate	97	(d)
Di-n-butyl phthalate	1400	(d)
Butyl benzyl phthalate	470	(d)
Bis(2-ethylhexyl)phthalate	3100	(d)
Di-n-octyl phthalate	69000	(d)
PHENOLS		
Phenol	120	1200
2-Methylphenol	10	72 (a)
4-Methylphenol	120	1200
2,4-Dimethyl phenol	10 (c)	50
Pentachlorophenol	140	(b)

TABLE II.11-2 (con.)

Chemical	SL*	ML*
MISCELLANEOUS EXTRACTABLES		
Benzyl alcohol	10 (c)	73
Benzoic acid	216 (c)	690 (a)
Dibenzofuran	54	540
Hexachloroethane	1,400 (f)	14,000 (e)
Hexachlorobutadiene	29	290
N-Nitrosodiphenylamine	22	220
VOLATILE ORGANICS		
Trichloroethene	160 (f)	1,600 (e)
Tetrachloroethene	14	210 (a)
Ethylbenzene	10	50 (a)
Total xylenes	12	160 (a)
PESTICIDES		
Total DDT	6.9	69
Aldrin	5	(g)
Chlordane	5	(g)
Dieldrin	5	(g)
Heptachlor	5	(g)
Lindane	5	(g)
TOTAL PCBs	130	2500

*The following procedures were used to develop SL and ML for the "selected effects level":

SL = 10% of ML or reference area concentration, whichever is higher, but never greater than the lowest AET for a range of biological indicators.

ML = Highest Apparent Effects Threshold Value (HAET) for a range of biological indicators.

Some of the SL and ML values reflect adjustments made in April 1988 as a result of information provided during the public review of the draft PSDDA Phase I documents. They represent the current guideline values for these chemicals of concern, subject to adjustment during annual review of the PSDDA program.

TABLE II.11-2 (con.)

(a) The ML set for this chemical is based on a biological indicator with a definitive AET. For further discussion see footnote a in table II.8-3.

(b) No ML is currently available for these compounds because there were no definitive AET for any biological indicator.

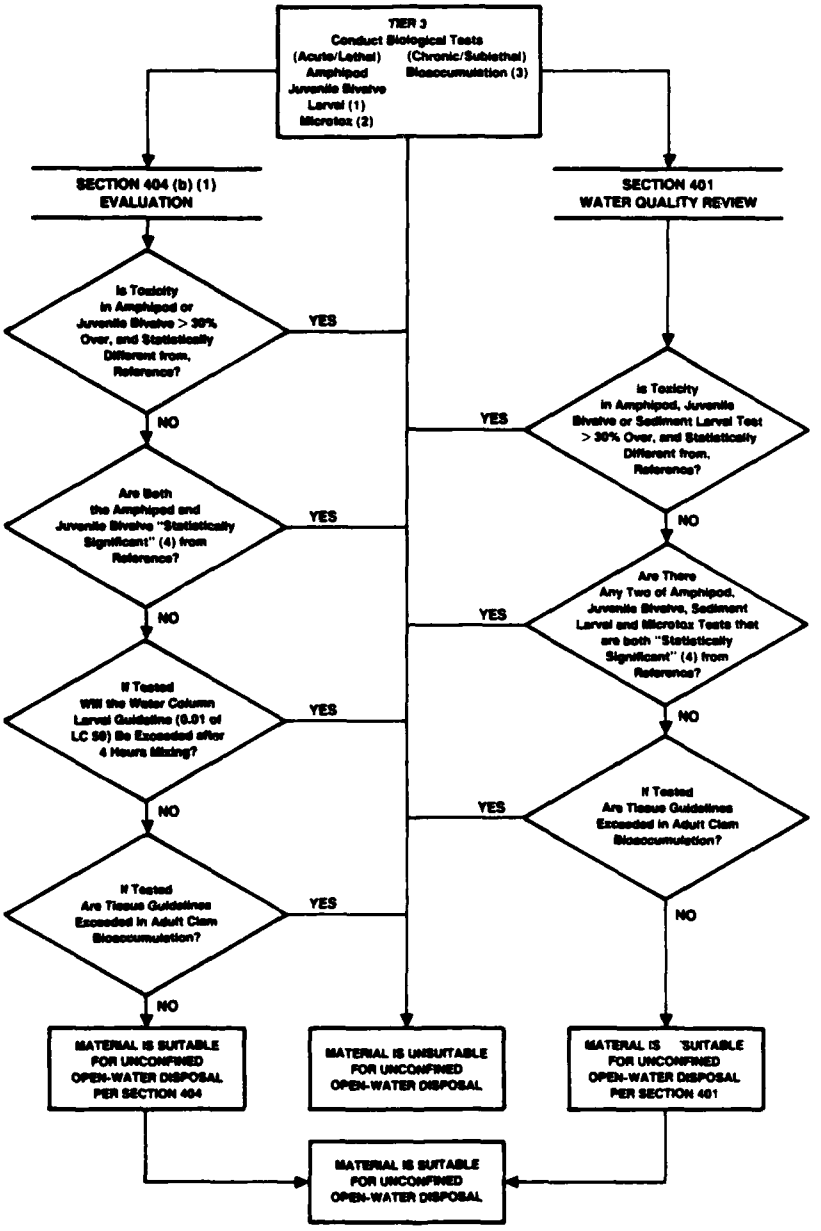
(c) For these compounds, the reference concentration was higher than the calculated value of SL so SL was set at the reference value.

(d) EPWG agreed that biological testing should not be triggered solely by the presence of phthalates. Because these compounds are often present as laboratory chemicals of concern, the highest AET was used as the screening level and no maximum levels were set.

(e) These ML were set using the Equilibrium Partitioning approach (Tetra Tech 1986j) because no AET values were available.

(f) For chemicals with ML values set by the Equilibrium Partitioning approach, SL was still calculated according to the formulas given above.

(g) SL for these pesticides was set to 5 times an assumed analytical detection limit of 1 ug/kg dry weight sediment. No sediment quality values were available for setting maximum levels.



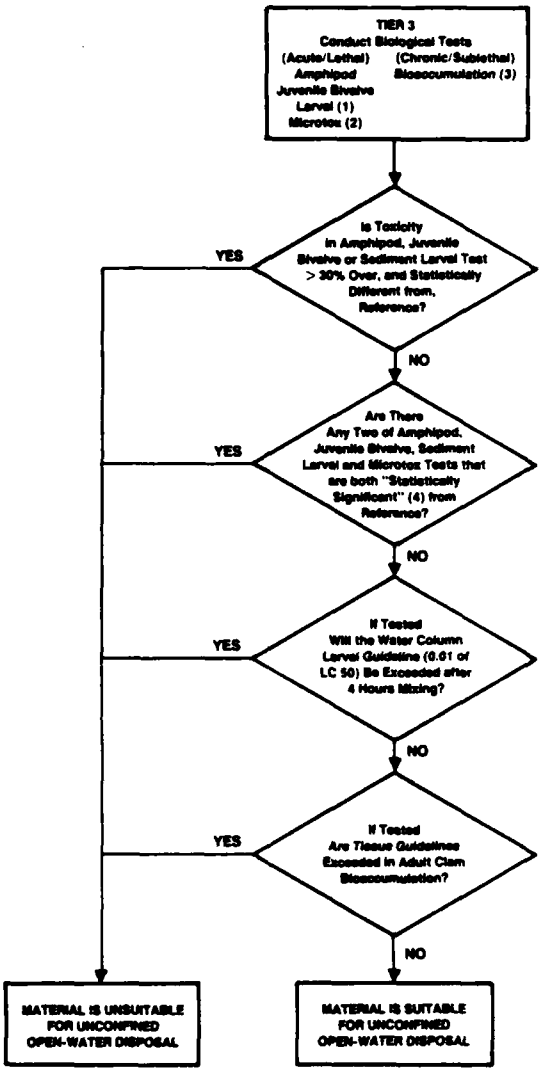
(1) The sediment larval test (for Section 401 reviews) is conducted whenever biological testing is required. The water column larval test (for Section 404 evaluations) is done only when water column effects are of concern.

(2) Microtox testing is required only for Section 401 reviews; it is not required for Section 404 evaluations.

(3) The chemical screening level that determines when bioaccumulation testing is required is higher than for other biological testing.

(4) "Statistically Significant" requires both a statistical difference from reference and total mortality response that is greater than 20 percent (absolute) over control.

Figure II.11-2. Section 404 and Section 401 disposal guidelines.



(1) The sediment larval test (for Section 401 reviews) is conducted whenever biological testing is required. The water column larval test (for Section 404 evaluations) is done only when water column effects are of concern.

(2) Microtox testing is required only for Section 401 reviews; it is not required for Section 404 evaluations.

(3) The chemical screening level that determines when bioaccumulation testing is required is higher than for other biological testing.

(4) "Statistically Significant" requires both a statistical difference from reference and total mortality response that is greater than 20 percent (absolute) over control.

Figure II.11-3. PSDDA disposal guidelines.

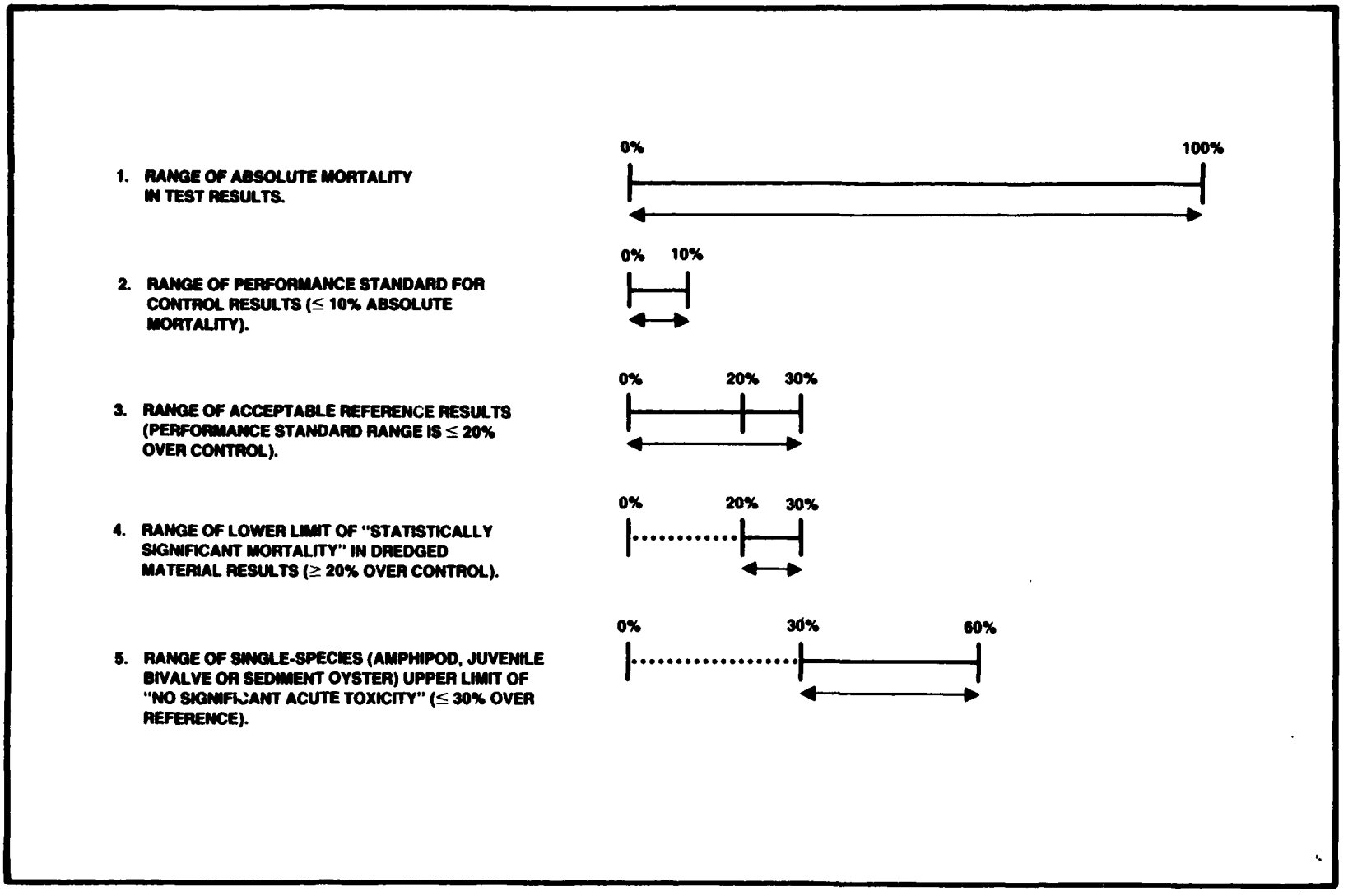


Figure II.11-4. Relationship of control, reference, and test treatment bioassay results in determining significant acute toxicity in sediment toxicity tests for dredged material.

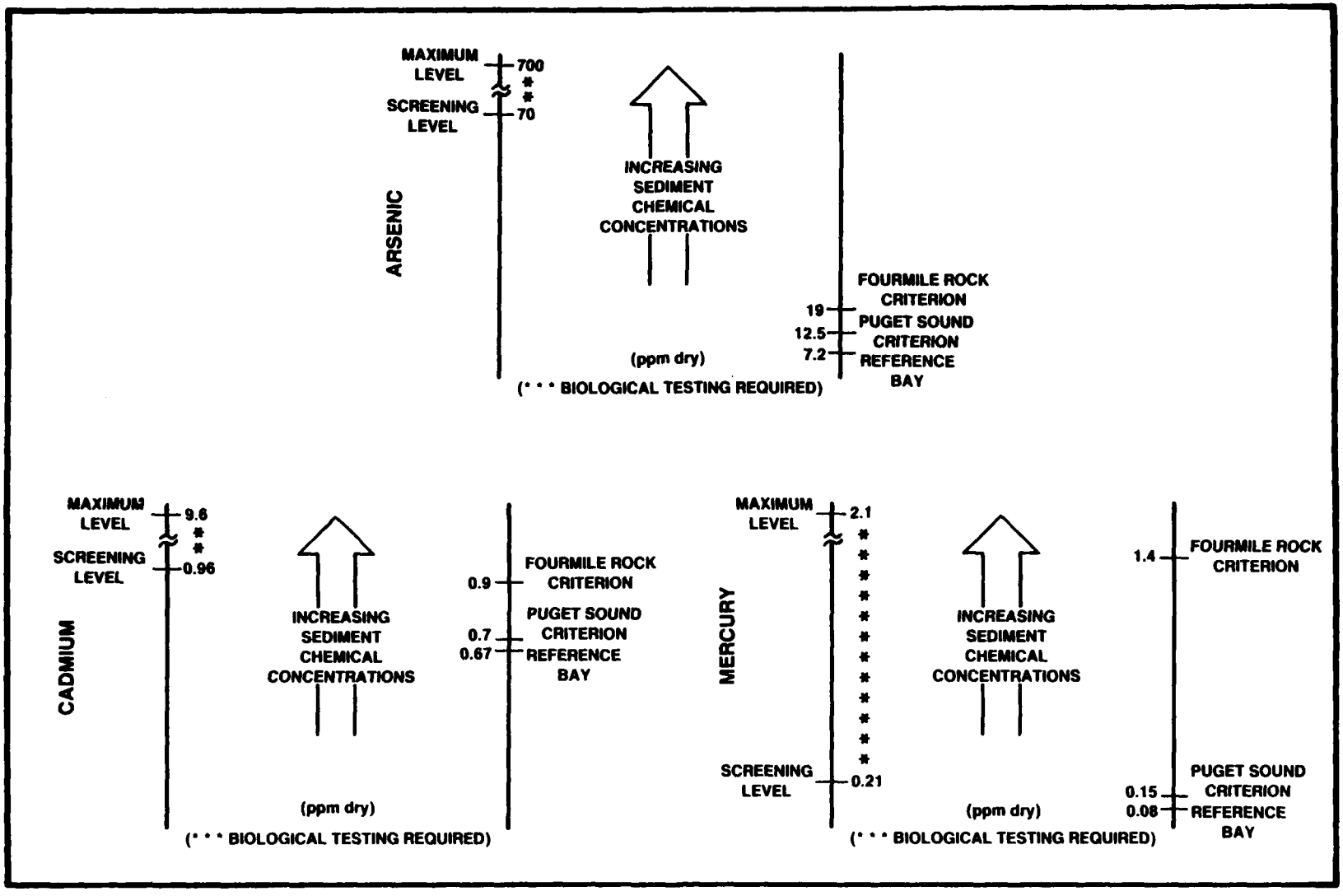


Figure II.11-5 Illustrated example of the differences between interim criteria and proposed PSDDA sediment quality values.

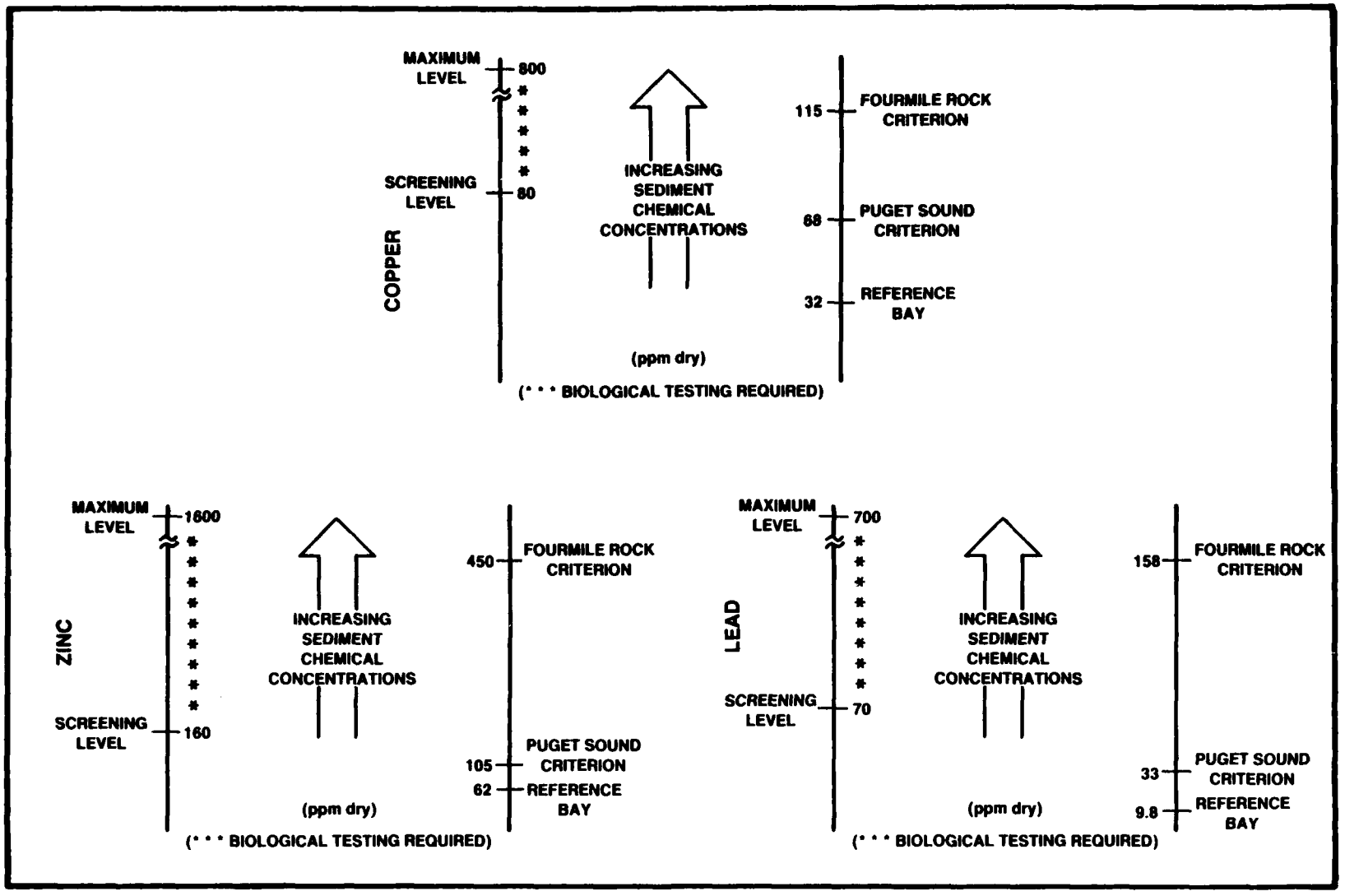


Figure II.11-6 Illustrated example of the differences between interim criteria and proposed PSDDA sediment quality values.

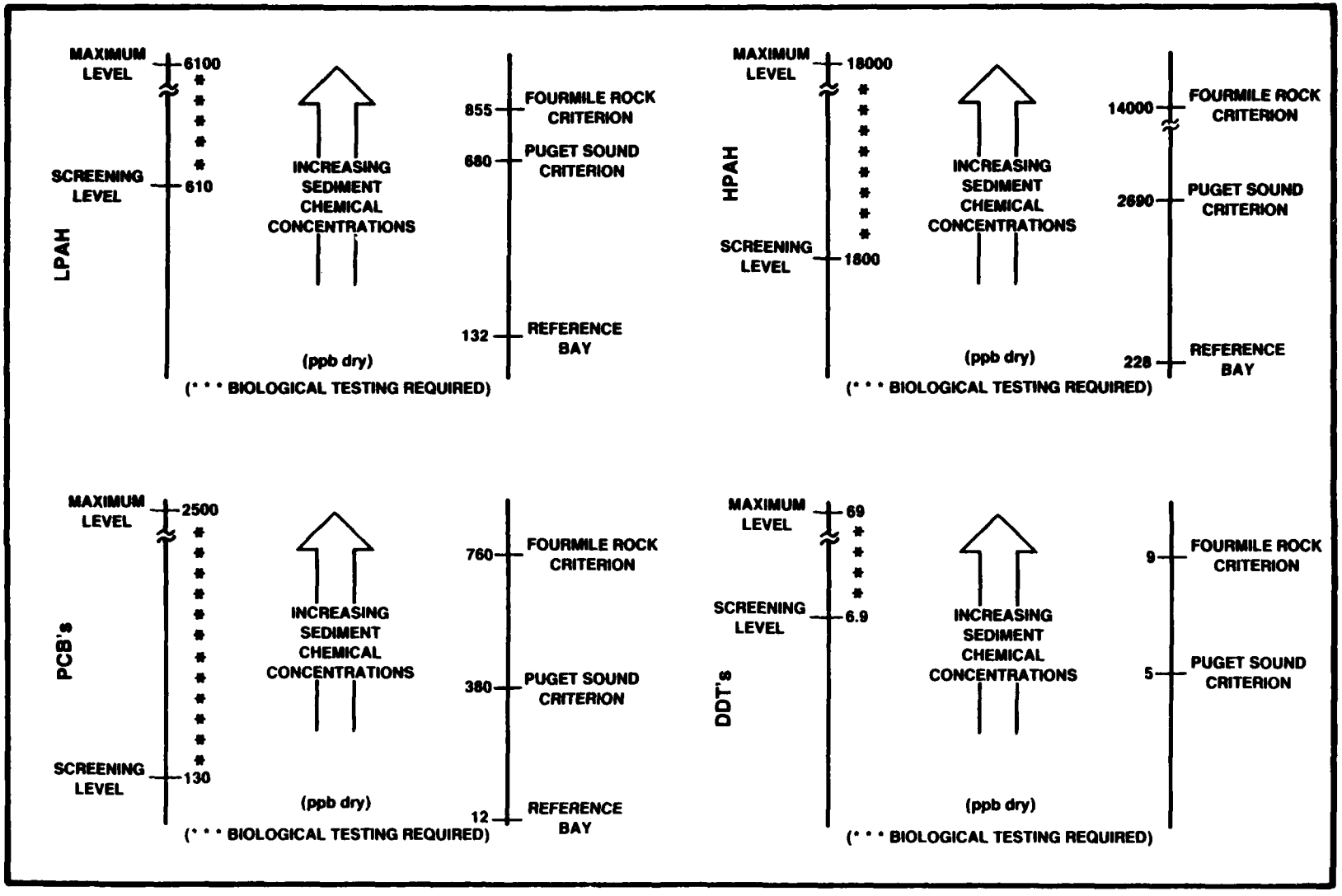


Figure II.11-7 Illustrated example of the differences between interim criteria and proposed PSDDA sediment quality values.

12. REVISIONS TO THE EVALUATION PROCEDURES

Implementation of the PSDDA Unconfined, Open-Water Disposal Management Plan (see MPTA appendix B) will require individual and cooperative action by government agencies, including close interagency coordination. Several local, State, and Federal agencies have overlapping authority regarding open-water disposal of dredged material. Some of the issues, particularly sediment evaluation, are highly technical and depend on the latest scientific information. This expertise rests in a few agencies and must be relied on by all. Likewise, environmental monitoring will be carried out by two agencies but evaluation of and recommendations to the PSDDA program will be a cooperative effort. This need for cooperation derives from the interrelation of program components. These issues are addressed in the MPTA. For these and other reasons, an annual review of the evaluation procedures will occur.

12.1 Annual Review of the Evaluation Procedures. Annual reviews are critical to the viability of the proposed program. In general, the proposed procedures contain several features that have not received full implementation in a regulatory program prior to PSDDA. In many cases, there were insufficient data to resolve key issues debated. Also, this insufficiency results in an inability to conclusively predict the impact of the proposed procedures. Consequently, the annual review process is essential to incorporate what is learned after implementation.

The reviews will consider both the monitoring data and the information obtained from implementing the testing program, and they will address both environmental and cost issues. (The key site users have generally agreed to submit cost data with the test data for their dredging projects, to facilitate this review.) It is likely that future improvements in agency ability to characterize the distribution of chemicals of concern in Puget Sound and to better understand the relationship between specific containment concentrations and biological effects at the disposal site will result in an eventual reduction in sampling and analysis requirements.

The portions of the text that address revisions to the PSDDA program should highlight certain topics of concern to be reviewed. The topics include:

- Utility, interpretation of, and need for, the material release screen
- Costs of testing and disposal resulting from implementation on the procedures
- Interpretation, results, and utility of microtox testing
- Scope and details of the dredger biological testing option (above the ML)
- Single chemical exceptions over the SL and ML

- o Sediment quality values (both the ML and SL values)
- o Results of monitoring relative to the predictions of the lab tests (what do the lab tests indicate about the field?)
- o Improved procedures for evaluation of "anomalous sediments."

12.2 General Considerations for Revising the Evaluation Procedures. Following are several general considerations for revising the evaluation procedures:

- o Changes to the evaluation procedures should be initiated by the agencies implementing PSDDA. Allowance is needed for public comments to request initiation of changes to the evaluation procedures.
- o The evaluation procedures were developed by experienced managers and regulators; these individuals must continue to be involved in the interpretation of PSDDA guidelines.
- o The evaluation procedures should be documented in a loose-leaf notebook to facilitate changes. All pages should be dated to indicate any revisions.
- o The sensitivity of new testing procedures should be "calibrated" in concurrent tests with the current recommended procedures.

A major purpose of these revision procedures is to enable a flexible approach in areas that may be subject to advancement in scientific knowledge. For example, the empirical sediment quality values used to determine the maximum level will be periodically reviewed to allow consideration of new data (including monitoring data). If improved sediment quality values become available, these may be adopted by PSDDA. Before changing the recommended disposal guidelines, the following conditions will be observed for reviewing changes to AET (AET are discussed in section II-7.2):

- o Changes must be procedurally logical, allowing the managed system to adjust over time
- o Monitoring will likely provide the necessary evidence that will enable changes to AET
- o The larger the discrepancy between the existing AET and new values, the greater the need to consider if the new data represent anomalies, or at least an isolated, low frequency event
- o The accuracy of any revised AET will be monitored in considering changes.

13. WORK GROUP CONCLUSIONS

13.1 Proposed, Allowable Site Condition. Of the three alternative site conditions, Site Condition II was considered by EPWG to be appropriate as the preferred condition for evaluation in the DEIS. The volumes of dredged material acceptable under Site Condition II guidelines are expected to produce no more than minor effects at the disposal sites. The total estimated management costs associated with Site Condition II allowable effects are lower than those estimated using existing Puget Sound Interim Criteria.

13.2 Additional Effort. Further work in the following areas is needed:

- Development of an approach and criteria for reducing (or expanding) the list of chemicals of concern (see section II-7.1.1).
- Development of appropriate chronic/sublethal tests (see section II-6.4).
- Investigation of the effect of losses of chemicals of concern on the surface microlayer from the disposal of freshwater sediments (see section II-6).
- Validation of the guideline recommended for the Microtox bioassay response (see section II-6.2) in a study of reference area sediments.
- Conducting of further studies of the nickel and chromium sediment quality values by conducting biological tests on sediments collected from reference areas that contain elevated levels of nickel and chromium of apparently natural origin [e.g., Hood Canal; such sediments were not available in the database used to develop sediment quality values (see section II-7.2)].
- Expansion of the existing sediment quality values database by reviewing and incorporating test results from dredging projects conducted under PSDDA.
- Performing a statistical analysis of the dredged material management unit concept using appropriate mathematical or statistical tools. One tool to be investigated is "Kriging," which is a technique for converting data from a sampling grid of single points distributed throughout an area to a map of meacured values showing contour intervals (e.g., contours of chemical concentration in a dredged material management unit).

- Development and/or establishment of a bioassay that more directly and fully addresses potential sublethal and chronic chemical effects.

- Improvement of the interpretation of the microtox test by comparing the test to other bioassays and reviewing test data from sediments around Puget Sound.

- Conducting a review of the need to add TBT to the list of chemicals of concern.

- Development of confined disposal guidelines, both for evaluation of the material and design of the site.

- Assessment of the potential for conducting future PCB chemical analyses by quantifying totals in isomer groups. This should include analysis for 32 specific congeners, based on environmental prevalance, relative abundance in animal tissues, and potential for toxicity. (McFarland, et al., 1986; Clarke, et al., in preparation.)

- Reviewing the sediment quality values for possible adjustments and conduct efficiency analyses (for predictive efficiency).

- Development of a data verification process or protocol for the dredged material "user manual."

- Refinement of the use of the "safety net" during review of available data.

- Continuing to explore and develop solid phase bioassays.

13.3 Suggested Policy on Research and Development. The following policy on research and development for dredged material management in Puget Sound is suggested:

- Research and development projects should generally be small scale (i.e., a large proposed dredging project that exceeds PSDDA disposal guidelines will not be appropriate under the guise of a research study).

- New bioassay tests that are proposed should be "calibrated" to the response of current bioassays (see section II-7) using good laboratory practice.

- All research and development proposals should be reviewed and approved by the PSDDA agencies.

- All research and development proposals should contain provisions for "technology transfer" to other areas and programs in Puget Sound.

- Encourage the use of data produced by research and development projects to improve existing sediment quality values.

PART III. OTHER DISPOSAL OPTIONS

1. INTRODUCTION

As discussed in part I, there are two separate routes to pursue if the material cannot go to an unconfined, open-water disposal site: "conventional" (i e., not using any special design or technology to restrict chemicals of concern) upland or nearshore disposal, or (2) "confined" (i.e., using special designs and/or technology to restrict chemicals of concern) disposal in water (CAD) or on land/shore. This part of the appendix briefly reviews some of the key issues associated with disposal of dredged material by these other options. In general, dredged material disposal by any option can have environmental consequences and cost tradeoffs that should be considered in project planning.

The PSDDA study is focused on unconfined, open-water disposal of dredged material for several reasons. First, unconfined, open-water is the least costly and usual first choice for dredged material disposal. Before the need for alternative disposal options can be addressed, it is necessary to determine the types and amounts of material that cannot go to unconfined, open-water. Second, while disposal in Puget Sound revolves around many regionwide and statewide issues, disposal on land (especially for material containing chemicals of concern) is very much associated with local government decisions regarding land uses. Third, the authorities of the various agencies involved in PSDDA are not all equally applicable to land. Land ownership is no longer vested primarily in the State, and clean water laws are less directly pertinent on land.

In deciding what types and amounts of dredged material might be acceptable for unconfined, open-water, it is necessary to consider the environmental consequences of the other disposal options. If material is not allowed in water, resources such as nearshore habitat and ground water will end up bearing the risk associated with that decision. These tradeoffs, or "total environmental effects," must be considered in the decision concerning what is acceptable for in water disposal. Additionally, because conventional land and nearshore disposal, and confined disposal, are more expensive than unconfined, open-water, the cost impacts of determining what types of dredged material will be acceptable for unconfined, open-water must also be assessed.

Both environmental effects and cost of the other disposal options will be determined by the evaluation (testing) and design requirements.

The major dredging centers in Puget Sound (e.g., urban waterways) have many projects that contain some material that will not be acceptable for unconfined, open-water. Often this material is located on the surface of the dredge cut, with the subsurface material being acceptable for unconfined, open-water. A plan for how to dispose of the material below the surface would be of little use in a dredging project that must first remove and dispose of the surface

material. Therefore, it is widely recognized that sites and guidelines for confined disposal of dredged material containing evelated chemical concentrations are essential. The Puget Sound Comprehensive Plan (January, 1987) prepared by the Puget Sound Water Quality Authority (PSWQA) calls for a study to identify and designate multiuser disposal sites for dredged material that cannot use the unconfined open-water method. This study, to be conducted by the Department of Ecology, will address all aspects of confined disposal of unacceptable sediments. The generic products prepared by PSDDA are expected to directly contribute to this Ecology study.

During Phase I, a substantive effort for PSDDA on confined and land/shore disposal was accomplished by the Corps' Waterways Experiment Station (WES). Two reports were completed in Phase I that address these options:

1. Guidance on Testing. In addition to guidance for unconfined, open-water, the WES Decisionmaking Framework (DMF) contains recommended tests and test interpretation guidance for evaluating dredged material disposal on upland and nearshore sites.

2. Confined Disposal Design Guidelines. The Dredged Material Alternatives Selection Strategy (DMASS) details available control and treatment technology for confined disposal of unacceptable sediments (all disposal options considered). More importantly, DMASS provides a decision procedure for selecting necessary site designs. However, a number of key decisions regarding design standards have been left to the Puget Sound regulatory agencies [i.e., Regional Administrative Decisions (RADS)].

2. CONVENTIONAL UPLAND AND NEARSHORE DISPOSAL January 1988 rev.

Upland disposal involves placement of dredged material at a site on land where the material eventually dries. Upland sites are usually diked to confine solids and to allow surface water from the disposal operation to be released. Nearshore disposal involves placement of dredged material behind a dike in water along a shoreline, with the final elevation of the fill above water. "Conventional" disposal additionally means that special contaminant controls or restrictions are not needed.

Traditionally, upland and nearshore disposal have been relied upon as the place to use when material was unacceptable for unconfined, open-water disposal. This has left an inherent, though technically imprecise, impression that material acceptable for unconfined, open-water must also be acceptable for conventional upland and nearshore disposal. Differing geochemistry at upland and nearshore sites (due to the presence of oxygen) can alter the availability of chemicals of concern to the environment.

Disposal of dredged material in upland and nearshore environments can create similar concerns for loss of habitat and for release of chemicals of concern as with unconfined, open-water disposal (see section II-2.1). Potential environmental pathways at upland disposal sites are shown in figure III.1-1. The potential concerns at these sites are similar to those at nearshore disposal sites (figure III.1-2). The potential problems that may occur at these sites include possible biological effects at the site and release of chemicals of concern into the environment, possibly resulting in biological effects.

Potential concerns for conventional upland and nearshore disposal of dredged material include direct effects caused by burial and disruption of the natural flora and fauna during preparation and filling of the site. Mechanisms of potential chemical release at these sites include leaching, volatilization, and bioturbation. Leaching occurs from precipitation and ground water, if the water table is high enough. Volatilization occurs as chemicals of concern are released directly to the atmosphere. Bioturbation (i.e., disturbance of the soil and sediment by organisms) can move chemicals of concern into the food web and off the site. If the sediment is dried, wind dispersal could also occur.

One major difference in the geochemical action at upland and shore sites versus aquatic sites is the presence of oxygen and aerobic reactions. Depending on the chemicals of concern present, the aerobic environment may be conducive to leaching of otherwise stable chemicals (e.g., metals).

2.1 Existing Guidelines for Conventional Upland and Nearshore Disposal. Historical decisionmaking for upland and nearshore disposal focused primarily on the achievement of water quality standards at the weir (for hydraulic

effluent) and at the edges of the designated mixing zone. Parameters of concern were typically dissolved oxygen (DO) and "conventional chemicals of concern" such as settleable solids, turbidity, pH, temperature, and salinity. Disposal of mechanically dredged material (not producing a significant effluent) was usually not a significant concern. Toxic chemicals, while mentioned in the state water quality standards and the subject of U.S. EPA water quality criteria, were not often assessed or measured in the effluent. Other chemical concentrations pathways, such as runoff, leachate, and animal/plant effects, were also not assessed.

Recent national attention on ground water chemical concentrations has produced Federal and State legal requirements pertaining to landfill operations. Though application of the Federal Resource Conservation and Recovery Act (RCRA) to dredged material is unresolved among Federal agencies, the related State dangerous waste requirements are being applied to dredged material disposal projects. The current requirements are aimed substantively at chemical concentrations levels that are considered "Dangerous" or "Extremely Hazardous." Though the law recognizes the less unacceptable "solid waste" material, requirements for disposal of these materials are less defined. State regulations for dangerous waste are in place at this time. State regulations for solid waste contain a "reserved" section for dredged material disposal pending development of standards.

The vast majority of dredged material (99% +) is not classifiable as dangerous or extremely hazardous. And within the solid waste group, managers of dredged material recognize that some contains chemical concentrations levels that would not produce significant adverse effects (lesser chemical concentrations), while some has the potential to produce such effects. In addition to the very large volumes of dredged material that are produced, there are also a number of technical con- siderations that are unique in the control and treatment of dredged material.

2.2 Upland and Nearshore Disposal Chemical Pathways. The key chemical pathways to be considered for both upland and nearshore disposal are:

- o Effluent
- o Runoff
- o Leachate
- o Animal toxicity and bioaccumulation
- o Plant bioaccumulation

Upland Disposal

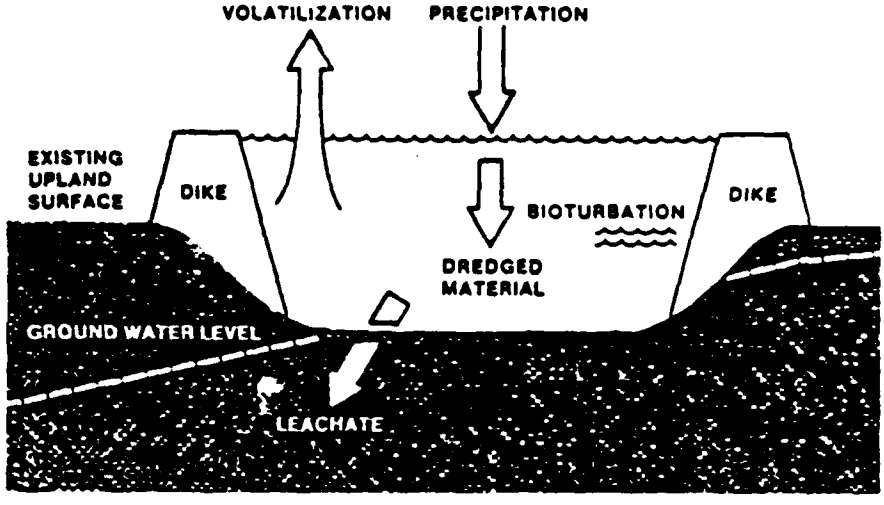


Figure III.1-1. Environmental pathways for conventional upland disposal.

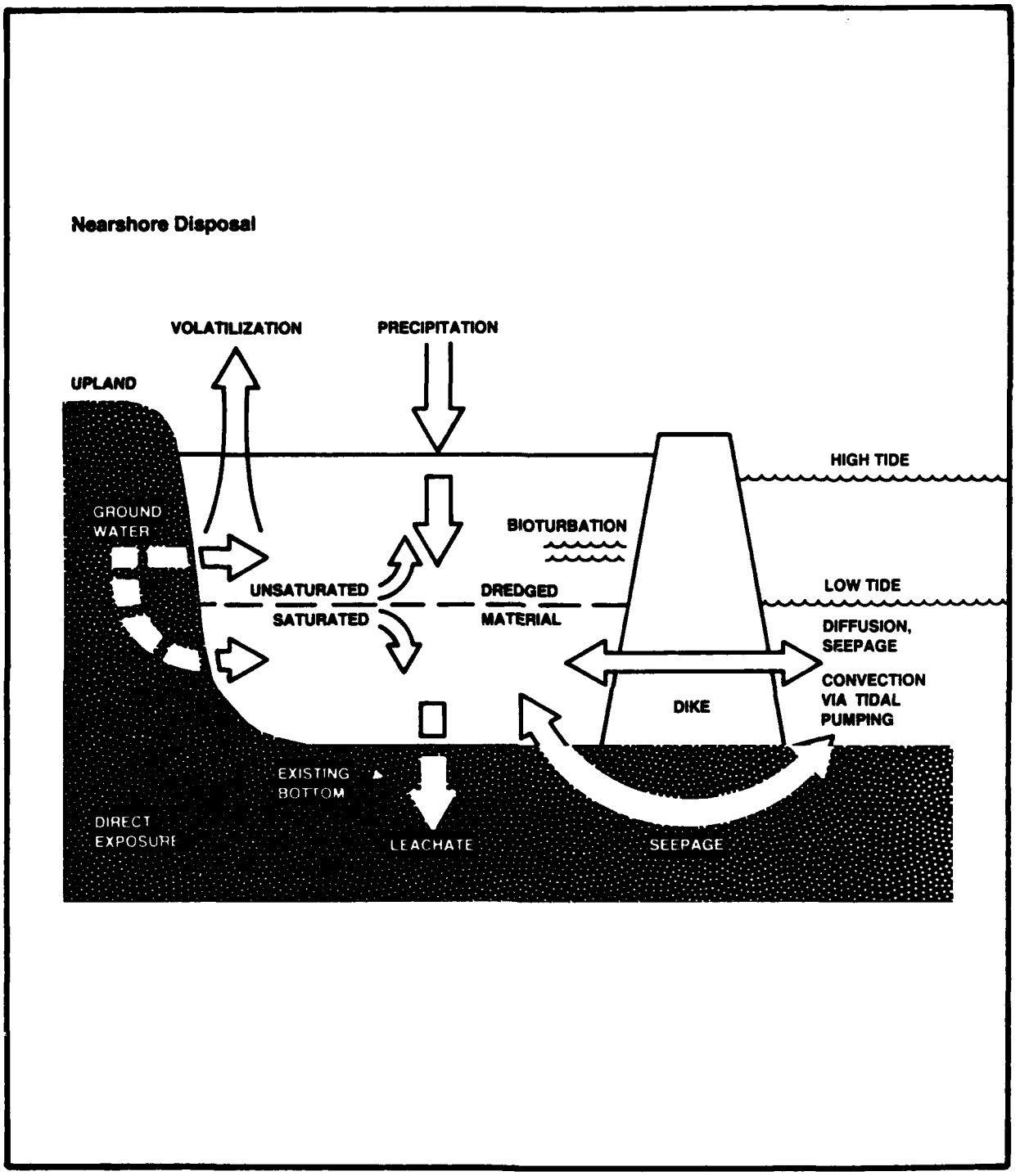


Figure III.1-2. Environmental pathways for conventional nearshore disposal.

The nearshore option has several notable differences from the upland option, including:

- Habitat losses (nearshore areas often include wetlands or juvenile salmonid feeding habitat)
- Disposal geochemistry (nearshore areas provide anaerobic disposal capacity in discharge areas below the water line)
- Water movement (nearshore areas can experience tidal water pressures that can enhance water movement through the face dike)
- Ground water resources (nearshore sites typically do not include potable ground water)

Site-specific habitat losses are often key to whether a proposed disposal actually occurs. Assessment of such losses is beyond the scope of the TA. However, the chemical concentrations assessment usually occurs independently from the detailed consideration of habitat present at a site. Most of the tests conducted in this assessment are the same for both upland and nearshore plant/ animal tests, effluent, runoff and leachate. The major differences will usually be associated with whether the leachate test is conducted aerobically or anaerobically, and how the consequences to ground water are interpreted.

3. CONFINED DISPOSAL

Confined disposal is a disposal method that isolates a unacceptable dredged material from the environment because of concern over potentially significant adverse biological effects. Confined disposal may be in aquatic, shore, or land environments. Confined aquatic disposal (CAD) is usually accomplished by placing a layer of sediment over material that has been placed on the bottom of a water body. Confined shore and land disposal usually involves isolating the dredged material using dikes or weirs to contain the material. Unacceptable chemical concentrations in one disposal environment does not necessarily imply the same in another disposal environment. If only one disposal environment has been considered (e.g., unconfined, open-water; see Section II), it is recommended that alternative environments (i.e., conventional land or shore disposal) be addressed before a decision is made to pursue confined disposal. Any disposal site can be designed to suitably contain unacceptable dredged material, given sufficient technology (and cost). For material that requires confinement, the primary issues in disposal are often siting and cost, both of which must be addressed on a project-specific basis.

3.1 Confined Disposal Assessment Issues. Mechanisms of contaminant release at confined aquatic disposal sites (figure III.3-1) are identical to those shown previously for unconfined, open-water sites (figure II.2-2). Placement of uncontaminated capping material over the site will reduce or possibly eliminate these processes. When capping restricts direct contact between organisms and the dredged material, toxic problems are also reduced.

Potential environmental pathways at confined nearshore disposal sites are the same as those for conventional nearshore disposal (figure III.1-2). Because these sites are typically diked and allowed to dry at the surface, volatilization of chemicals of concern through the cap into the atmosphere may occur. Leaching of chemicals of concern from the dredged material into surrounding ground water systems is also a major concern. Other processes that could be at work are similar to those described previously.

An important mechanism in nearshore sites for the mobilization of chemicals of concern is tidal pumping, whereby the amount of material within the site is saturated by water at different levels, depending on the height of the tide outside the dike. This process causes some of the dredged material to be alternately saturated and unsaturated. The movement of saturating water in and out of the site through the dikes may enhance the mobility of chemicals of concern. Losses of wetlands or juvenile salmonid feeding habitats must also be considered in nearshore areas.

Potential environmental pathways at confined land disposal sites are identical to those shown for conventional upland sites (figure III.1-1). The potential concerns at these landfills are similar to those at shore disposal sites, although only aerobic processes are generally of importance (nearshore areas provide anaerobic disposal capacity in discharge areas below the water line). Potential chemical concentrations of potable ground water is a concern typically limited to land sites.

3.2 Confined Disposal Testing Requirements. A number of contaminant pathways do not become significant unless contaminant concentrations are greatly elevated. In addition, simpler screening tests that may be adequate at lower contaminant concentrations may not be appropriate at higher concentrations. Both of these factors contribute to the need for testing beyond that required for assessing unconfined, open-water or conventional land or nearshore disposal.

Modified elutriate and/or water column bioassays enable evaluation of water column release and sediment resuspension in the dredging area. These tests are conducted similarly for different projects regardless of the disposal option being considered. For the CAD option, water column testing is also pertinent for evaluation of the disposal site. For confined land and shore, leachate and runoff tests, and earthworm and plant bioaccumulation tests are available tests that may be used as appropriate.

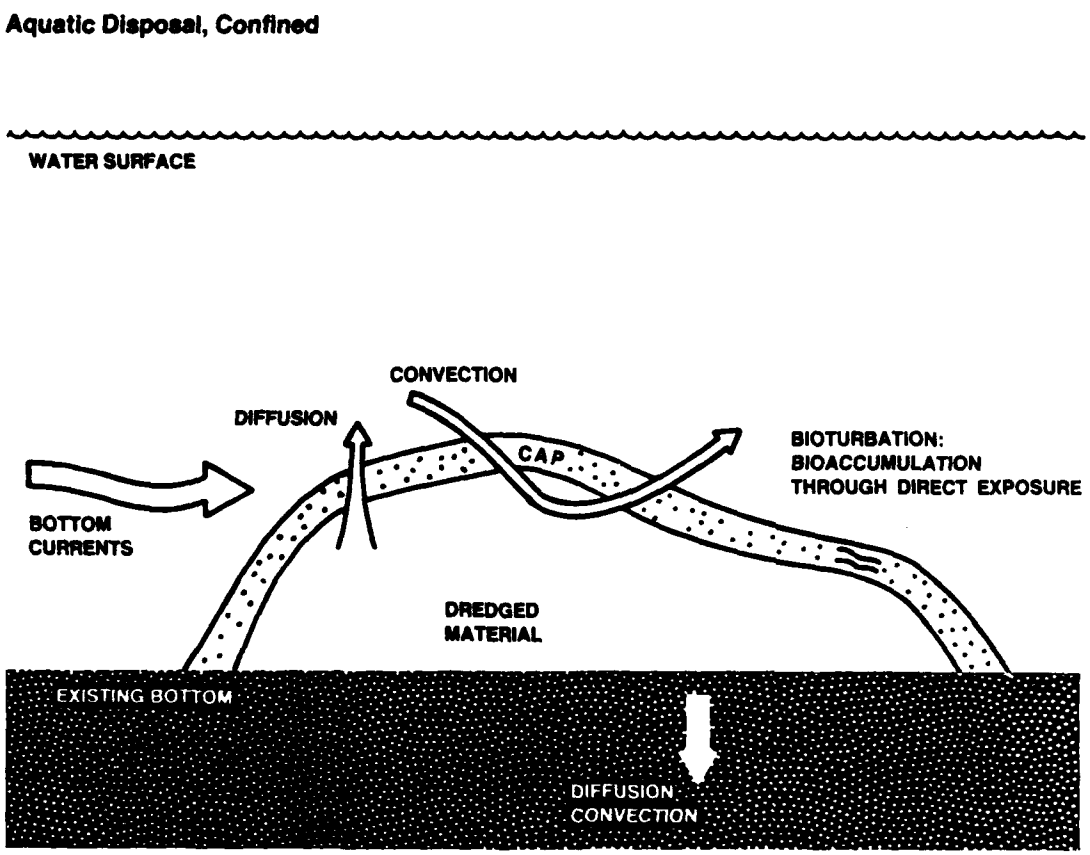


Figure III.3-1. Environmental pathways for confined aquatic disposal.

The chemical concentrations assessment process for nearshore and upland sites is basically similar. Effluent, runoff, leachate, land animal exposure, and plant exposure are the common contaminant pathways of concern that must be considered for these sites. Differences in the leachate test methods (to account for anaerobic conditions below the waterline at shore sites) and interpretation of test results (relative to nonpotable ground water) can be incorporated into the assessment.

Different tests are used to evaluate the appropriateness of confined aquatic disposal (CAD). These tests include an assessment of water column effects and of requirements for the effective placement of a cap.

3.3 Comparison of Disposal Options. The steps for comparing and selecting the preferred confined disposal option for any given project may include the use of a comparative risk analysis (see exhibit E.16; Tetra Tech 1986a). The interaction of contaminant control design and site selection can be fairly complex. Given the need for chemical concentrations confinement in disposal, there are three levels of questions to consider in this evaluation:

- What disposal options exist? Where are the sites?
- How should confinement be achieved at each site? What design is needed to achieve acceptable confinement?
- How do the designed sites compare? Which is preferred?

Consequently, a comparison of the different confined disposal options includes the following three steps:

1. Compare the available sites based on other than chemical concentrations issues. Given project needs, habitat considerations, and other factors, which are the best sites? Concurrently, conduct sediment tests to determine confinement requirements.
2. Design each disposal option to attain an acceptable level of confinement (the design is independent for each option because the acceptability of chemical concentrations containment designs are site-specific).
3. Use comparative risk analysis to compare the design options. The comparison of different options is required for the selection of a final site (e.g., according to specifications of NEPA, Clean Water Act, and other legislation). The primary influence of chemical concentrations concerns in this analysis is the cost of achieving the necessary design.

Comparative risk analysis provides a framework for evaluating the potential environmental and human health effects of alternative dredged material disposal options. The conceptual approach to comparative risk analysis includes six major components:

- Hazard identification - What chemicals of concern are present, and what are the potential toxic effects of these chemicals?
- Dose-response assessment - What is the relationship between the amount of exposure to a chemical and the prevalence of the toxic effect in a population?
- Exposure assessment - What biological resources and human populations are exposed to the chemicals of concern; what is the magnitude, duration, and route of exposure(s)?
- Risk characterization - What is the probability of toxic effects from the estimated exposure?
- Comparative analysis - How do the risks of alternative disposal options compare?
- Uncertainty analysis - What is the degree of confidence in the answers to the above questions?

Tradeoffs between risks to land and water resources must be considered when evaluating land and aquatic disposal options. Once relative values are placed on terrestrial wildlife and fish, for example, the decisionmaker can rank disposal options by using an assessment model. The assessment model enables summing of weighted risk indices for each option.

3.4 Alternatives to Confined Disposal. Two alternatives to confined disposal were reviewed: disposal in areas that provide greater dilution and have relatively fewer resources than Puget Sound (i.e., the Straits or the ocean), and pretreatment of the material (exhibit E.20) prior to unconfined, open-water disposal.

Both alternatives are more expensive than most confined disposal alternatives, which severely limits their utility in many cases. For Straits and ocean disposal, the premise that greater dilution and relatively fewer resources should permit the disposal of greater degrees of chemical concentrations is subject to both regulatory (under the Ocean Dumping Act) and environmental concerns. For pretreatment, a major obstacle is the development status of the technology. Much of it is not available and that which is has not been tried on dredged material.

Disposal in the Straits and ocean disposal are discussed in section II-10.4 in relation to the cost analysis for alternative disposal options.

The following discussion on pretreatment of dredged material is abstracted from a recent draft report on the feasibility of pretreatment (U.S. Army Corps of Engineers 1986b; Exhibit E.20). Confined disposal results from the presence of chemicals of concern associated with the sediment. On a mass basis, these chemicals are a small fraction of the total amount of dredged material. Recently, concepts based on the treatment of dredged material followed by either unconfined, open-water disposal, or open-water disposal with less stringent restrictions than would be applied to the untreated dredged material, have been proposed. These concepts generally fall into two categories:

- Separation of the chemicals from the dredged material
- Immobilization of the chemicals in the dredged material (Contaminant destruction has also been proposed).

3.4.1 Contaminant Separation. Separation of chemicals of concern from the dredged material is a method of reducing the amount of material that must be placed at confined disposal sites. Typically, contaminant separation schemes result in a large volume of relatively uncontaminated dredged material and a smaller volume of highly contaminated material. Ideally, the large volume of relatively uncontaminated material is acceptable for unconfined, open-water disposal. The smaller volume of highly contaminated material is subjected to further treatment or confined disposal. Both physical and chemical separation technologies have been proposed.

3.4.2 Physical Separation. Most chemicals of concern are assumed to be closely bound to the finer material found in sediments. As a result, separation of the sediment into fine- and coarse-grained fractions should result in relatively uncontaminated coarse-grained material and a more contaminated fine-grained material. Physical separation and classification equipment have been described by the Waterways Experimental Station of U.S. Army Corps of Engineers (1986b).

Sediment classification schemes have been demonstrated on the laboratory pilot scale (Tiederman and Reischman 1973; van der Burgt 1985) using hydrocyclones. This concept has not been used on a field-scale project. Neither the technical nor the economic feasibility of this concept have been evaluated in detail. Technical feasibility will depend on the grain size distribution of the sediment and, thus, is highly project-specific. Designs for floating and shore-based equipment is expected to be substantial; however, these costs will be mitigated by the anticipated reduction in disposal costs.

The operation and maintenance cost of applying this concept is expected to substantially increase the cost of dredging operations.

Because the required equipment is highly dependent upon project-specific requirements, it is not possible to provide quantitative cost data for to estimate the cost of implementation.

Sediment classification is recommended by Corps/WES as a potential demonstration project (U.S. Army Corps of Engineers 1986b). Such a project could provide meaningful information on technical effectiveness and economic feasibility of the concept.

3.4.3 Contaminant Extraction. A concept similar to contaminant separation is contaminant extraction. This concept, as applied to contaminated soils, is the subject of much ongoing research (U.S. EPA 1985). Various solvents are being tested as extractants of chemicals of concern. A brief review of the current status of this technology is presented by U.S. Army Corps of Engineers (1986b). Application of this concept to dredged material may have potential; however, use on a large scale is many years in the future. To date, no research has been performed on the extraction of chemicals of concern from dredged material slurries. Equipment requirements and cost have not been evaluated, although both are expected to be substantial.

3.4.4 Chemical Immobilization. Contaminant immobilization technologies, as applied to contaminated soils, have been investigated (U.S. EPA 1985) and are reviewed by U.S. Army Corps of Engineers (1986b). In general, these methods have not been applied to the immobilization of chemicals of concern in dredged material slurries or solids. Chemical solidification/stabilization (S/S) of dredged material solids have been investigated on a laboratory scale and found to be technically feasible. S/S of dredged material slurries and solids have not been attempted on field-scale projects. Concepts that couple S/S technology with shore and land disposal are presented by U.S. Army Corps of Engineers (1986b) as potential demonstration projects.

Contaminant immobilization coupled with unconfined, open-water disposal has not been attempted. Most immobilization techniques are based on the premise that the stabilized material will be placed in a dry or substantially dry environment. Disposal is an open-water environment has not been investigated. This concept may have merit, but a substantial research and development investment will be required to demonstrate its technical effectiveness.

The floating and onshore equipment requirements and costs for this concept have not been developed. Both are expected to be substantial. The primary drawback to this technology are the large quantities of material that must be handled.

3.4.5 Contaminant Destruction. Contaminant destruction followed by unconfined, open-water or conventional land or shore disposal of the residue is sometimes proposed as an appropriate method of disposal for contaminated dredged material. These proposals are usually based on incineration technologies for contaminant destruction. Unfortunately, incineration has been shown to be extremely costly and economically infeasible for the vast majority of dredging projects. There may be special cases where this concept is applicable (i.e., small volumes of sediments with high concentrations of organic compounds). Incineration technology is discussed by U.S. Army Corps of Engineers (1986b).

3.4.6 Summary. Although pretreatment of the contaminated dredged material followed by unconfined, open-water disposal is an attractive concept, there have been no field-scale demonstrations. Floating and shore-based equipment is not readily available and the cost is both high and uncertain.

PART IV. REFERENCES

Bates, T. S., E. H. Hamilton, and J. D. Cline. 1984. Vertical transport and sedimentation of hydrocarbons in the Central Main Basin of Puget Sound, Washington. Environ. Sci. Technol. 18:299-305.

Battelle Northwest. 1985. Detailed chemical and biological analyses of selected sediments from Puget Sound. Volume 1. Prepared for U.S. Environmental Protection Agency, Region X. Battelle Marine Research Laboratory, Sequim, Washington. 300 pp.

Bloom, N. S., and E. Crecellius. 1983. Determination of mercury in seawater at sub-nanogram per liter levels. Mar. Chem. 14:49-59.

Bulich et al. 1981. Reliability of the bacterial luminescence assay for determination of the toxicity of pure compounds and complex effluent. In: Aquatic Toxicology and Hazard Assessment: Proceedings of the Fourth Annual Symposium. ASTM STP 737 (1981) 338-47.

Cardwell, R. D., 1976. Sediment and Elutriate Toxicity to Oyster Larvae. Proc. Dredging and Its Environmental Effects, P.A. Krenkel, et al. (eds), Amer Soc Eng. N.Y., N.Y.

Clarke, J. U., V. A. McFarland, and B. D. Pierce, in preparation. Preliminary recommendations for a congener-specific PCB analysis in regulatory evaluation of dredged material. Miscellaneous Paper in preparation, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Crecilius, E. 22 October 1985. Personal Communication (phone by Dr. Charles R. Lytle). Battelle Marine Research Laboratory, Sequim, Washington.

Crecilius, E. A., and C. W. Apts. 1984. Concentration and speciation of arsenic in flatfish and crabs collected from Commencement Bay. Tacoma-Pierce County Health Department, Tacoma, Washington. 14 pp.

Cullinane et al. 1986. Guidelines for selecting control and treatment options for contaminated dredged material. Misc. paper EL-86. Prepared for Puget Sound Dredged Disposal Analysis. Dept. of the Army, Waterways Experiment Station, Corps of Engineers. Vicksburg, Mississippi. 434 pp. plus appendices.

Curl, H. C., Jr. 1981. Office of Marine Pollution Assessments Annual Report. Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration. Seattle, Washington. pp. 1-328.

Dexter, R. N., D. E. Anderson, E. A. Quinlan, L. S. Goldstein, R. M. Strickland, S. P. Pavlov, J. R. Clayton, Jr., R. M. Kocan, and M. Landolt. 1981. A summary of knowledge of Puget Sound related to chemical contaminants. NOAA Technical Memorandum OMPA-13. National Oceanic and Atmospheric Administration, Boulder, Colorado.

Dillon, T. June 1986. Personal Communication. (by Michael Johns) Waterways Experiment Station, Vicksburg, Mississippi.

Engler, et al., 1987. The Corps Environmental Effects Dredging Progams, MP87-(in press) USAE Waterways Experiment Station, Vicksburg, Miss.

Envirosphere. 1986a. Open-water disposal of material in Canadian waters. Final report. Prepared for Cooper Consultants, Inc., for U.S. Environmental Protection Agency in support of the Puget Sound Dredged Disposal Analysis. Envirosphere Company, Bellevue, Washington.

Envirosphere. 1986b. User's manual — Puget Sound dredged material inventory data management system. Draft Report. Prepared for Cooper Consultants for U.S. Environmental Protection Agency. Envirosphere Company, Bellevue, Washington.

Ervine, G. 29 July 1986. Personal Communication (phone by Pieter N. Booth). City of Everett, Washington.

Evans Hamilton. 1986. The surface microlayer: review of literature and evaluation of potential effects of dredge activities in Puget Sound. Final Report. Prepared for U.S. Army Corps of Engineers, Seattle District. Evans Hamilton, Inc., Seattle, Washington.

Evans Hamilton. 1986. Determination of disposal sites for dredged material in PSDDA phase I areas - Puget Sound technical appendix of the disposal site working group. First Draft. August 1986. 261 pp.

Feigner, K. D. 1986. Memorandum to E. Tower, Washington Department of Ecology. August 14, 1986. Waste Management Branch, U.S. Environmental Protection Agency, Region X, Seattle, Washington.

Galvin, D. V., G. P. Romberg, D. R. Houck, and J. H. Lesniak. 1984. Toxicant pretreatment planning study. Summary Report. Municipality of Metropolitan Seattle, Seattle, Washington. 202 pp.

Godfrey. 1983. Building construction cost data. Robert Snow Means Co., Inc. Kingston, Maine. 434 pp.

Hardy, J. T., and C. E. Cowan. 1986. Model and assessment of the contribution of dredged material disposal to sea-surface contamination in Puget Sound. PSDDA Report, prepared by Battelle's Pacific Northwest Laboratory, Richland, Washington.

Hardy, J. T., and J. Word. 1986. Contamination of the waters of Puget Sound. Puget Sound Notes, November 1986, U.S. Environmental Protection Agency, Region 10, pp 3-6.

Johns, D. M. 10 July 1986. Memorandum for record. Meeting with RPA/Tetra Tech on cost analysis task. 3 pp.

Johnson and Pettit. 1986. National Solid Wastes Management Association's 1985 tipping fee survey. Waste Age 17(3):58-60.

Jones and Stokes. 1983. Water quality management program for Puget Sound. Prepared for U.S. Environmental Protection Agency, Region X. Jones and Stokes Associates, Inc. Sacramento, California.

Keith, L. J., W. Crummet, J. Deegan, Jr., R. R. Libby, J. K. Taylor, G. Weatles. 1983. Principles of environmental analysis. Anal. Chem. 55:2210-2218.

King and Millison. 1985. National construction estimator. 33rd edition. King, P. A. and J. Millison (eds). Craftsman Book Co., Carlsbad, California 512 pp.

Konasewich, D. E., P. M. Chapman, E. Gezenchez, G. Vigers and N. Treloar. 1982. Effects, pathways, pressures, and transformation of Puget Sound contaminants of concern. NOAA Technical Memorandum OMPA-20. National Oceanic and Atmospheric Administration, Boulder, Colorado. 357 pp.

Kozoloff, E. N. 1983. Seashore life of the northern Pacific coast. University of Washington Press. Seattle, Washington. 370 pp.

Lazor, P. 1985. Memorandum to A. Sumeri. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. December 7, 1985.

Lee et al. 1985. Decisionmaking framework for management of dredged material: applications to Commencement Bay, Washington. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. Prepared for Washington Dept. of Ecology. 177 pp. plus appendices.

London Dumping Convention. 1985. Guidelines for the application of the annexes to the disposal of dredged material. Report of Experts Meeting, 31 October 1985. 8 pp.

McFarland, V.A., J.U. Clarke, and A.B. Gibson, 1986. Changing concepts and improved methods for evaluating the importance of PCBs as dredged sediment contaminants. Miscellaneous Paper D-86-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Malins, D. C., B. B. McCain, D. W. Brown, A. K. Sparks, and H. O. Hodgins. 1980. Chemical contaminants and biological abnormalities in central and southern Puget Sound. NOAA Technical Memorandum OMPA-2. National Oceanic and Atmospheric Administration, Boulder, Colorado. 295 pp.

Malins, D. C., S. L. Chan, B. B. McCain, D. W. Brown, A. K. Sparks, and H. O. Hodgins. 1981. Puget Sound pollution and its effects on marine biota. Progress report to OMPA for the period May 1 to September 30, 1980. National Marine Fisheries Service, Seattle, Washington.

Malins, D. C., B. B. McCain, D. W. Brown, A. K. Sparks, and H. O. Hodgins. 1982. Chemical contaminants and abnormalities in fish and invertebrates from Puget Sound. NOAA Technical Memorandum OMPA-19. National Oceanic and Atmospheric Administration, Boulder, Colorado. 168 pp.

Means. 1984. Means, Inc.

Phillips, K., J. Malek, and B. Hamner. 1985. Evaluation of alternative dredging methods and equipment, disposal method and sites, and site control and treating practices for contaminated sediments. Final report by the U.S. Army Corps of Engineers, Seattle District. 151 pp. plus appendices.

Phillips, et al. 1985 updated to 1986.

Plumb, Jr., R.H., 1981. Procedures for Handling and Chemical Analysis of Sediment and Water Samples. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Miss. Prepared for U.S. Environmental Protection Agency/Corps of Engineers Technical Committee on Criteria for Dredged and Fill Material.

PSDDA. 1985. Regional administrative decisions. Draft Report. Evaluation Procedures Work Group for Puget Sound Dredged Disposal Analysis, Seattle, Washington.

PSDDA. 1986a. Phase I: central Puget Sound environmental monitoring plan. Draft Report. Disposal Site Work Group and Evaluation Procedures Work Group for Puget Sound Dredged Disposal Analysis, Seattle, Washington.

PSDDA. 1986b. Puget Sound dredged disposal analysis open-water unconfined disposal sites plan of study. Revised Report. Puget Sound Dredged Disposal Analysis, Seattle, Washington. 26 pp. plus exhibits and appendices.

PSDDA. 1986. Preliminary findings report. Issue No. 2. Puget Sound Dredged Disposal Analysis. U.S. Army Corps of Engineers, Seattle District, Seattle, Washington.

PSDDA News. 1986. Preliminary findings report. Issue No. 2. Puget Sound Dredged Disposal Analysis. U.S. Army Corps of Engineers, Seattle District, Seattle, Washington.

Quinlan, E. A., P. M. Chapman, R. N. Dexter, D. E. Konusewish, C. C. Ebbesmeyer, G. A. Erickson, B. R. Koalski, and T. A. Silver. 1985. Toxic chemicals and biological effects in Puget Sound: states and scenarios for the future. Draft. NOAA Technical Memorandum. National Oceanic and Atmospheric Administration, Boulder, Colorado. 334 pp.

Rubenstein, N. June 1986. Personal Communication (by Gordon Bilyard).

Saucier, R.T., et al., 1980. Executive Overview and Detailed Summary. Technical Report DS-78-22 (NTIS AD-A074531) U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Schiewe et al. 1985. Use of a bacterial bioluminescence assay to assess toxicity of contaminated marine sediments. Can. J. Fish. Aquat. Sci., 42, 1244-8.

Shields. 1984. Fundamentals of capping contaminated dredged material. In: Dredging and Dredged Material Disposal. R. L. Montgomery and J. W. Leach (eds). Proceedings of the 1984 Dredging conference. Published by American Society of Civil Engineers. pp. 446-460.

Spencer, J. R. 1982. Memorandum to C. H. Capper, Office of Solid Waste and Emergency Response. February 1, 1982. U.S. Environmental Protection Agency Region X, Seattle, Washington.

Sumeri. 1984. Capped in-water disposal of contaminated dredged material. In: Dredging and Dredged Material Disposal. R. L. Montgomery and J. W. Leech (eds). Proceeding of the 1984 Dredging Conference. Published by American Society of Civil Engineers. pp. 644-653.

Tetra Tech. 1984. Laboratory analytical protocol for the Anaconda smelter RI/FS. Tetra Tech, Bellevue, Washington.

Tetra Tech. 1985a. Commencement Bay nearshore/tideflats remedial investigation. Volume 1. Prepared for Washington State Department of Ecology and U.S. Environmental Protection Agency, Region X. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1985b. Bioaccumulation monitoring guidance. 3. Recommended analytical detection limits. Prepared for U.S. Environmental Protection Agency, Washington, D.C. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1985c. Decision-making for contaminated dredged material management: an illustrated guide. Draft Report. Prepared for Resource Planning Associates by U.S. Army Corps of Engineers. Tetra Tech, Inc., and Milmanco Corp., Bellevue, Washington.

Tetra Tech. 1985d. Evaluation of approaches for the development of sediment quality values for Puget Sound. Task 3. Draft Report. Prepared for Resource Planning Associates for U.S. Army Corps of Engineers. Tetra Tech, Inc., Bellevue, Washington. 58 pp.

Tetra Tech. 1985e. Evaluation of Puget Sound data sets for the development of sediment quality values. Task 1. Draft Report. Prepared for Resource Planning Associates and U.S. Army Corps of Engineers. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1986a. A framework for comparative risk analysis of dredged material disposal options. Task 5b. Final Report. Prepared for Resource Planning Associates for U.S. Army Corps of Engineers. Seattle District. Tetra Tech, Inc., Bellevue, Washington. 94 pp. plus appendices.

Tetra Tech. 1986b. Application of selected sediment quality value approaches to Puget Sound data. Sediment quality values Tasks 4 and 5a. Draft Report. Prepared for Resource Planning Associates for U.S. Army Corps of Engineers, Tetra Tech, Inc., Bellevue, Washington. 59 pp.

Tetra Tech. 1986c. Cost analysis. Task 3.2. Draft Report. Prepared for Resource Planning Associates for U.S. Army Corps of Engineers. Seattle District. Tetra Tech, Inc., Bellevue, Washington. 83 pp., plus appendix.

Tetra Tech. 1986d. Evaluation and development of navigation positioning and monitoring protocols for dredged material disposal in Puget Sound. Task C. Final Report. Prepared for Resource Planning Associates for U.S. Army Corps of Engineers, Seattle District. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1986e. Evaluation of statistical relationships among chemical and biological variables using pattern recognition techniques. Task 2. Draft Report. Prepared by Tetra Tech and G. A. Erickson and Associates for Resource Planning Associates for U.S. Army Corps of Engineers, Seattle District. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1986f. Metals protocol development for Puget Sound studies. Task A-4. Final Report. Prepared for Resource Planning Associates for U.S. Army Corps of Engineers, Seattle District. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1986g. Positioning protocols for sampling in Puget Sound. Task B. Final Report. Prepared for Resource Planning Associate for U.S. Army Corps of Engineers, Seattle District. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1986h. Recommended protocols for conducting laboratory bioassays on Puget Sound sediments. Final Report. Prepared for E.V.S. Consultants, Inc. for U.S. Environmental Protection Agency, Region X. Tetra Tech, Bellevue, Washington.

Tetra Tech. 1986i. Recommended protocols for measuring organic compounds in Puget Sound sediment and tissue samples. Final Report. Prepared for U.S. Environmental Protection Agency, Region X. Tetra Tech, Inc., Bellevue, Washington.

Tetra Tech. 1986j. Development of sediment quality values for Puget Sound. Task 6. Final Report. Prepared for Resource Planning Associates for U.S. Army Corps of Engineers. Tetra Tech, Inc., Bellevue, Washington. 1128 pp., plus appendices.

Tetra Tech. 1986k. QA/QC project plan. Prepared for Anaconda Minerals Company. Tetra Tech, Inc., Bellevue, Washington. March 1986.

Tetra Tech. 1986l. Recommended protocols for measuring selected environmental variables in Puget Sound. Prepared for Puget Sound Estuary Program.

Tiederman and Reischman. 1973. (from pretreatment technical memorandum)

Tietjen, J. H. and J. L. Lee. 1984. The use of free-living nematodes as a bioassay in estuarian sediments. Mar. Env. Res. Vol. 11. p. 223-251.

Unger, M. A., W. G. MacIntyre, J. Greaves, and R. J. Huggett. 1986. GC determination of butylins in natural waters by flame photometric detection of hexyl derivative with mass spectrometric confirmation. Chemosphere. 15(4):461-470.

U.S. Army Corps of Engineers. 1976. Interim Guidance Manual.

U.S. Army Corps of Engineers. 1985. Regulatory program: applicant information. U.S. Government Printing Office, Washington, D.C. 21 pp.

U.S. Army Corps of Engineers. 1985a. Code of Federal Regulations Title 33, Pts 323 through 330. 1985 ed.

U.S. Army Corps of Engineers. 1985b. Program transfer to states. Code of Federal Regulations Title 33, Pt. 323, Sec. 323.5. 1985 ed.

U.S. Army Corps of Engineers. 1985c. Processing of Department of the Army permits. Code of Federal Regulations Title 33, Pt. 325. 1985 ed.

U.S. Army Corps of Engineers. 1985d. Processing of applications. Code of Federal Regulations Title 33, Pt. 325, Sec 325.2. 1985 ed.

U.S. Army Corps of Engineers. 1986a. Decision-making framework for management of dredged material: application to Commencement Bay, Washington. Technical Report D-86. Revised May, 1986. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

U.S. Army Corps of Engineers. 1986b. Guidelines for selecting control and treatment options for contaminated dredged material. Misc. Paper EL-86. Final Report. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

U.S. Environmental Protection Agency. 1979. Methods for chemical analysis of water and wastes. U.S. Environmental Protection Agency Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.

U.S. Environmental Protection Agency. 1980a. Ambient water quality criteria for chloroform. EPA-44015-80-033. PB81-117442. U.S. Environmental Protection Agency, Criteria and Standards Division, Washington, D.C. October 1980. 70 pp.

U.S. Environmental Protection Agency. 1980b. Ambient water quality criterion for mercury. U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1986. Interim decision criteria for unconfined disposal of dredged material at the Port Gardner open-water disposal site. Memorandum dated February 12, 1986. 15 pp.

U.S. Environmental Protection Agency. 1985a. Section 404(b)(1). "Guidelines for specification of Disposal Sites for Dredged or Fill Material." Code of Federal Regulations Title 40, Pt. 230. 1985 ed.

U.S. Environmental Protection Agency. 1985b. Code of Federal Regulations Title 40, Pts 220 through 229. 1985 ed.

U.S. Environmental Protection Agency. 1985c. Section 404(c) procedures. Code of Federal Regulations Title 40, Pt. 231. 1985 ed.

U.S. Environmental Protection Agency. 1985d. Contract laboratory program statement of work. Inorganic analysis, multi-media, multi-concentration. SOW No. 785. July 1985. Environmental Support Monitoring Laboratory, Las Vegas, Nevada.

U.S. Environmental Protection Agency, Region X. 1984. Interim decision criteria for disposal of dredged material at the Fourmile Rock open-water disposal site. Memorandum dated June 13, 1984. Seattle, Washington. 18 pp.

Van der Burgt. 1985. (from pretreatment technical memorandum)

Williams, et al. 1986. A comparative evaluation of marine sediment toxicity using bacterial luminescence, oyster embryo and amphipod sediment bioassays. Mar. Env. Res. 19 (1986). pp. 225-249.

White, A. W., and C. M. Lewis. 1982. Resting cysts of the toxic, red tide dinoflagellate Gonyaulax excavata in Bay of Fundy sediments. Can. J. Fish. Aquat. Sci. 39:1185-1194.

Word, J., L. S. Word, J. N. McElroy, and R. M. Thom. 1986. The surface microlayer: review of literature and evaluation of potential effects of dredge activities in Puget Sound. PSDDA report, prepared by Evans Hamilton, Inc., Seattle, Washington.

Word, J., J. Hardy, E. Crecelius, and S. Kiesser. 1987. U.S. Navy Homeport--Sea surface microlayer analysis: laboratory studies of floatable contaminants from a dredged material disposal. Prepared for the U.S. Army Corps of Engineers, Seattle District, per related service agreement with the U.S. Department of Energy Contract DE-AC06-76RLO 1830.

GLOSSARY OF TERMS AND ABBREVIATIONS

PUGET SOUND DREDGED DISPOSAL ANALYSIS (PSDDA)
GLOSSARY OF TERMS

Amphipods. Small shrimp-like crustaceans (for example, sand fleas). Many live on the bottom, feed on algae and detritus, and serve as food for many marine species. Amphipods are used in laboratory bioassays to test the toxicity of sediments.

Apparent Effects Threshold. The sediment concentration of a contaminant above which statistically significant biological effects would always be expected.

Area Ranking. The designation of a dredging area relative to its potential for having sediment chemicals of concern. Rankings range from "low" potential to "high" potential, and are used to determine the intensity of dredged material evaluation and testing that might be required.

Baseline Study. A study designed to document existing environmental conditions at a given site. The results of a baseline study may be used to document temporal changes at a site or document background conditions for comparison with another site.

Bathymetry. Shape of the bottom of a water body expressed as the spatial pattern of water depths. Bathymetric maps are essentially topographic maps of the bottom of Puget Sound.

Benthic Organisms. Organisms that live in or on the bottom of a body of water.

Bioaccumulation. The accumulation of chemical compounds in the tissues of an organism. For example, certain chemicals in food eaten by a fish tend to accumulate in its liver and other tissues.

Bioassay. A laboratory test used to evaluate the toxicity of a material (commonly sediments or wastewater) by measuring behavioral, physiological, or lethal responses of organisms.

Biota. The animals and plants that live in a particular area or habitat.

Bottom-Dump Barge. A barge that disposes of dredged material by opening along a center seam or through doors in the bottom of the barge.

Bottomfish. Fish that live on or near the bottom of a body of water, for example, English sole.

Bulk Chemical Analyses. Chemical analyses performed on an entire sediment sample, without separating water from the solid material in a sample.

Capping. See confined aquatic disposal.

Carcinogenic. Capable of causing cancer.

Clamshell Dredging. Scooping of the bottom sediments using a mechanical clamshell bucket of varying size. Commonly used in over a wide variety of grain sizes and calm water, the sediment is dumped onto a separate barge and towed to a disposal site when disposing in open water.

Code of Federal Regulations. The compilation of Federal regulations adopted by Federal agencies through a rule-making process.

Compositing. Mixing sediments from different samples to produce a composite sample for chemical and/or biological testing.

Confined Disposal. A disposal method that isolates the dredged material from the environment. Confined disposal may be in aquatic, nearshore, or upland environments.

Confined Aquatic Disposal (CAD). Confined disposal in a water environment. Usually accomplished by placing a layer of sediment over material that has been placed on the bottom of a water body (i.e., capping).

Contaminant. A chemical or biological substance in a form or in a quantity that can harm aquatic organisms, consumers of aquatic organisms, or users of the aquatic environment.

Contaminated Sediment.

Technical Definition: A sediment that contains measurable levels of contaminants.

Management or Common Definition: A sediment that contains sufficient concentration(s) of chemicals to produce unacceptable adverse environmental effects and thus require restriction(s) for dredging and/or disposal of dredged material (e.g., is unacceptable for unconfined, open water disposal or conventional land/shore disposal, requiring confinement).

Conventional Nearshore Disposal. Disposal at a site where dredged material is placed behind a dike in water along the shoreline, with the final elevation of the fill being above water. "Conventional" disposal additionally means that special contaminant controls or restrictions are not needed.

Conventional Pollutants. Sediment parameters and characteristics that have been routinely measured in assessing sediment quality. These include sulfides, organic carbon, etc.

Conventional Upland Disposal. Disposal at a site created on land (away from tidal waters) in which the dredged material eventually dries. Upland sites are usually diked to confine solids and to allow surface water from the disposal operation to be released. "Conventional" disposal additionally means that special contaminant controls or restrictions are not needed.

Depositional Analysis. A scientific inspection of the bottom sediments that identifies where natural sediments tend to accumulate.

Depositional Area. An underwater region where material sediments tend to accumulate.

Disposal. See confined disposal, conventional nearshore disposal, conventional upland disposal, and unconfined, open-water disposal.

Disposal Site. The bottom area that receives discharged dredged material; encompassing, and larger than, the target area and the disposal zone.

Disposal Site Work Group. The PSDDA work group that is designating locations for open-water unconfined dredged material disposal sites that are environmentally acceptable and economically feasible.

Disposal Zone. The area that is within the disposal site that designates where surface release of dredged material will occur. It encompasses the smaller target area. (See also "target area" and "disposal site".)

Dredged Material. Sediments excavated from the bottom of a waterway or water body.

Dredged Material Management Unit. The maximum volume of dredged material for which a decision on suitability for unconfined open-water disposal can be made. Management units are typically represented by a single set of chemical and biological test information obtained from a composite sample. Management units are smaller in areas of higher chemical contamination concern (see "area ranking").

Dredger. Private developer or public entity (e.g., Federal or State agency, port or local government) responsible for funding and undertaking dredging projects. This is not necessarily the dredging contractor who physically removes and disposes of dredged material (see below).

Dredging. Any physical digging into the bottom of a water body. Dredging can be done with mechanical or hydraulic machines and is performed in many parts of Puget Sound for the maintenance of navigation channels that would otherwise fill with sediment and block ship passage.

Dredging Contractor. Private or public (e.g., Corps of Engineers) contractor or operator who physically removes and disposes of dredged material for the dredger (see above).

Disposal Site Work Group. The PSDDA work group that is designating locations for open-water unconfined dredged material disposal sites that are environmentally acceptable and economically feasible.

Ecosystem. A group of completely interrelated living organisms that interact with one another and with their physical environment. Examples of ecosystems

are a rain forest, pond, and estuary. An ecosystem, such as Puget Sound, can be thought of as a single complex system. Damage to any part may affect the whole. A system such as Puget Sound can also be thought of as the sum of many interconnected ecosystems such as the rivers, wetlands, and bays. Ecosystem is thus a concept applied to various scales of living communities and signifying the interrelationships that must be considered.

Effluent. Effluent is the water flowing out of a contained disposal facility. To distinguish from "runoff" (see below) due to rainfall, effluent usually refers to water discharged during the disposal operation.

Elutriate. The extract resulting from mixing water and dredged material in a laboratory test. The resulting elutriate can be used for chemical and biological testing to assess potential water column effects of dredged material disposal.

Entrainment. The addition of water to dredged material during disposal, as it descends through the water column.

Environmental Impact Statement. A document that discusses the likely significant environmental impacts of a proposed project, ways to lessen the impacts, and alternatives to the proposed project. EIS's are required by the National and State Environmental Policy Acts.

Erosion. Wearing away of rock or soil via gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical and chemical forces.

Estuary. A confined coastal water body where ocean water is diluted by inflowing fresh water, and tidal mixing occurs.

Evaluation Procedures Work Group. The PSDDA work group that is developing chemical and biological testing and test evaluation procedures for dredged material assessment.

Gravid. Having eggs, such as female crabs carrying eggs.

Ground Water. Underground water body, also called an aquifer. Aquifers are created by rain which soaks into the ground and flows down until it collects at a point where the ground is not permeable.

Habitat. The specific area or environment in which a particular type of plant or animal lives. An organism's habitat provides all of the basic requirements for life. Typical Puget Sound habitats include beaches, marshes, rocky shores, bottom sediments, mudflats, and the water itself.

Hazardous Waste. Any solid, liquid, or gaseous substance which, because of its source or measurable characteristics, is classified under State or Federal law as hazardous, and is subject to special handling, shipping, storage, and disposal requirements. Washington State law identifies two categories of hazardous waste: dangerous and extremely hazardous. The latter category is more hazardous and requires greater precautions.

Hopper Dredge. A hydraulic suction dredge that is used to pick up coarser grain sediments (such as sand), particularly in less protected areas with sea swell. Dredged materials are deposited in a large holding tank or "hopper" on the same vessel, and then transported to a disposal site. The hopper dredge is rarely used in Puget Sound.

Hydraulic Dredging. Dredging accomplished by the erosive force of a water suction and slurry process, requiring a pump to move the water-suspended sediments. Pipeline and hopper dredges are hydraulic dredges.

Hydraulics Project Approval. RCW 75.20.100 Approval from the Washington Department of Fisheries and Washington Department of Wildlife for the use, diversion, obstruction or change in the natural flow or bed of any river or stream, or that will use any salt or fresh waters of the State.

Hydraulically Dredged Material. Material, usually sand or coarser grain, that is brought up by a pipeline or hopper dredge. This material usually includes slurry water.

Hydrocarbon. An organic compound composed of carbon and hydrogen. Petroleum and its derived compounds are hydrocarbons.

Infauna. Animals living in the sediment.

Intertidal Area. The area between high and low tide levels. The alternate wetting and drying of this area makes it a transition between land and water organisms and creates special environmental conditions.

Leachate. Water or other liquid that may have dissolved (leached) soluble materials, such as organic salts and mineral salts, derived from a solid material. Rainwater that percolates through a sanitary landfill and picks up contaminants is called the leachate from the landfill.

Local Sponsor. A public entity (e.g., port district) that sponsors Federal navigation projects. The sponsor seeks to acquire or hold permits and approvals for disposal of dredged material at a disposal site.

Loran C. An electronic system to facilitate navigation positioning and course plotting/tracking.

Management Plan Work Group. The PSDDA work group is developing a management plan for each of the open-water dredged material disposal sites. The plan will define the roles of local, State, and Federal agencies. Issues being addressed include: permit reviews, monitoring of permit compliance, treatment of permit violations, monitoring of environmental impacts, responding to unforeseen effects of disposal, plan updating, and data management.

Material Release Screen. A laboratory test proposed by PSDDA to assess the potential for loss of fine-grained particles carrying chemicals of concern from the disposal site during disposal operations.

Mechanical Dredging. Dredging by digging or scraping to collect dredged materials. A clamshell dredge is a mechanical dredge. (See "hydraulic dredging.")

Metals. Metals are naturally occurring elements. Certain metals, such as mercury, lead, nickel, zinc, and cadmium, can be of environmental concern when they are released to the evironment in unnatural amounts by man's activities.

Microlayer, Sea Surface Microlayer. The extremely thin top layer of water that can contain high concentrations of natural and other organic substances. Contaminants such as oil and grease, many lipophylic (fat or oil associated) toxicants, and pathogens may be present at much higher concentrations in the microlayer than they are in the water column. Also the microlayer is biologically important as a rearing area for marine organisms.

Microtox. A laboratory test using luminescent bacteria and measuring light production, used to assess toxicity of sediment extracts.

Molt. A complex series of events that results in the periodic shedding of the skeleton, or carapace by crustaceans (all arthropods for that matter). Molting is the only time that many crustaceans can grow and mate (particularly crabs).

Monitor. To systematically and repeatedly measure something in order to detect changes or trends.

Nutrients. Essential chemicals needed by plants or animals for growth. Excessive amounts of nutrients can lead to accelerated growth of algae and subsequent degradation of water quality due to oxygen depletion. Some nutrients can be toxic at high concentrations.

Overdepth Material. Dredged material removed from below the dredging depth needed for safe navigation. Through overdepth is incidentally removed due to dredging equipment precision, its excavation is usually planned as part of the dredging project to ensure proper final water depths. Common overdepth is 2 feet below the needed dredging line.

Oxygen Demanding Materials. Materials such as food waste and dead plant or animal tissue that use up dissolved oxygen in the water when they are degraded through chemical or biological processes. Chemical and biological oxygen demand (COD and BOD, respectively) are different measures of how much oxygen demand a substance has.

Parameter. A quantifiable or measurable characteristic of something. For example, height, weight, sex, and hair color are all parameters that can be determined for humans. Water quality parameters include temperature, pH, salinity, dissolved oxygen concentration, and many others.

Pathogen. A disease-causing agent, especially a virus, bacteria, or fungi. Pathogens can be present in municipal, industrial, and nonpoint source discharges to the Sound.

Permit. A written warrant or license, granted by an authority, allowing a particular activity to take place. Permits required for dredging and disposal of dredged material include the U.S. Army Corps of Engineers Section 404 permit, the Washington State Department of Fisheries Hydraulics Permit, the city or county Shoreline Development Permit, and the Washington Department of Natural Resources Site Use Disposal Permit.

Persistent. Compounds that are not readily degraded by natural physical, chemical, or biological processes.

Pesticide. A general term used to describe any substance, usually chemical, used to destroy or control organisms (pests). Pesticides include herbicides, insecticides, algicides, and fungicides. Many of these substances are manufactured and are not naturally found in the environment. Others, such as pyrethrum, are natural toxins which are extracted from plants and animals.

pH. The degree of alkalinity or acidity of a solution. Water has a pH of 7.0. A pH of less than 7.0 indicates an acidic solution, and a pH greater than 7.0 indicates a basic solution. The pH of water influences many of the types of chemical reactions that occur in it. Puget Sound waters, like most marine waters, are typically pH neutral.

Phase I. The PSDDA study is divided into two, 3-year long, overlapping phases. Phase I covers the central area of Puget Sound including Seattle, Everett, and Tacoma. Phase I began in April 1985.

Phase II. The PSDDA study is divided into two, 3-year long, overlapping phases. Phase II covers the north and south Sound (including, Olympia, Bellingham, and Port Angeles)--the areas not covered by Phase I. Hood Canal is not being considered for location of a disposal site. Phase II began in April 1986.

Pipeline Dredge. A hydraulic dredge that transports slurried dredged material by pumping it via a pipe. (See "hydraulic dredge".)

Point Source. Locations where pollution comes out of a pipe into Puget Sound.

Polychaete. A marine worm.

Polychlorinated Biphenyls. A group of manmade organic chemicals, including about 70 different but closely related compounds made up of carbon, hydrogen, and chlorine. If released to the environment, they persist for long periods of time and can concentrate in food chains. PCB's are not water soluble and are suspected to cause cancer in humans. PCB's are an example of an organic toxicant.

Polycyclic (Polynuclear) Aromatic Hydrocarbon. A class of complex organic compounds, some of which are persistent and cancer-causing. These compounds are formed from the combustion of organic material and are ubiquitous in the environment. PAH's are commonly formed by forest fires and by the combustion

of fossil fuels. PAH's often reach the environment through atmospheric fallout, highway runoff, and oil discharge.

Priority Pollutants. Substances listed by EPA under the Clean Water Act as toxic and having priority for regulatory controls. The list includes toxic metals, inorganic contaminants such as cyanide and arsenic, and a broad range of both natural and artificial organic compounds. The list of priority pollutants includes substances that are not of concern in Puget Sound, and also does not include all known harmful compounds.

Puget Sound Water Quality Authority. An agency created by the Washington State legislature in 1985 and tasked with developing a comprehensive plan to protect and enhance the water quality of Puget Sound. The Authority adopted its first plan in January 1987.

Range Markers. Pairs of markers which, when aligned, provide a known bearing to a boat operator. Two pairs of range markers can be used to fix position at a point.

Regional Administrative Decisions. A term used in PSDDA to describe decisions that are a mixture of scientific knowledge and administrative judgment. These regionwide policies are collectively made by all regulatory agencies with authority over dredged material disposal to obtain Sound-wide consistency.

Regulatory Agencies. Federal and State agencies that regulate dredging and dredged material disposal in Puget Sound, along with pertinent laws/permits, include:

U.S. Army Corps of Engineers

- River and Harbor Act of 1899 (Section 10 permits)
- Clean Water Act (Section 404 permits)

U.S. Environmental Protection Agency

- Clean Water Act (Section 404 permits)

Washington Department of Natural Resources

- Shoreline Management Act (site use permits)

Washington Department of Ecology

- Clean Water Act (Section 401 certifications)
- Shoreline Management Act (CZMA consistency determinations)

Washington Department of Fisheries

- Hydraulics Project Approval

Washington Department of Wildlife (Formerly Washington Department of Game)

- o Hydraulics Project Approval

Local shoreline jurisdiction e.g., City of Seattle, City of Everett, Pierce County

- o Shoreline permit to non-Federal dredger/DNR

U.S. Fish and Wildlife Service (Key reviewing agency)

National Marine Fisheries Service (Key reviewing agency)

The Resource Conservation and Recovery Act. The Federal law that regulates solid and hazardous waste.

Respiration. The metabolic processes by which an organism takes in and uses oxygen and releases carbon dioxide and other waste products.

Revised Code of Washington. The compilation of the laws of the State of Washington published by the Statute Law Committee.

Runoff. Runoff is the liquid fraction of dredged materials or the flow/seepage caused by precipitation landing on and filtering through upland or nearshore dredged material disposal sites.

Salmonid. A fish of the family Salmonidae. Fish in this family include salmon and trout. Many Puget Sound salmonids are anadromous, spending part of their life cycles in fresh water and part in marine waters.

Sediment. Material suspended in or settling to the bottom of a liquid, such as the sand and mud that make up much of the shorelines and bottom of Puget Sound. Sediment input to Puget Sound comes from natural sources, such as erosion of soils and weathering of rock, or anthropogenic sources, such as forest or agricultural practices or construction activities. Certain contaminants tend to collect on and adhere to sediment particles. The sediments of some areas around Puget Sound contain elevated levels of contaminants.

Site Condition. The degree of adverse biological effects that might occur at a disposal site due to the presence of sediment chemicals of concern; the dividing line between "acceptable" (does not exceed the condition) and "unacceptable" (exceeds the site condition) adverse effects at the disposal site. Other phrases used to describe site condition include "biological effects condition for site management" and "site management condition."

Spot Checking. Inspections on a random basis to verify compliance with permit requirements.

Statistically Significant. A quantitative determination of the statistical degree to which two measurements of the same parameter can be shown to be different, given the variability of the measurements.

Subtidal. Refers to the marine environment below low tide.

Suspended Solids. Organic or inorganic particles that are suspended in water. The term includes sand, mud, and clay particles as well as other solids suspended in the water column.

Target Area. The specified area on the surface of Puget Sound for the disposal of dredged material. The target area is within the disposal zone and within the disposal site.

Toxic. Poisonous, carcinogenic, or otherwise directly harmful to life.

Toxic Substances and Toxicants. Chemical substances, such as pesticides, plastics, detergents, chlorine, and industrial wastes that are poisonous, carcinogenic, or otherwise harmful to life if found in sufficient concentrations.

Treatment. Chemical, biological, or mechanical procedures applied to an industrial or municipal discharge or to other sources of contamination to remove, reduce, or neutralize contaminants.

Turbidity. A measure of the amount of material suspended in the water. Increasing the turbidity of the water decreases the amount of light that penetrates the water column. Very high levels of turbidity can be harmful to aquatic life.

Unconfined, Open-Water Disposal. Discharge of dredged material into an aquatic environment, usually by discharge at the surface, without restrictions or confinement of the material once it is released.

Variable Range Radar. Radar equipped with markers which allow measurement of bearings and distances to known targets.

Vessel Traffic Service (VTS). A network of radar coverage for ports of Puget Sound operated by the Coast Guard to control ship traffic. Most commercial vessels are required to check in, comply with VTS rules, and report any change in movement.

Volatile Solids. The material in a sediment sample that evaporates at a given high temperature.

Washington Administrative Code. Contains all State regulations adopted by State agencies through a rulemaking process. For example, Chapter 173-201 WAC contains water quality standards.

Water Quality Certification. Approval given by Washington State Department of Ecology which acknowledges the compliance of a discharge with Section 401 of the Clean Water Act.

Waterways Experiment Station (WES). Corps of Engineers (Corps) research facility located in Vicksburg, Mississippi, that performs research and support projects for the various Corps districts.

Wetlands. Habitats where the influence of surface or ground water has resulted in development of plant or animal communities adapted to such aquatic or intermittently wet conditions. Wetlands include tidal flats, shallow subtidal areas, swamps, marshes, wet meadows, bogs, and similar areas.

Zoning. To designate, by ordinances, areas of land reserved and regulated for specific land uses.

ABBREVIATIONS

AET. Apparent Effects Threshold.

CFR. Code of Federal Regulations.

Corps. U.S. Army Corps of Engineers.

CWA. The Federal Clean Water Act, previously known as the Federal Water Pollution Control Act.

DEIS. Draft Environmental Impact Statement.

DMRP. Dredged Material Research Program.

DNR. Washington Department of Natural Resources.

DSS TA. Disposal Site Selection Technical Appendix.

DSWG. Disposal Site Work Group.

Ecology. Washington Department of Ecology.

EIS. Environmental Impact Statement.

EPA. Environmental Protection Agency.

EPTA. Evaluation Procedures Technical Appendix.

EPWG. Evaluation Procedures Work Group.

FVP. Field Verification Program.

HPA. Hydraulics Project Approval. RCW 75.20.100.

ML. Maximum Level.

MPTA. Management Plans Technical Appendix.

MPWG. Management Plan Work Group.

NEPA. National Environmental Policy Act.

PAH. Polycyclic (Polynuclear) Aromatic Hydrocarbon.

PCB's. Polychlorinated Biphenyls.

PMP. Proposed Management Plan.

PSDDA. Puget Sound Dredged Disposal Analysis.

PSEP. Puget Sound Estuary Program.

PSIC. Puget Sound Interim Criteria.

PSWQA. Puget Sound Water Quality Authority.

RAD's. Regional Administrative Decisions.

RCRA. The Resource Conservation and Recovery Act.

RCW. Revised Code of Washington.

SEPA. State Environmental Policy Act.

SL. Screening Level.

SMA. Shoreline Mangement Act.

WAC. Washington Administrative Code.

WES. Waterways Experiment Station.

401. Section 401 of the Clean Water Act.

404. Section 404 of the Clean Water Act.

4MR. The Fourmile Rock DNR disposal site in Elliott Bay.

January 1988 rev.

EXHIBIT A

EPWG PLAN OF STUDY

January 1988 rev.

EXHIBIT A

EPWG PLAN OF STUDY

1. Task 3a: Basis and Scoping of the Evaluation Procedures. The EPWG, with input from the invited and general public, will define the overall goal of the evaluation procedures and select the approach or combination of approaches (i.e., the basis) to implementing that goal. The evaluation procedures basis specifies the philosophy to be used in dredged material management. It defines the factors that will be considered in decisions regarding dredged material disposal and the tools (i.e., tests) to be used in this assessment. The development of the evaluation procedures will also be scoped during this task. (Reference: POS Task 3b)

2. Task 3b: Inventory of Dredged Material Sources. Dredged material sources that are anticipated to require use of unconfined, open-water disposal sites will be characterized by synthesis of existing information. Volumes and frequency of dredging will be summarized from past permit and port records and estimated through the year 2000. Available information for the physical, chemical, and biological response (e.g., bioassay test results) characteristics of the dredged materials will also be summarized. The inventory will provide input to the definition of contaminants of concern, will provide information necessary for disposal site selection and management, and will be used to conduct the cost and environmental review of alternative evaluation procedures. A review of the rules and regulations pertaining to open-water, unconfined disposal of dredged material in the Strait of Juan de Fuca will also be conducted as part of this task. (Reference: POS task 3c)

3. Task 3c: Improve and Quantify Interpretation of Test Results. Existing evaluation procedures will be refined to improve interpretation of test results by application of available information. Known biological effects data will be used to quantify interpretation of bioaccumulation test results. Ongoing research on biological effects of contaminants will be incorporated into test interpretation. Approaches under development for estimating bioavailability of, and body burdens resulting from, sediment contamination will be reviewed to determine their potential use in the evaluation procedures. Other testing methods for assessment of chronic and sublethal effects of sediment contamination (other than bioaccumulation) will also be reviewed and their applicability determined. Recent improvements to test methods and ongoing field verification of test results will be assessed. Application of the evaluation procedures to small projects and operational sequencing of testing to maximize time and cost efficiency will be addressed. (Reference: POS task 3d minus 3df and task 3f)

4. Task 3d: Resolve Mass Loss, Confinement, and Non-Marine Issues. Existing evaluation procedures will be revised to resolve and incorporate known dredged material disposal issues by application of existing information and consensus

development. Test methods and interpretation for assessing loss of contamination associated with suspended particulate matter will be developed. Concerns of RCRA and state dangerous waste and solid waste regulations will be addressed for dredged material. Evaluation of upland excavation materials that are co-located with a dredging project and that are proposed for unconfined, open-water disposal will be addressed. Disposal of freshwater or brackish sediments into marine environments will be assessed. (Reference: POS task 3d2 minus 3d2a)

5. Task 3e: Identify Contaminants of Concern and Incorporate Conventional Contaminants. Testing procedures and interpretation for assessing disposal impact of "conventional pollutants" (e.g., COD, sulfides, ammonia, turbidity, etc.) will be developed. State water quality standards will be incorporated into the interpretation framework. The identification, measurement, and evaluation of "contaminants of concern" will be addressed, including specification of analytical detection levels and limits of quantitation. Ancillary sediment parameters that should be measured to assist in dredged material evaluations will be specified. (Reference: POS tasks 3d2a and 3d3)

6. Task 3f: Review and Evaluate Current Information on Sediment Quality Values and "Apparent Effects" Contaminant Levels. Available synoptic chemical and biological data from the Puget Sound will be reviewed to estimate "apparent effects levels" or measured contaminants. This information will then be evaluated to determine its applicability for assessment of dredged material disposal based on bulk sediment chemistry values. "Levels of no concern" that indicate no need for detailed testing may also be identified. (Reference: POS task 3d1 of phase II)

7. Task 3g: Dredged Material Risk Analysis. FDA standards, EPA carcinogenic risk values for priority pollutants, and EPA Acceptable Daily Intake values for noncarcinogenic priority pollutants will be used to develop human health risk assessment guidelines for interpreting the results of bioaccumulation tests. These guidelines will utilize available information on human consumption of Puget Sound species as the primary exposure pathway to be analyzed. This task will also address the concept of "acceptable" versus "unacceptable" risk as it can be related to dredged material disposal. A state-of-the-art, consensus methodology for comparing relative/estimated risk among various disposal options will be developed. Risk analysis will be applied to each of the open-water sites to be designated by the Disposal Site Work Group, as a means to objectively decide on the quality of material to be discharged at these sites. (Reference: POS task 3d1f)

8. Task 3h: Protocol Development and Quality Assurance/Quality Control. The method protocols for the dredged material tests recommended by the evaluation procedures will be defined by application of existing information with consensus development where necessary. Field sampling, handling, and storage of sediments and test organisms will be described. Chemical and biological testing procedures will be detailed. Quality assurance and quality control requirements for conducting the dredged material tests will be specified. (Reference: POS task 3e)

9. Task 3i: Cost and Environmental Review of the Evaluation Procedures. The information from the dredged material inventory will be used to assess the cost and environmental impact potentially resulting from various alternative evaluation procedures. The quantity of dredged material that might require confined disposal under various levels of protection (risk management allocations) will be estimated. The cost of disposing of this quantity in confined disposal areas relative to open-water, unconfined disposal sites will be determined. The potential environmental consequences of confining this amount of dredged material (e.g., loss of nearshore or upland habitat) will be assessed. (Reference: POS task 3e)

10. Task 3j: Administrative Decisions for the Evaluation Procedures. Completion of the evaluation procedures will require a diverse array of decisions that are partially scientific and partially administrative. These "administrative decisions" include such things as selecting the toxicity bioassay exposure period, deciding on the acceptability of mixing and dilution as a management tool, identifying the reference area to be used for dredged material evaluations, and setting interim and long-term goals for water and sediment quality in the Sound. While the final decisions rest with the decisionmakers of the various federal and state regulatory authorities, these decisions require broad and iterative input from the scientific and general public. Available scientific information and consensus development synthesized under the previous tasks will be used in making the final administrative decisions. (Reference: POS task 3d5)

11. Task 3k: Design and Selection of Confinement Options. Guidance for selection of the appropriate contaminant confinement, control or treatment options will be provided for confined disposal in aquatic (capped), upland, and nearshore (intertidal) sites. Guidance will describe available confinement options, testing methods for selection of appropriate options, and design guidelines for contaminant control and treatment. Potential for pre-treatment of dredged material prior to open-water, unconfined disposal will be assessed. Dredging equipment and dredged material transportation requirements for materials requiring confined disposal will also be addressed. (Reference: POS task 3g)

12. Task 3l: Monitoring Plan for Open Water Disposal Sites. A plan specifying monitoring parameters, monitoring techniques, monitoring frequency, and remedial response to monitoring indications, will be prepared to address the potential chemical effects to biological resources that may occur at the open-water disposal sites.

13. Task 3m: Sea Surface Microlayer Contamination. A literature search will be conducted to investigate the potential for dredged material to contribute to contamination of the sea surface microlayer. The search will include an assessment of the possible significance of dredging contributions, as well as

technical proposals for any needed lab or field studies to further document dredging effects in this area. A scientists meeting on the subject of micro-layer contamination will be used as a forum for deciding on the need for additional study.

14. Task 3n: Technical Appendix. A preliminary findings report will be prepared in early 1986 to encourage public and agency review of results and decisions to date. Upon completion of the tasks outlined above and using the preliminary findings report and comments received, the results of the work group activities will be summarized and consolidated in a technical appendix to the overall study EIS.

15. Task 3o: Work Group Support and Management. Staff time for each of the four agencies to attend work group meetings is included in this task. As needed, technical review of work group/contractor products may involve hired experts.

EXHIBIT B

REGIONAL ADMINISTRATIVE DECISIONS

EXHIBIT B

REGIONAL ADMINISTRATIVE DECISIONS

Introduction.

Exhibit B.1 presents the original EPWG development work on the Regional Administrative Decisions (RADs) that was completed in October, 1985. The list of RADs and questions presented reflect the early understanding of EPWG on the types of decisions within dredged material evaluation procedures. These decisions would be determined by regional factors that are partially scientific and partially administrative. The RADs outlined here formed the basis of the work that led to the evaluation procedures presented in the Technical Appendix.

SEDIMENT ASSESSMENT

Other Options Considered.

1. Pre-sampling Assessment of Sediment: The primary objective in the initial assessment "reason to believe" review is to determine if the sediment may be contaminated such that characterization is needed. The following presents the other options considered by EPWG in developing the regional administrative decision on the initial assessment of material from a proposed dredging project.

Option a. Continue with the past practice of applying the "reason to believe" review derived from the Section 404 requirements, on a project-by-project basis. Among the factors considered are previous data for the vicinity, identification of all source inputs, recent spills, and the probability of land runoff. If a project was suspected to be free of contamination above background levels, it was passed for dredging and disposal without further testing.

Option b. Develop a consolidated, centralized, and detailed "reason to believe" review procedure that could be used for all projects. An agency would have the lead in developing and maintaining the "reason to believe" database.

Option c. Require a "safety net" of information on each project to ensure that the project does not contain contamination. The minimum would be a single bulk sediment chemical analysis.

2. Sampling and Analysis Protocol. EPWG considered several approaches to determining project characterization based on the number of samples and analyses that would be required. Options included setting analyses based on volume, contamination sources, or costs.

Option a. Set minimum standards by project size (volume and cut depth).

Option b. Set minimum standards by project location (project concern ranking, whether the project is in an urban vs. relatively contaminant-free area).

Option c. Use qualitative adjustment factors to modify minimum standards. Factors considered were:

project volume
project area
project configuration
local hydrodynamics
contaminant sources
overall project costs

Option d. Use quantitative adjustment factors to modify minimum standards. Factors considered were the same as those listed in option (c), however, quantitative values would be derived for the factors.

Option e. Characterize project by taking 1 core per 4,000 cy of material to be dredged but composite all of the cores into a single analysis for a "project decision". This option was suggested by staff at the Waterways Experiment Station.

Option f. Develop characterization approach on a project-by-project basis taking into account the cost implications involved in sampling larger projects

Option (a) was presented in the following format:

Project Categorization by Volume

Project Size	Volume (cy)	Average Cut
Small	10,000	less than 4
	20,000	greater than 4
Moderate	10 - 100,000	less than 4
	20 - 250,000	greater than 4
Large	greater than 100,000	less than 4
	greater than 250,000	greater than 4

Option (b) was presented in the following formats:

Categorization by Location

Category	Sources
Few Sources	-No historic or current adjacent sources -No past navigation dredging
Some Sources	-Sources such as marinas -Has active navigation -Populated area
Many Sources	-Urban areas -Isolated industries

A combination of options (a) and (b) was also considered:

Categorization by Location and Size

	Project Size		
Sources	Small	Moderate	Large
Few	Low Concern	Low	Moderate
Some	Moderate	Moderate	High
Many	High	High	High

Options (c) and (d) were felt to be unnecessarily difficult to implement.

AQUATIC CONCERNS

Options Considered. EPWG considered many contaminant pathways in assessing which routes of exposure were important with respect to dredging and disposal operations. Although all pathways could potentially be important, EPWG felt that several were of greater concern than the others. The following factors were considered in arriving at the EPWG recommendations concerning aquatic concerns for contaminant mobility:

Option a. Dissolved Contaminants: These are more important during dredging and disposal operations and should be only of minor concern thereafter. Past elutriation tests and field measurements have not indicated adverse effects.

Option b. Suspended solids could be a problem during dredging operations if the concentration of contaminants is great enough and the sediment being dredged is fine-grained and easily resuspended. Temporary oxygen depletion can also occur at the dredging and disposal site due to the chemical oxygen demand of the suspended solids.

Suspended solids may also be an enviromental problem at the Open water disposal site during disposal operations and resuspension of previously deposited dredged material. In most cases, the amount of material lost during these phases of the diposal operation are expected to be low and have no lasting environmental impact. However, for easily resuspended material with higher degrees of contamination, concern with potential losses via suspended solids are more important. To assess the loss of dissolved contaminants into the water column and the displacement of particle-bound contaminants during disposal, the potential for material release will be determined for the more contaminated material via a water column toxicity evaluation and a simulated material release test.

Option c. Deposited Sediment: The primary effect of dredging will occur on benthic organisms at the dredging and disposal sites. Impact to the benthos can occur through three processes. First, impact may be expected at the disposal site due to physical covering of animals beneath the disposal mound. For multiple use sites, where dredged material disposal is frequent, burial of the newly settled species will occur. This will hinder any recolonization of the deposited material. The other two impacts on the benthos will be chemical-related. Both acute and chronic effects might be expected on species in and around the disposal mound depending on the level of chemical contamination of the material being disposed. Acute effects on the disposal mound are expected only if higher contamination levels (Category 3 or 4 material) are allowed for unconfined, open water disposal.

The major concern remaining with lower degrees of contamination will be chronic effects, including impacts on growth and reproduction. The primary exposure route will be species-specific and will depend upon the type of for interaction the organism has with the sediment. The primary route of exposure filter-feeders is through the ingestion of suspended particles containing contaminants. The primary route of exposure for sediment burrowers, however, will be through direct contact of body surfaces with contaminated sediment and interstitial waters.

Bioaccumulation and contaminant mobility through the food chain is also of concern, especially if the disposal site is large and is likely to be populated or visited by boraging or resident fish and/or shellfish species that are used for human consumption.

AQUATIC BIOLOGICAL TESTS

Options Considered.

1. Number of Species Used: The options proposed for the number of species to use in byological testing included: (1) single; (2) multiple; and the number of species used depends on the area being dredged. Options and (3) were not selected because they fail to address interspecific differences in sensitivity (option 1) and the need to apply tests consistently for all projects (option 3).

2. Use of Acute Tests: Consideration was given to whether sensitive acute tests could be used for chronic/sublethal testing. Discussion pointed out that acute effects and chronic/sublethal effects exhibited by organisms require different tests. Different compounds are probably responsible fmr differing effects. In a multiply contaminated sediment, different compound classes would be expected to act as acute and chronic affectors. Highly volatile/soluble compounds usually produce acute effects while less soluble contaminants are responsible for chronic/sullethal effects.

3. Available Chronic Tests: A variety of tests were considered for chronic testing including the the following bioassays. Provided with each test is a summary of the strengths and weaknesses of each test.

a. Oligochaete Respiration: Respiration is highly influenced by other factors other than contaminants that will cause significant variation in the results and test interpretation. If respiration is to be done at all it should be measured in conjunction with other bioenergetic measurements.

b. Carcinogenicity/Mutagenicity: Tests considered included the AMES Test, Anaphase Abberation and Sister Chromatid Exchange. These procedures may give some information on possible mutagenicity, however, test interpretation is very difficult at this time, especially relative to field consequences.

c. Copepod Reproduction: Reproduction information is desired in chronic testing as is any measure of growth. The use of copepods is questionable, however, since most species in culture are pelagic. Those harpacticoids currently in culture require approx. 120 days for a life cycle; a time period too long for routine testing requirements.

d. Scope for Growth and Bioenergetics: Scope for growth is an instantaneous measure of the potential for growth while bioenergetics measures and considers those factors responsible for actual changes in growth. Both are potentially useful as they integrate several physiological variables into one measure. Both techniques require experience in physiological experimentation and may not be appropriate in a regulatory testing program. Growth, by itself, should be considered an endpoint for chronic tests.

e. Adenylate Energy Charge (AEC): AEC tends to be extremely sensitive to slight variations in laboratory procedural techniques. Contaminant-related changes in AEC are obscured by those caused by other factors. Consequently, the translation of laboratory test results to potential field effects is extremely difficult.

f. Histopathological Testing: Histopathological testing requires substantial time, probably too much time for use in a regulatory program. In addition, a specialist is needed to diagnose histopathological changes, especially those occurring over a relatively short period of time.

g. Intrinsic Rate of Population Growth (IRPG): IRPG is a sensitive testing procedure that provides information on growth, reproduction, and the integration of all biological processess. For some species, the test can be conducted in 30 days and involves all major life cycle stages. In addition to measuring growth and reproduction on individuals, it also measures effects at the population level. The main problem in implementing this test for Puget Sound is the lack of local species that can be used.

h. Bioaccumulation: Bioaccumulation is a valuable assessment tool as it helps to define those sediment associated contaminants that are biologically available. Such tests define the extent of contaminant mobility that can be expected. While bioaccumulation data can not be used to predict cause and effect relationships for organisms, the data can be used in assessing potential human health risks associated with eating organisms collected at the disposal site or from eating prey species which feed on the disposal mound.

i. Biochemical/Metabolism Studies: Evaluation of biochemical pathways can provide information on the impact of contaminants on cellular metabolic and physiological functions. The most promising to date is evaluation of the mixed function oxidase system in some aquatic organisms. The MFO system is a detoxification mechanism effective in metabolizing aromatic and chlorinated hydrocarbons.

AQUATIC CHEMISTRY TESTS AND INTERPRETATION

Options Considered:

1. Use of Bulk Chemistry: EPWG considered several options as to the use of bulk chemistry values. They were:

a. No Use
b. Used to Smt Screening Level Only
c. Used to Set Maximum Level Only
d. Used to Set Both Screening and Maximum Level

EPWG felt that the Sediment Quality Value database was sufficient to warrant their use of the information in setting both a screening level and a maximum level. Although there was confidence in setting and applying chemistry values in a decisionmaking framework, EPWG placed relatively low weight to chemistry in decisionmaking relative to the weight given biological data. The SL values were set low such that only relatively clean sediments would pass without biological testing. Also the ML values were set at relatively high concentrations such that only fairly contaminated material would fail for unconfined, open water disposal and would not go through biological testing. All sediments having chemical concentrations between the SL and ML would be biologically tested for their suitability for unconfined, open water disposal. EPWG felt that a large majority of the sediment that would be proposed for dredging from the Phase I area would have contaminant concentrations that will fall between the SL and ML values and thus be biologically tested before a decision is made on their suitability for unconfined, open water disposal.

2. Setting Screening Level (SL) Values: EPWG considered 7 alternatives in setting the SL. They were:

a. Take lowest Apparent Effects Threshold (LAET)
b. Apply safety factor (SF; decrease value) to AET
c. Use Potential Effects Threshold (PET) or a factor of PET
d. Use Lower Limit of AET (LLAET)
e. Use maximum level found in Puget Sound reference areas
f. Percentile of projects cut-off
g. Use Probable No-effects Level (SLC's)

Following discussion, EPWG deleted options a,f, and g from further consideration. Choice (a.) was dropped because the AET, by definition, is set as the highest concentration that does not cause an effect. EPWG members felt this was too high for an SL and would give chemistry a high weight in decisionmaking relative to biological testing. Choice (f.) was dropped as it does not have any scientific standing, and choice (g.) was deleted from further consideration, because the available database supporting the PNEL values is much smaller than it is for the AET's. A revised list of choices was made as follows:

a. Apply SF to AET
b. Use PET or apply factor
c. Use LL of AET
d. Use Reference values or apply factor
e. Use maximum reference values
f. Apply SF to b-f
g. Apply SF to LAET

Following an evaluation of the chemical values represented by these choices, EPWG chose to set the SL value at 10% of the AET as long as the resulting value was above reference values and below the LAET.

3. Setting Maximum Level Values for Category 2 material (ML2): EPWG considered how best to apply the AET's to use in setting the ML for Category 2 material. The options included use of the low AET, the middle AET, the high AET, and a combination of the misclassification schem for each of the AET's. Conceptually, the choices can be drawn as follows:

2LL 1LL LAET HL

2LL 1LL MAET HL

2LL 1LL HAET HL

Where: LAET = lower AET value
MAET = middle AET value
HAET = highest AET value
2LL = AET value assuming 2 miscalculations under AET
1LL = AET value assuming 1 miscalculation under AET
HL = AET value assuming 1 miscalculation over AET

Following evaluation of the values developed for all three choices, EPWG decided to set the maximum level chemistry values for Category 2 material equal to the High AET. In doing so, the SL values would represent 10% of the High AET.

4. Setting Maximum Level Values for Category 1 material (ML1): EPWG considered 3 options in setting the ML1 values. They were:

a. LL of AET
b. LAET
c. 25% of High AET

Following evaluation of the chemistry values set by all three options, EPWG set the ML1 equal to the LAET. Tha LAET values were found to fall between the SL and ML2 values and therefore represented a graded level of chemistry and probable biological effects between the two.

5. Setting the Maximum Level Values for Category 3 material (ML3): EPWG considered two options in setting the ML3 values. They were:

a. HL of HAET
b. 2 (ML2)

EPWG recommended option (b.) because it best represents the upper end of a typical toxicity curve assuming that ML2 values represent 50%, and ML3 represents 90%, mortality.

EXHIBIT C

SECTION 404 TESTING GUIDELINES

CENPD

Corps of Engineers Disposal Guidelines

The following discussion presents the procedures by which the U.S. Army Corps of Engineers (Corps) regulates and manages the disposal of dredged material in the waters of the United States under its authorities and polices described in Chapter 5 of the PSDDA Proposed Management Plan report (August 1987). It should be noted that these procedures have been developed and have evolved over the past decade and are subject to additional change and modification as new information and technology develop and are adequately evaluated.

Section 404 of the Clean Water Act provides that guidelines developed by EPA in conjunction with the Corps be applied by the Corps in selecting disposal sites and in the permit application review process. EPA published technical guidelines in 1975 for use by the Corps in conducting the required ecological evaluation of proposed disposal activities. The Corps issued final regulations for the Regulatory Program in July 1977 to be used in evaluating proposed discharges of dredged or fill material into inland and ocean water. In May 1976, the Corps issued an interim guidance manual, as specified in the Federal Register, to initiate technical implementation of the program.

The guidelines are to include:

a. the effect of disposal of pollutants on human health or welfare, including but not limited to plankton, fish, shellfish, wildlife, shorelines, and beaches;

b. the effect of disposal of pollutants on marine life including the transfer, concentration, and disposal of pollutants or their byproducts through biological, physical, and chemical processes; changes in marine ecosystem diversity, productivity, and stability and species and community population changes;

c. the effect of disposal of pollutants on aesthetics, recreation, and economic values;

d. the persistence and permanence of the effects of disposal of pollutants;

e. the effect of the disposal at varying rates of particular volumes and concentrations of pollutants;

f. other possible locations and methods of disposal and recycling of pollutants including land-based alternatives; and

g. the effect on alternate uses of the oceans, such as mineral exploration and scientific study.

These "legal/technical" considerations form the framework from which the ecological evaluations must be developed. Several of the considerations and inclusions are, however, at the forefront of the state-of-the-art and require research level approaches to be implemented into a dynamic, field-oriented regulatory program.

The Section 404(b)(1) Guidelines recognize that compliance evaluation procedures will vary depending on the seriousness of the proposal's potential for unacceptable adverse impacts (40 CFR 230.10), and provide general guidance for evaluation and testing. Pursuant to the Guidelines, specific evaluation procedures, including chemical and biological tests, are furnished by the District Engineer (DE) on a case-by-case basis ("interim guidance by the permitting authority," 40 CFR 230.61).

To assist the Corps in the overall long-term management of the disposal of dredged material, a management strategy was developed by the U.S. Army Engineer Waterways Experiment Station (MP D-85-1, Francinques, Palermo, Lee and Peddicord, 1985, "Management Strategy for Disposal of Dredged Material: Contaminant Testing and Controls"). This strategy has been adopted as Corps policy and is incorporated by reference in 51 FR 19694; proposed revision to 33 CFR 290.145 (39 FR 26636, 22 July 1974). The steps for managing dredged material disposal consist of the following:

a. Evaluate contamination potential.

b. Consider potential diposal alternatives.

c. Identify potential problems.

d. Apply appropriate testing protocols.

e. Assess the need for diposal restrictions.

f. Select an implementation plan.

g. Identify available control options.

h. Evaluate design considerations.

i. Select appropriate control measures.

Following the development of the management strategy, it was utilized as a framework for an example application for highly contaminated material at Commencement Bay, Washington, (a Superfund site) under the sponsorship of the State of Washington Department of Ecology and the U.S. Army Engineer District, Seattle (MP D-86, Peddicord, Lee, Palermo and Francinques 1986, "General Decisionmaking Framework for Management of Dredged Material, Example Application of Commencement Bay, Washington"). This example application considers all alternatives for disposal, and provides detailed technical rationales and flowcharts for evaluating disposal alternatives based on the results of appropriate testing.

Since the mid-1970's, the Corps has been involved in the disposal of dredged material under the authority of 33 CFR Parts 320 through 330 and 40 CFR Part 230 (1975) for waters of the United States and under the authority of applicable Sections of 40 CFR 220-229 (1977) for ocean dumping. In fulfilling the obligations and responsibilties mandated by those authorities, it has conducted extensive research under the Dredged Material Research Program and continues to conduct research under the Field Verification Program and the Long-Term Effects of Dredging Program, and provides field assistance and management activities under the Dredging Operations Technical Support Program.

In addition, it has published two guidance manuals, one for the Clean Water Act (MP D-76-17, Ecological Evaluation of Proposed Discharge of Dredged or Fill Material into Navigable Waters, 1976) and a joint manual with the U.S. Environmental Protection Agency for ocean dumping (Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters, 1977; the "implementation manual"); the latter provides much more detailed guidance than the former. Although these documents were state-of-the-art at the time of publication, subsequent operational experience has led to changes in specific application. In particular, there has been a tendency for Corps coastal Districts to use, depending on the subject of concern, portions or all of the testing procedures in the ocean waters implementation manual for Section 404(b)(1) Clean Water Act determinations whenever estuarine or marine waters are involved. Although a major reason for this is the detailed guidance, others include similarities between the 404 Guidelines and those in Section 102(a) of Public Law 92-532, and the fact that saline waters are involved. Additionally, shortly after the issuance of the Corps/EPA implementation manual on ocean dumping, the Corps and EPA were sued by the National Wildlife Federation. The suit was based on the technical validity of the testing procedures and interpretation of test results. Judgment was made in favor of the Corps and EPA and there has been no further challenge. Because of the above factors, the ocean dumping testing procedures and interpretive approaches have been in widespread use and have led to the informal but widespread adoption of the general testing and evaluation protocol from ocean dumping to 404(b)(1) evaluations.

This should not be construed to imply that the ocean dumping procedures/ interpretation are "required" or "mandated" for 404(b)(1) evaluations. They should be considered in light of local or regional concerns and, where appropriate, <u>may</u>, in part or in whole, be used. However, they do, <u>de fact</u>, constitute an acceptable and widely used technique which has withstood court challenge and for which a major technical data base exists. That no absolute procedure exists for 404(b)(1) evaluations is further evidenced by cooperative efforts currently in progress between the Corps and EPA to establish standard testing and evaluation procedures. The protocol is given below.

In essence, the protocol consists of a tiered approach with each successive tier being based on a "reason to believe" that there is potential for unacceptable adverse effects. Such multiple tests are clearly allowed by 40 CFR 230.4-1 ("No single test or approach can be applied in all cases to evaluate the effects of proposed discharges of dredged or fill material," and

"Suitability of the proposed disposal sites may be evaluated by the use, where appropriate, of sediment analysis or bioevaluation."). However, such tests must be conditioned by, "In order to avoid unreasonable burdens on applicants in regard to the amounts and types of data to be provided, consideration will be given by the District Engineer to the economic cost of performing the evaluation, the utility of the data to be provided, and the nature and magnitude of any potential environmental effect."

The first tier of the existing protocol consists of a "reason to believe" that contaminants are or are not present and is commonly referred to as the "exclusion clause" (40 CFR 230.4-1(b)(1). If there is no reason to believe that contaminants are present and if certain other conditions are met including grain size and chemical/physical similarity of the dredged material and the substrate at the disposal site, no further testing is required. If there is reason to believe that contaminants are present, or if sufficient information is not available, a second tier or evaluation may be conducted which consists of a bulk sediment analysis. Should sufficient information be available from previous testing and evaluation no additional chemical analyses are necessary.

The bulk sediment analysis is essentially an inventory of contaminants of concern and is used to compare the chemical composition of the dredged material to the composition of the material at the disposal site, with emphasis generally placed on heavy metals, PCB's, PAH's, pesticides, and other substances of ecological or human health significance. If substantially greater concentrations are observed in the dredged material and there is reason to believe that the substances are bioavailable, and sufficient information is not available, a third tier or testing may be required. This tier includes testing for water column impacts and/or benthic impacts.

If there is concern regarding water column impacts, an elutriate test is performed to evaluate contaminant release into dredging or disposal site water. The results of the elutriate test are compared to water quality standards. If there are no water quality standards or the standards are thought to be inappropriate or inadequate, a water column liquid and/or solid suspended particulate phase bioassay may be conducted. Again, depending on where the concern lies, the water column bioassay may address the dissolved constituents and/or the suspended solid particulate phase.

If there is concern regarding impacts to benthic organisms, a benthic bioassay may be conducted. In general, for a comprehensive assessment of potential impacts, three organisms are generally used; a filter-feeder, a deposit-feeder, and a burrowing species. These relate to different ecological niches at the disposal site. In addition, a Mysid shrimp is recommended and has been widely used as an internal standard and to form a basis for quality assurance.

If there is a reason to believe that bioaccumulation is of concern, a second component of the third tier consists of evaluating the potential uptake of contaminants. This may be done either in the field or in the laboratory, whichever is most appropriate. If done in the laboratory, it is customary to utilize survivors of the toxicity bioassays for bioaccumulation assessment if sufficient biomass is present in the survivors.

The tiered testing approach described above is essentially the procedure followed for the evaluation of the aquatic disposal alternative in the development of the Federal Standard for a given dredging project. This approach should be applied consistently to each and every dredging project, Federal or permit. The approach is flexible to some extent in allowing consideration of the three phases of the aquatic environment (liquid, suspended solids, and solid), as appropriate, that potentially could be impacted by the discharge of dredged material. Testing of the appropriate phase is determined by the reason to believe that a potential for unacceptable adverse impacts in one or more phases could occur. Additional flexibility is incorporated in the approach in relation to the selection of bioassay species to be used in the tests. Species can be selected such as bivalve, polychaete and a crustacean (mysids, amphipods, shrimp) or other available, appropriate, developed and evaluated local species. The intent is to evaluate the potential impact on a deposit feeder, a burrower and a suspension feeder representative of major ecological compartments.

The following discussion addresses in more detail the interpretation of bioassay test results from the tiered testing approach used to evaluate the aquatic disposal alternative portion of the Federal Standard. Additional detail on the evaluation of the aquatic disposal alternative can be found in Peddicord, Lee, Palermo, and Francinques 1986.

If there is reason to believe that the dredged material contains contaminants of concern at concentrations higher than those contained in the disposal site sediment and that these contaminants are potentially bioavailable and could result in a significant adverse impact, then bioassay tests should be conducted. The bioassay tier is used to determine if there is reason to believe contaminants in the dredged material will result in an unacceptable adverse impact to the water column and/or the benthic component of the aquatic disposal environment. The water column consists of a dissolved phase and a suspended solid particulate phase. There is an overwhelming preponderance of evidence from years of studies relating the potential of water column impacts of contaminants released from dredged material disposal to demonstrate that adverse impacts on the water column from dissolved contaminants released from dredged material are negligible. While this evidence does not unequivocally prove that water-column impacts will not occur with aquatic disposal, it does indicate that such impacts are sufficiently unlikely that the District Engineer must decide whether it is appropriate to focus evaluation on the other issues rather than testing for potential water column impacts in association with disposal in aquatic sites, where the majority of the material is deposited on the bottom and the remainder is subject to rapid dispersion and dilution. In many cases it will be possible to assess the potential for water column impacts on the basis of previous water column testing and characteristics of the disposal site without conducting additional sediment specific testing.

There may be a reason to believe that the suspended solid particulate phase of the water column may result in a potential unacceptable adverse impact to the disposal environment. If this is the case, the suspended solid bioassays may

be conducted. Likewise, if there is reason to believe that unacceptable adverse impact may occur in the solid phase then a solid phase bioassay can be conducted.

If the results of the bioassay tests show unacceptable toxicity to the test species, further testing may be required. In the case of suspended solids phase bioassay testing, consideration of mixing zone at the disposal site should be evaluated to determine if an acceptable mixing zone is available to eliminate significant adverse impact of the potential toxicity at the disposal site. If unacceptable toxicity is shown in the solid phase test and mortality is sufficiently elevated above control and/or reference, a significant impact has been shown.

If unacceptable toxicity is not observed in the solid phase test species and there is reason to believe that there is a potential for bioaccumulation, or the results of the bioassays are not conclusive, further testing may be required. The surviving bioassay animals may be analyzed for bioaccumulation after exposure to the dredged material for an appropriate length of time.

Bioaccumulation of bioassay species exposed to the dredged material is compared to that of species exposed to disposal site sediment of an appropriate reference site in the disposal site environment. Additional discussion of test result interpretation can be found in Peddicord, Lee, Palermo and Francinques (1986).

The above discussion has addressed the first four steps of the Management Strategy (Francinques, Palermo, Peddicord, and Lee, 1985). Additional information on the need for restrictions and control measures for aquatic disposal and the evaluation of other disposal alternatives can be found in Francinques, Palermo, Peddicord, and Lee (1985). A more comprehensive discussion of the interpretation of test results is provided by Peddicord, Lee, Palermo, and Francinques (1987).

January 1988 rev.

EXHIBIT D

COST ANALYSIS CASE STUDIES

January 1988 rev.

EXHIBIT D

SAMPLING AND TESTING COST CASE STUDIES

Introduction. PSDDA analyzed four specific projects in a case study to assess the likely costs of dredged material sampling and testing under PSDDA for comparison with costs actually incurred meeting current guidelines (Fourmile Rock Interim Criteria). Three of the projects were Corps maintenance dredging, and one project was new construction by the Port of Seattle. The projects included work done in waterways classified by PSDDA as high concern and moderate concern areas, and ranged in size from 32,000 cy to 137,000 cy of material removed from the project area (Table 1).

Table 1. Projects Analyzed In PSDDA Phase I Case Study

Project:	PSDDA Area Ranking:	Volume Dredged (cy):
Kenmore Navigation Channel Maintenance Dredging	High	32,000
Seattle Harbor Navigation Project Maintenance Dredging, West Waterway and Lower Duwamish (Shoal removal)	High	83,000
Seattle Harbor Navigation Project Maintenance Dredging, Upper Turning Basin	Moderate/High	137,000
Port of Seattle, Terminal 30 Construction Dredging	High	135,000

Factored into the case study was the cost of sediment sampling (boat, equipment, and coring costs) at the project site, and the cost of physical, chemical and biological testing required to evaluate the project material (including QA/QC costs). Dredging and disposal costs were not considered in the case study except for the Seattle Harbor Navigation, Upper Turning Basin dredging project, where the impact of applying PSSDA evaluation procedures and interpretive guidelines on total project costs was estimated.

The sampling and testing costs estimated for the PSDDA evaluation procedures represent the best judgement of what would be necessary to determine the technical suitability of dredged material for unconfined, open-water disposal. Several assumptions were made in applying PSSDA-required sampling and testing that have an impact on the cost analysis, including:

The PSDDA coring and compositing schemes represent the minimum number of cores and samples that would be needed to adequately characterize the project area. In practice, the number of samples taken for a project may, at the choice of the dredger, be higher than the required minimum, depending on the type of sediment horizons encountered during coring. A project proponent can choose to do less compositing (resulting in a greater number of samples that will require testing) if a difference in sediment horizons appears in the sediment cores such that separate analysis may be warranted in order to reduce the amount of material required to go to more costly confined disposal. Decreasing the number of composites will increase the number of samples which, in turn, will increase testing costs. The overall effect of better sediment horizon characterization, is that while testing costs will be increased there could be an overall project cost reduction. A better definition of material that is technically suitable for unconfined, open-water disposal may increase the amount of project material that meets this test.

When developing sampling and compositing schemes that would be required under PSDDA, dredging prisms and volumes of material to be removed were determined using available project information (e.g., construction and project drawings). These drawings typically show the general shape of the dredging prism but often do not show the deviations from the ideal that may be needed to develop a completely realistic sampling and compositing scheme. During coring and compositing, changes in the sampling plan may have to be made that would result in higher costs than estimated.

Finally, it was assumed that the chemical data obtained for the project are reflective of the sediment chemical concentrations that would have resulted from the PSDDA sampling and compositing scheme. The existing chemical data were compared to the PSDDA screening level and maximum level guideline values to determine whether biological testing would be required to make a decision on the technical suitability of material for unconfined, open-water disposal.

Testing costs under PSDDA are influenced by the chemical concentrations found in sediment samples. Initial testing of material to be dredged includes physical and conventional chemical analysis, and a determination of the concentration of chemicals of concern of a sediment sample. Further testing that may be required (and total cost of testing) is dependent on the chemical quality of material to be dredged. The need to conduct biological testing will depend on the concentration of chemicals of concern found in the sediment sample. Samples having chemical concentrations below the screening level

guideline values will not require biological testing. The volume of sediment (e.g. management unit) characterized by a sample having chemical concentrations below the SL would be considered technically suitable for unconfined, open-water disposal without the need for biological testing. Similarly, if the chemical concentrations in the sediment sample are above the maximum level (ML) guideline values, for these case studies it is assumed that aquatic biological testing would not be conducted since there is reason to believe that the material would be unacceptable for unconfined, open-water disposal. Although biological testing of sediments with chemical concentrations over the ML is allowed in order to determine suitability of the material for unconfined, open-water disposal under 404, for the purposes of the case studies, it was assumed that material exceeding the ML guideline values would not undergo further testing. The only exception to this is with Corps projects, in which biological testing was assumed to be conducted on all sediment samples having chemical concentrations above the ML guideline values.

The case study presents the overall impact to sampling and testing costs of conducting dredged material evaluation using PSDDA guidelines. Detailed calculations needed to estimate the overall impact are illustrated for one of the projects. Exhibit 1 contains the assumptions and detailed calculations needed to determine the impact of the PSDDA guidelines. The steps shown in Exhibit 1 were also generally applied to all of the case studies.

CASE STUDY

1. Kenmore Navigation Channel Maintenance Dregding

Project Description: This dredging was undertaken to maintain the head of the Kenmore navigation channel at the authorized depth. Project depths range from shanlow (less than 4 bt.) to depths greater than 12 ft. Approximately 32,000 cy of material were dredged from the project area. Sediment analyzed for this project was collected in July 1985.

Costs of Sampling and Testing as Conducted Under the Fourmile Rock Interim Criteria: A total of 2 cores and 4 grabs were used to collect material to characterize the project area. On the average, a core (or grab sample) was taken for every 6,400 cy of material. A total of 7 samples were derived from the 6 cores and grabs taken. Two of the grabs and one core were analyzed as separate samples, while the two remaining grabs were composited into a single sample and 1 core wis horizontally split into three separate samples.

Each of the 7 samples was subjected to the following physical, chemical, and biological analyses:

Physical Analysis --Grain Size
Sulfides
Oil and Grease
Total Organic Carbon
Percent Solids
Percent Volatiles

Chemical Analysis --Metals
Polyaromatic Hydrocarbons
PCB's
Pesticides

Biological Tests --Amphipod Bioassay
Microtox Bioassay

Costs of sampling and testing are presented below. Sediment collection and compositing required 2 days including mobilization and demobilization.

Sampling Cost:	$ 3,480.00
Testing Costs:	25,585.00
Total Sampling and Testing Cost:	$ 29,065.00

Average Sampling Cost per Core (or grab):	$ 580.00
Average Testing Cost per Sample:	3,655.00
Average Sampling and Testing Costs per cy:	$ 0.91/cy

Projected Sampling and Testing Requirements and Estimated Costs Under PSDDA: For purposes of determining sampling requirements, the Kenmore area was ranked as a high area of concern. Under PSDDA, a minimum of 9 cores would be required to collect sediment for physical, chemical, and biological characterization of the project sediments. In determining the number of cores required, it was estimated that 50% of the project volume (16,829 cy) was between the surface and 4 feet cut depth and that the remaining volume was below 4 ft. Following collection, the 9 cores could have been composited to a minimum of 6 samples. Each of these samples would be used for characterization of the sediments. The PSDDA physical, chemical, and biological testing requirements are presented below:

Physical and Conventional Chemical Analysis —Grain Size
Total Solids
Total Volatile Solids
Total Organic Carbon
Sulfides
Ammonia

Chemicals of Concern List--Metals
Polyaromatic Hydrocarbons
Chlorinated Aromatic Hydrocarbons
Phthalates
Pesticides
PCB's
Miscellaneous Compounds

Biological Testing--10-day Amphipod Bioassay
Juvenile bivalve
Bivalve Larvae (or) Echinoderm Larvae Sediment
Toxicity and Water Column Bioassay
Microtox

Estimated sampling and testing costs that might be expected under PSSDA requirements are presented below. It was assumed that the same number of days would be required for sampling and that the cost of obtaining each core would be the same as incurred by the actual project. Testing costs include physical and conventional chemical analysis and chemical of concern testing of all 6 samples. Comparison of the available project chemistry to the SL and ML guideline values indicates that under the PSDDA sampling scheme 4 samples

would have had chemical concentrations above the ML level and 2 samples would have had chemical concentrations between the SL and ML. (Based on a comparison of the sediment chemistry to the Fourmile Rock Interim Criteria and the PSDDA guideline values, no difference in the volume of material going to confined disposal would have resulted from application of the PSDDA evaluation procedures.) Testing costs include the cost of conducting biological testing on the 2 samples having chemical concentrations between the SL and ML guideline values.

Total Sampling Cost:	$ 5,220.00
Total Testing Cost:	14,544.00
Total Sampling and Testing Cost:	$ 19,764.00
Average Sampling Cost per Core:	$ 580.00
Average Testing Cost per Sample:	2,424.00
Average Cost per cy:	0.62/cy

2. Seattle Harbor Navigation Project, Maintenance Dredging, West Waterway

Project Description: The Seattle Harbor Navigation Project maintenance dredging of the West waterway is scheduled to remove shoaled channel sediment along the Pidgeon Point Reach of West Waterway and Duwamish River up to a point just below the upper turning basin. Project depths are characterized as shallow (average depths are below 4 ft), although some shoals will be dredged to 9 ft. A total of eight reaches will be worked with approximately 83,000 cy of material being dredged for the entire project including shoals containing between 1,000 cy and 30,000 cy of material. Sediment analyzed for this project was collected in May and June 1986.

Costs of Sampling and Testing as Conducted under the Fourmile Rock Interim Criteria: Most of the coring was accomplished above 4 ft., although two shoals were sampled below 4 ft. A minimum of 2 cores were taken for every reach that was to be dredged. For one reach (estimated volume of 1,000 cy) this meant a core was taken for every 500 cy of material. For another reach, a total of six cores were taken; each core characterized 5,000 cy of material. In all, 24 cores were taken for the entire 83,000 cy. On average, each core characterized approximately 3,500 cy.

Sample compositing was based on several criteria including: the volume associated with a particular reach, (2) the proximity of one reach to another,

and (3) the expected depth to be dredged. Two reaches (total of 4 cores, representing 3,500 cy of material) which are situated in cloce proximity to one another in Pidgeon Point reach were composited to one sample for physical, chemical, and biological analysis. Ten vibracore samples taken from a single reach representing 30,000 cy of material were composited into 3 samples (two representing depths less than 4 ft depths and one representing depths greater than 4 ft.).

Each of the 12 composited samples were subjected to the following physical, chemical, and biological analyses:

Physical Analysis -- Grain Size
Sulfide

Chemical Analysis -- Metals
Polyaromatic Hydrocarbons
Phenols
Chlorinated Aromatic Hydrocarbons
Phthalates
Pesticides
Miscellaneous Compounds

Biological Testing --Amphipod Bioassay
Microtox Bioassay
Macoma Bioaccumulation

Costs for sampling and testing are presented below. Sampling and compositing required 3 days including mobilization and demobilization of crew and equipment.

Sampling Costs:	$ 6,072.00
Testing Costs:	56,056.00
Total Costs:	62,128.00

Average Sampling Cost per Core:	$ 253.00
Average Testing Cost per Sample:	4,671.00
Average Cost per cy:	0.81/cy

Projected Sampling and Testing Requirements and Estimated Costs Under PSDDA:
The West waterway maintenance work would require a minimum of 17 cores to adequately characterize the project sediments. However, two cores would be taken per station to collect enough sediment to conduct chemical and biological tests. Therefore, a total of 34 cores would be needed. Similar sampling requirements were also used for the project as it was conducted

(e.g., of the 24 samples collected, 12 were duplicates to collect additional sediment). Under PSDDA, the 34 cores would have been composited to 15 samples.

The PSDDA testing requirements are similar to those undertaken for this project. In addition to the tests conducted, PSDDA would include a juvenile bivalve test, bivalve larvae or echinoderm larvae test, and the need to only conduct biological testing if the bulk chemical contaminant levels are above the SL and below the ML guideline values. Chemical test unit costs are estimated at $1,345/sample; biologiccal test unit costs at $2,800/sample.

Estimated sampling and testing costs that might be expected under PSDDA requirements are presented below. It was estimated that the increase in coring would have required 2 extra days including mobilization and demobilization. Testing costs include physical and conventional chemical analysis and chemical testing for all 15 samples. Comparison of the project chemistry data to the SL and ML guideline values indicates that 2 of the 15 samples would not require biological testing. One sample would be below the SL guideline values, while the other sample would have chemical concentrations exceeding the ML values.

Sampling Costs:	$ 8,602.00
Testing Costs:	74,610.00
Total Sampling and Testing Costs:	$ 83,212.00
Average Sampling Cost per Core:	$ 253.00
Average Testing Cost per Sample:	5,547.00
Average Cost per cy:	1.00/cy

3. Seattle Harbor, Upper Turning Basin, Maintenance Work

Project Description: The upper turning basin on the Duwamish River serves as a settling basin for sediment transported by the river, particularly in periods of high run-off and particlulate loading and as the uppermost turning point for ships. Sedimentation in the turning basin requires that it be dredged nearly every year. Material reaching the turning basin is typically free of chemicals that are of concern in dredged material since few source inputs exist above the basin. As such, the turning basin acts to "trap" clean sediment prior to passing through the industrialized areas of the Duwamish that exist downstream. The net effect of the turning basin is to reduce the need for frequent downstream dredging of material that may adsorb contaminants from the various source inputs found in the area.

Sediment analyzed for this project was collected in September 1985. Approximately 137,000 cy of material were dredged from the project area.

Sampling and Testing Scheme as Conducted under Fourmile Rock Interim Criteria: Nineteen (19) cores were taken to evaluate the material in this project (representing approximatley one core for every 7,250 cy of material). These 19 cores were composited into 8 samples which were used to chemically and biologically characterize the material to be dredged. In most cases, the entire core (up to 6 ft. in depth) was composited with other cores, with no spliting of the core across dredging or sediment horizons. In one case a core was split at the 4 foot horizon; with one section not composited with other cores, the other section composited with three other cores. The compositing scheme used in this evaluation resulted in each sample representing an average of approximately 17,000 cy of material.

Each of the 8 composited samples was subjected to the following physical, chemical, and biological analyses:

Physical and Conventional Chemical Anlaysis -- Grain Size
Oil and Grease
Total Solids
Volatile Solids
Sulfides

Chemicals of Concern Analysis-- Metals
Polyaromatic Hydrocarbons
Chlorinated Aromatic hydrocarbons
Phthalates
Pesticides
PCB's
Miscellaneous Compounds

Biological Analysis -- 10-day Amphipod Bioassay

Sampling and testing costs are presented below. Sampling required 4 days including mobilization and demobilization of crew and equipment.

Total Sampling Cost:	$ 5,130.00
Total Testing Cost:	33,175.00
Total Sampling and Testing Cost:	$ 38,305.00
Average Sampling Cost per Core:	$ 270.00
Average Testing Cost per Sample:	4,146.88
Average Cost per cy:	$ 0.28/cy

Projected Sampling and Testing Requirements and Estimated Costs Under PSDDA: Under PSDDA, 18 cores would be required to adequately characterize the project area. This represents the minimum number of cores that would have to taken to collect sediment to satisfy the compositing and analysis requirements. The 18 cores could be composited to a minimum of 18 samples. The number of samples required was influenced by both the ranking of the area to be dredged and the depth of sediment to be removed. The upper end of the turning basin is ranked as moderate allowing for greater compositing than allowed in areas ranked high. The rest of the project area is ranked as high, meaning that the volume of sediment characterized by each sample limited the amount of compositing allowed.

The PSDDA physical and chemical testing requirements described earlier were applied to this project. Biological testing included amphipod, juvenile clam, larvae (sediment toxicity only) and microtox tests. Comparison of the existing chemical data to the PSDDA SL and ML guideline values indicate that all sediment samples, except for one sample representing sediment located near the 250+00 section of the Duwamish River, contained chemical concentrations below the screening level values. This means that the sediment represented by those samples with chemical concentration below the guideline values would be considered technically suitable for unconfined, open water disposal without further testing. The one sample having chemical concentrations above the screening level would require biological testing before a decision could be made on technical suitability for unconfined, open-water disposal.

Estimated sampling and testing costs that might be expected under PSDDA requirements are presented below. It was estimated that sampling would have required 4 days including mobilization and demobilization of crew and equipment.

Total Sampling Cost:	$ 4,860.00
Total Testing Cost:	30,942.00
Total Sampling and Testing Cost:	$ 35,802.00
Average Sampling Cost per Core:	$ 270.00
Average Testing Cost per Sample:	1,989.00
Average Cost per cy:	$ 0.26/cy

4. Terminal 30 Expansion Project, Port of Seattle

Project Description: The project was undertaken to extend Terminal 30 to the north of the existing structure. Dredging requirements for this project were defined by the depth and length of the berth required and the angle of repose

for bank construction stability. Dredging was in two sections, one 750 ft. long by 300 ft. wide and the other 200 ft. long by 200 ft. wide. The depth of the berth was -50.0 ft., requiring a dredging depth of -55.0 ft. (mllw) with a 2:1 slope projection. This resulted in a dredging prism that ranged up to 32 ft. below the existing sediment surface. Approximately 135,000 cy of material were dredged. Sediment analyzed for this project was collected in 1984.

Sampling and Testing Scheme as Conducted Under Interim Criteria: In all, 12 cores were taken for both sections of the project area. Because of the depth of coring needed to characterize the project dredging depths, compositing resulted in 31 samples for analyses. In general, compositing was undertaken along similar depth contours. In some instances, where definite sediment horizons appeared in the core, these horizons were analyzed separately without any compositing, further increasing the number of samples.

Each of the 31 composited samples was subjected to the following physical, chemical, and biological analyses:

Physical and Conventional Chemical Anlaysis -- Grain Size
Oil and Grease
Total Organic Carbon
Volatile Solids
Sulfides

Chemicals of Concern Analysis-- Metals
Polyaromatic Hydrocarbons
Chlorinated Aromatic hydrocarbons
Phthalates
Pesticides
PCB's
Miscellaneous Compounds

Biological Analysis -- 10-day Amphipod Bioassay
Oyster Larvae Bioassay

Sampling and testing costs are presented below. Because of the depth of coring, sampling required use of a drilling rig rather than the vibra-core typically used in sample collection. As such, sampling costs incurred in the project are considerbly higher than those incurred in the other case studies.

Total Sampling Cost:	$ 49,750.00
Total Testing Cost:	91,050.00
Total Sampling and Testing Cost:	$ 140,800.00

Average Sampling Cost per Core:	$ 4145.83
Average Testing Cost per Sample:	2601.43
Average Cost per cy:	$ 1.04/cy

Projected Costs using Proposed PSDDA Sampling and Testing Requirements: Under PSDDA, 11 cores would be required to adequately characterize the project area. The represents the minimum number of cores that would have to be taken to collect sediment to satisfy compositing and analysis requirements. The 11 cores would be composited to a minimum of 20 samples. This contrasts to the 31 samples resulting from the project as it was conducted (based on the Port of Seattle's option to do less compositing). The 11 extra samples reflects the presence of definitive sediment horizons in the core samples that affected compositing. It could be assumed that a greater number of samples would be needed if the project were conducted under the PSDDA guidelines, however, the PSDDA agencies will not track sediment horizons and it would still be at the option of the dredger to decide if isolation of sediment horizons is warranted. As discussed in the introduction, isolation of sediment horizons may effectively reduce overall project costs by providing a better definition between material that is technically suitable for unconfined, open-water disposal and material that is not. In applying the PSDDA guidelines no adjustemts in compositing were made for sediment horizons.

The PSDDA physical, chemical, and biological testing requirements described earlier were applied to tnis project. Comparison of existing project chemical data to the PSDDA SL and ML guideline values indicate that only 9 of the 20 sediment samples would require biological testing. Two of the samples were found to have chemical concentrations below the SL, while 9 samples were found to have chemical concentrations above the ML.

Estimated sampling and testing costs might be expected under PSDDA requirements are presented below. Sampling costs included the use of a drilling rig rather than the customary vibracore sampler because of the depth to which sediment had to be sampled. Testing costs include physical and conventional chemical analysis and chemical tesing for all 20 samples and the cost of biological testing for 9 of the 20 samples. It was assumed that biological testing was not conducted on the 9 samples having chemical concentrations above the ML guideline values since the material would not be permitted for unconfined, open-water disposal under 401.

Total Sampling Cost:	$ 45,595.00
Total Testing Cost:	52,100.00
Total Sampling and Testing Cost:	97,695.00
Average Sampling Cost per Core:	$ 4,145.00
Average Testing Cost per Sample:	2,605.00
Average Cost per cy:	0.72/cy

Discussion:

Impacts to Sampling and Testing Costs. The impact of applying PSDDA sampling and evaluation procedures on dredging project cost will depend on project-specific characteristics. Project area ranking, project sediment chemical "quality," dredging prism, and the project-specific requirements under which the project was evaluated can affect sampling and testing costs. In one of the cases studied, sampling and testing costs that would be incurred under PSDDA are 35% higher than actual costs, while in the other cases studied, costs that would be incurred under PSDDA are estimated to be lower than the actual sampling and testing costs (16 to 32% lower) (Table 2).

Reasons for the different outcome of each project are varied. A review of the factors that had an affect on the cost differences is presented in Table 3. The key factors accounting for the differences in costs appear to be (1) differences in the number of cores and samples actually taken and the number that would be required under PSDDA to characterize the project sediments, and (2) differences in average testing cost per sample between actual costs and those expected under PSDDA.

Table 2. Comparison of Sampling and Testing Costs

Difference Project:	Costs Actual:	Costs Estimated Under PSDDA:	% From Actual
Kenmore	$29,065	$19,764	-32%
Seattle Harbor, West Waterway	62,128	83,212	+34%
Seattle Harbor, Upper Turning Basin	38,305	35,802	-6%
Port of Seattle, Terminal 30	140,800	91,170	-31%

The impact of significantly changing the number of cores and/or samples taken to characterize dredged material is illustrated in both the West Waterway and Terminal 30 projects. In the West Waterway project, 24 cores were taken, which were composited to 12 samples. Under PSDDA, the same project would require a minimum of 34 cores and 15 composited samples for analysis. The increase in number of cores taken and samples analyzed resulted in an increase in sampling and testing costs, even though the average per sample cost for testing was estimated to be lower under PSDDA than was incurred. The opposite trend in coring and sampling can be seen in the Terminal 30 project. As conducted, the project resulted in 12 cores and 31 samples, while under PSDDA, only 11 cores and 20 samples would be required. As previously discussed, the large number of samples resulting from this project were primarily due to minimal compositing of the coring material. Sediments associated with this project included definitive sediment horizons that the project proponent chose to analyze separately in order to possibly reduce overall project costs.

The other key factor influencing sampling and testing costs is the cost of characterizing the material for suitability for unconfined, open-water disposal (presented as average testing cost per sample in Table 3). In all of the projects analyzed in this case study, the average testing cost per sample is estimated to be lower under PSDDA than was incurred during the project. Although PSDDA requires a potentially greater amount of testing than required under the Fourmile Rock Interim criteria to characterize dredged material, the tiered testing approach utilized under PSDDA helps to reduce overall testing costs. Use of the SL and ML chemistry guidelines values provides for an early determination of the technical suitability of dredged material for unconfined, open-water disposal (per State 401 guidelines) without the need for evaluating the material using the relatively costly biological testing procedures. The cost effectiveness of the PSDDA testing approach is illustrated in the Upper Turning Basin maintenance dredging project. All sediment samples (except for one) collected in the project area were found to have chemical concentrations that were below the SL guideline values. Under the Fourmile Rock Interim criteria both chemical and biological testing was required on each sample at an average cost per sample of $4,146. Under PSDDA, the samples meeting the SL guideline values would have required only physical and chemical testing at an estimated cost of $1,345 (plus QA/QC). It should be remembered, however, that for those projects having a large portion of samples with chemical concentrations between the SL and ML guideline values, the average cost of testing will be higher under PSDDA than would be seen under the Fourmile Rock Interim criteria. In such cases, where the technical suitability of dredged material for unconfined, open-water disposal is uncertain with chemical information, complete characterization using biological tests will be required.

Table 3. Factors Affecting Sampling and Testing Costs

Cost per Project		Number of Cores:	Number of Samples:	Testing cost per Sample:	Testing cost per cy:
Kenmore:	As Conducted	6	7	3,655	0.91
	Under PSDDA	9	6	2,424	0.62
Seattle Harbor, West Waterway:	As Conducted	24	12	4,671	0.75
	Under PSDDA	34	15	5,548	1.00
Seattle Harbor, UTB:	As Conducted	19	8	4,146	0.28
	Under PSDDA	18	18	1,989	0.26
T30:	As conducted	12	31	2,601	1.04
	Under PSSDA	11	20	2,605	0.72

Impacts to Overall Project Costs. The effects of the PSSDA procedures on total project costs is of prime importance in evaluating the cost impacts of PSSDA to dredging projects. Overall project costs are heavily influenced by the method of disposal required for the dredged material. In general, it costs much more to dispose of dredged material at a confined site than it does to dispose of the material unconfined, at an open water disposal site. E.g., currently in the Puget Sound region, upland disposal can cost up to over $19 + dollars per cubic yard (at existing landfills), while open water disposal costs $2-3 per cubic yard depending on how far the project is from the disposal site. Therefore, the more material from a project required to be placed at confined sites the greater the overall project costs will be.

An analysis presented in Evaluation Procedures Technical Appendix suggests that PSDDA, while resulting in higher costs for dredged material evaluation (e.g., sampding and testing costs) for some projects, will overall lead to lower dredged material disposal costs. The main reason for this is that the

Fourmile Rock and Puget Sound Interim criteria under which dredging projects in Puget Sound are currently evaluated would require more material to be disposed at confined sites than would be required under PSDDA.

The Seattle Harbor Navigation maintenance work at the upper turning basin was evaluated to determine the impact of PSSDA testing requirements and interpretation guidelines on total project costs (e.g., costs of dredging and disposal). As the project was conducted, approximately 137,000 cy of material were dredged. Of this, 33,637 cy were placed in a confined disposal site at a cost of $191,248 ($5.69/cy), while the remaining volume (103,598 cy) was disposed at an open water site at a costs of $253,815 ($2.45/cy). This resulted in project costs (for dredging and disposal) of $445,063.

Results of the chemical analysis of the project sediments indicate that under PSDDA, a majority of the sediment would have been found suitable for unconfined open-water disposal without biological testing (e.g., sediment chemical conentrations uere below the SL guideline values). Of the total of 137,000 cy of material dredged, approximately 16,818 cy of material would require biological testing before a decision could be made on the technical suitability of the material for unconfined, open-water disposal. Review of the available bioasssay testing data indicate that all of the material might have been allowed for disposal at the open water site. If all the material would have been allowed for unconfined open-water disposal, cowts of dredging and disposal would have been $336,226, a potential project cost reduction of $108,837. If the 16,818 cy of material requiring biological testing exceeded the guidelines and required confined disposal, costs of dredging and disposal would have been $390,713, a potential project cost reduction of $54,350.

January 1988 rev.

EXHIBIT 1

DETAILED CALCULATIONS FOR ESTIMATING SAMPLING AND TESTING COSTS FOR TERMINAL 30 UNDER PSDDA EVALUATION PROCEDURES

The determination of sampling and testing requirements that would be needed under PSDDA, required an evaluation of the project dredging prism in order to allocate coring and sample compositing, and the use of existing project chemistry data to estimate the probable chemical concentrations of the samples resulting from the PSDDA compositing scheme. Once these two steps were completed, then projected costs of conducting PSSDA evaluation procedures could be applied as appropriate. Although this exhibit presents approach used to determine sampling and testing costs for tha Terminal 30 project, a similar approach was used with all the project presented in the case study.

Estimation of Coring and Sampling Requirements Under PSDDA. The project dredging prism needed to be determined in order to allocate coring and sampling requirements. To determine the dreding prism, construction plans for the project area were used (Figures 1, 2 and 3). In addition to determining dredging prism, the volume of sediment associated with the 0 to 4 ft. depth and the volume of sediment associated with depths greater than 4 ft must be determined in order to allocate coring and sample compositing. For the Terminal 30 project, the following assumptions were made in determining the dredging prism and the number of cores required and sample compositing allowed. It was assumed that:

* the Terminal 30 project included dredging at the north end of the existing terminal space and dredging at Pier 28.

* the project volume of 135,000 cy included both the Terminal 30 and Pier 28 dredging areas.

* both the Terminal 30 and Pier 28 dredging areas could be generally described as being rectangular in shape, with Terminal 30 having dimensions of 750 ft by 200 ft and with Pier 28 having dimensions of 200 ft by 200 ft.

* both dredging areas have a dredging prism represented by the cross-sectional view in Figure 3 (Section A).

* both the Terminal 30 and Pier 28 dredging areas were dredged to similar overall depths and these depths were greater than 4 ft.

* the slope of the bank to be dredged, as well as the slope of the bank following construction were the same for the Terminal 30 and Pier 28 areas (Figures 1 and 3).

From these assumptions volumes associated with each section of the dredging prism and coring and compositing requirements could be determined. Volumes of material associated with each section of the dreding prism was determined as follows:

Total volume of material associated with project is 135,000 cubic yards (cy). The volume of material associated with 0 to 4 ft. depth of prism for each dredging area was determined by calculating the volume having the dimensions of the dredging area and a depth of 4 ft. This volume was then adjusted to units of cubic yards. For the lerminal 30area the volume would be: (750 ft x 300 ft x 4 ft) / (27 ft/cy) = approximately 33,000 cy. For the Pier 28 area, the volume would be: (200 ft x 200 ft x 4 ft) / (27 ft/cy) = 6,000 cy. Therefore, of the total volume to be dredged (135,000 cy), 39,000 cy (33,000 cy + 6,000 cy) was associated with the 0 to 4 ft section of the prism. This leaves approximately 96,000 cy associated with the dredging prism with depths greater than 4 ft.

The volume of material associated with dredging depths greater than 4 ft. was determined by allocating a portion of the total remaining volume (96,000 cy) to each of the dredging areas based on the percentage of the total project surface area associated with each of the dredging areas (this method of allocation is appropriate since it is assumed that the overall dredging depth of each dredging area was approximately the same and reflects the volume of material that would be found in the dredging prism). The percentage of the total surface area for Terminal 30 dredging area is 85%, while for the Pier 28 area it is 15%. Therefore the volume of material to be dredged form the greater than 4 ft depth section of the prism for the Terminal 30 dredging area is: 96,000 cy (.85) = 82,000 cy. For the Pier 28 area, the volume is: 96,000 cy (.15) = 15,000 cy.

To summarize, the volumes allocated to each section of the dredging prism are as follows:

Area:	0 - 4 ft:	4 + ft:	Total
Terminal 30	33,000 cy	81,000 cy	115,000 cy
Pier 28	6,000 cy	15,000 cy	21,000 cy

The number of core sections that would be required for each of the dredging prisms under PSDDA was determined by dividing the volume of material in each prism by the maximum volume of material that can be represented by a single sediment sample (see EPTA for discussign on mangement unit sizes). The Duwamish River is ranked by PSDDA as a high concern area, therefore every 4,000 cy of material to be dredged must be represented by a single core section. The number of cores for the Terminal 30 dredging area would be 9

core sections for the 0 to 4 ft prism (33,000 / (4,000 cy/core section)) and 21 core sections for the greater than 4 ft prism section (82,000 / 4,000). The number of core sections for the Pier 28 dredging area would be 2 core sections for the 0 to 4 ft prism (6,000 / 4,000) and 4 core sections for the greater than 4 ft prism section (15,000 / 4,000).

As described for sediment sampling, the number of analysis that would be required under PSDDA was determined by dividing the volume of material in each prism by the maximum amount of material that can be represented by asingle analysis (see EPTA for a discussion of analysis requirements). The minimum number of samples allowed in the Terminal 30 dredging area would be 9 samples for the 0 to 4 ft section (33,000 cy / 4,000 cy/analysis) and 7 samples for the greater than 4 ft section of the prism (82,000 cy / 12,000 cy/analysis). Tje minimum number of samples allowed in the Pier 28 dredging area would be 2 samples for the 0 to 4 ft section (6,000 cy / 4,000 cy/analysis) and 2 samples for the greater than 4 ft section (15,000 cy / 121,000 cy/analysis).

Following determination of the number of core sections and number of samples required for analysis, the number of cores needed to provide sufficient core sections to be composited into the minimum number of analysis for testing can be determined. The factor limiting the munimum number of cores that need to be taken is the number of 0 to 4 ft core sections needed to meet minimum coring and analysis requirements. For the Terminal 30 project, this would be 11 cores (9 for the Terminal 30 dredging area and 2 for the Pier 28 area).

Determination of Testing Requirements for Each Sample. As discussed in Chapter 2 of EPTA, the amount of testing to which a sedimenv sample is subjected to (as well as the cost of testing the sample) is largely dependent on a comparison of the chemical concentrations found in the sediment to the screening level (SL- and maximum level (ML) guideline values. In order to estimate the cost of testing project samples for suitability for unconfined, open-water disposal under PSDDA, existing chemical concentrations associated with the original project evaluation had to be applied to the PSDDA-derived samples. In the case of the Terminal 30 project the amount of coring and analysis of the chemical analysis of the coring sections was such that the data could be applied in a fairly straight forward manner to develop the PSDDA estimates. The 9 cores taken from the Terminal 30 dredging area (Figure 1) were assumed to be in the same location and drilled to the same depth as would be required under PSDDA. Because of this, the chemistry data resulting from analysis of the project samples was used to estimate the chemical concentrations that would have been from the PSDDA composited samples. In much the same way, the 2 cores taken in the Pier 28 dredging area were used to estimate the chemical concentrations for the required PSDDA samples.

The existing coring sections and chemistry data were applied to the proposed PSDDA samples in the following manner:

* Cores HC-6 through HC-14 (Figure 1) and accompanying chemistry data were used to characterize the Terminal 30 dredging area.

*Chemical data from core sections HC-6A, HC-12A, and HC-8A were used to characterize the 0 to 4 ft. depth of dredging for the Terminal 30 dredging area.

*Chemical data from core sections HC-6B, HC-7B, HC-9B, HC-10B, HC-12B, and HC-13B were used to characterize the 4 to 10 ft. depth of dredging for the Terminal 30 dredging area.

*Chemical data from core sections HC-6C/D, HC-7C, HC-9C/D, HC-10B/C, HC-12C/D/E, and HC-13C were used to characterize the 10 to 16 ft. depth of dredging for the Terminal 30 dredging area.

*Chemical data from core sections HC-10D and HC-13D were used to characterize the 16 to 20 ft. depth of dredging for the Terminal 30 dredging area.

*Chemical data from core sections LC-7E/F, HC-10E, and HC-13E were used to characterize depths greater than 20 ft. for the Terminal 30 dredging area.

*Cores 28-A and 28-B and accompanying chemistry data were used to characterize the Pier 28 dredging area.

*Chemical data from core sections 28-A and 28-B were used to characterize the 0 to 4 ft. depth of dredginc for the Pier 28 dredging area.

*Chemical data from core section 28-B were used to characterize the 4 to 8 ft. depth of dredging for the Pier 28 dredging area.

*Chemical data from core section 28-A-W, 28-B-C, and 28-B-D were used to characterize depths greater than 8 ft. for the Pier 28 dredging area.

The results of the sediment chemical characterization and comparison to the SL and ML guideline values indicated that 2 out of the 20 PSDDA samples would have met the SL guideline values, 9 samples would have exceeded the ML values, and 9 would have been between the SL and ML guideline values. Therefore, of the 20 samples chemically analyzed 9 of the samples (those with chemical concentrations between the SL and ML guideline values) would have required biological testing before a decision on the technical suitability of the material for unconfined, open-water disposal can be made.

For the 2 samples with chemical concentrations below the SL guideline values, material associated with these two samples would be considered technically suitable for unconfined, open-water disposal without biological testing. For tne 9 samples with chemical concentrations above the ML values, material associated with these samples would have been considered technically unsuitable for unconfined, open-water disposal per State 401. In such situations the dredging proponent could undertake biological testing of the sediment samples to determine suitability of the material per 404. It was assumed for the purpose of the Terminal 30 project that the Port of Seattle would not have opted to conduct biological testing on sediment samples with chemical concentrations above the ML because of the State 401 interpretation of the ML guideline values.

Estimation of Sampling and Testing Costs Expected Under PSDDA. Following determination of the dredging volume and prism, allocation of minimum coring and sampling requirements, chemical characterization of the samples, and a determination of the number of samples that would require biological tersting, sampling and testing costs that would be expected if the PSDDA evaluation procedures were used can be estimated. The per unit sampling and testing costs presented below were used in estimating the cost of conducting PSDDA required sampling and testing on the Terminal 30 project. In most cases these same per unit costs were also used in estimating the sampling and testing costs of the other cases presented in this study. The major exception is the cost of coring. In the Terminal 30 project, a drilling rig was required to collect the core material and the costs associated with using the rig were applied to the project. Coring costs for all other projects in the case study were based on using a vibracore to collect the sediment samples.

Per Unit Costs For Sampling And Testing

Activity	Per Unit Cost ($)
Coring (a)	$4,145.00
Chemical Characterization	$1,345.00
Biological Testing (b)	$2,800.00

(a) Coring costs for most projects are typically $200.00 to 600.00 per core when a vibracore is used for sediment collection.

EXHIBIT 1 (con.)

January 1988 rev.

Estimated sampling and testing costs for the Terminal 30 project would be:

11 cores @ $4,145.00/core	$45,595.00
20 samples chemically analyzed @ $1,345.00/sample	$26,900.00
9 samples biologically tested @ $2,800/sample	$25,200.00
Total	$97,695.00

January 1988 rev.

EXHIBIT E

SUMMARY OF REPORTS PREPARED FOR OR RELEVANT TO THE EVALUTION PROCEDURES WORK GROUP

jointly prepared by

Shapiro & Associates, Inc.,
Tetra Tech, Inc., and
PTI Environmental Services

CONTENTS

Exhibit		Page
E.1	PUGET SOUND DREDGED DISPOSAL ANALYSIS PLAN OF STUDY	E-3
E.2	DESCRIPTION OF EVALUATION PROCEDURES WORK GROUP TASKS CONDUCTED IN PHASE I	E-6
E.3	REGIONAL ADMINISTRATIVE DECISION PAPER	E-9
E.4	PRELIMINARY FINDINGS REPORT	E-11
E.5	DREDGED MATERIAL INVENTORY SYSTEM	E-13
E.6	DECISION-MAKING FRAMEWORK DEVELOPED WITH COMMENCEMENT BAY DATA	E-15
E.7	ILLUSTRATED GUIDE TO DREDGED MATERIAL DISPOSAL	E-17
E.8	PATTERN RECOGNITION REPORT	E-18
E.9	SEDIMENT QUALITY VALUES REPORT	E-22
E.10	MICROLAYER REPORT	E-27
E.11	PROTOCOLS FOR BIOASSAYS	E-29
E.12	PROTOCOLS FOR NAVIGATION AND SITING	E-31
E.13	PROTOCOLS FOR ANALYSIS OF METALS	E-37
E.14	PROTOCOLS FOR ANALYSIS OF ORGANIC COMPOUNDS	E-39
E.15	REPORT ON GUIDELINES FOR CONFINED DISPOSAL	E-41
E.16	COMPARATIVE RISK ANALYSIS AND REPORT WORKSHOP	E-44
E.17	CHEMICAL AND BIOLOGICAL MONITORING OF DISPOSAL SITES	E-47
E.18	COST ANALYSIS FOR TESTING AND DREDGED MATERIAL MANAGEMENT	E-49
E.19	REVIEW OF CANADIAN REGULATIONS FOR DISPOSAL OF DREDGED MATERIAL IN OPEN WATER	E-52
E.20	WATERWAYS EXPERIMENTAL STATION DRAFT PRETREATMENT REPORT	E-54

CONTENTS (con.)

Exhibit		Page
E.21	DREDGED MATERIAL ALTERNATIVE ELECTION STRATEGY (DMASS) REPORT	E-55
E.22	NOAA SUBLETHAL BIOASSAY REPORT	E-57

EXHIBIT E.1 PUGET SOUND DREDGED DISPOSAL ANALYSIS PLAN OF STUDY

TITLE: Puget Sound Dredged Disposal Analysis Open-water Unconfined Disposal Sites Plan of Study (Preliminary Scope). Revised Plan of Study -- Appendix A

PREPARER: Puget Sound Dredged Disposal Analysis (PSSDA)

REPORT DATE: Plan of study 20 March 1985. Revised plan of study 2 May 1986

STUDY PURPOSE

The purpose of this document is to provide a plan of study addressing the need for unconfined open-water disposal of dredged material and the scope, goal, and objectives for conducting an analysis of Puget Sound open-water dredged material disposal sites and associated disposal evaluation procedures. The strategy is for cooperative planning by the U.S. Army Corps of Engineers (COE), Seattle District; U.S. Environmental Protection Agency (EPA), Region X; Washington Department of Natural Resources (WDNR); and the Washington Department of Ecology (Ecology). These studies will be used to prepare environmental impact statements (EIS) providing the basis for subsequent implementation actions by the state of Washington and EPA regarding designation and use of Puget Sound open water disposal sites.

SUMMARY OF RESULTS AND CONCLUSIONS

This plan of study identifies PSSDA's scope, goal, and objectives. The following are PSDDA objectives:

1. Public Participation. Public involvement would be sought during the scoping and conduct of the analysis in accordance with NEPA/SEPA procedures.

2. Disposal Sites. Following a review of existing state disposal site guidelines, new criteria for selecting unconfined open-water disposal sites would be developed and literature review of all pertinent information conducted. Criteria would be applied to Puget Sound using existing information to determine areas suitable for disposal sites. preferred disposal sites would be selected by applying the criteria to the characterization data.

3. Disposal Evaluation Procedures. Chemical and biological evaluation procedures would be developed for assessing the acceptability of dredged material

proposed for open-water disposal. Alternative evaluation procedures and alternative methods of disposal would be considered.

4. Site Management Plan. Open-water dredged disposal site management plans would be developed covering disposal site management responsibilities, dredged sediment testing requirements, and operational requirements of the users. Alternative management practices would be considered.

5. Report/EIS. For each of two study phases joint NEPA/SEPA Draft and Final Environmental Impact Statements, combined with a report and appropriate appendices would be prepared, distributed for public review, and filed with EPA. The Corps would have joint lead responsibility with WDNR for the preparation of the EIS's. The EPA would be a cooperating Federal agency and Ecology a cooperating State agency.

Work tasks were developed for each of these major objectives.

PSDDA would be undertaken as a sound wide study in two overlapping phases. The first phase would include Central Puget Sound (Everett to Tacoma) and take about 2 yr to complete. Phase II would cover the balance of Puget Sound beginning about 1 yr after the start of Phase I and also take about 2 yr to complete. The total study would be completed in approximately 3 yr. A separate NEPA/SEPA document is planned for each phase.

An organization and management plan includes development of numerous committees. A policy review committee and technical steering committee will provide review of PSSDA progress and products. The Disposal Site Work Group (DSWG)'s goal will be to locate open water unconfined dredged material disposal sites that are environmentally acceptable and economically feasible. The DSWG will accomplish tasks to complete this objective using technical support from agencies and/or consultants. A Disposal Evaluation Procedures Work Group EPWG will be formed to accomplish a goal to develop chemical and biological testing and test evaluation procedures for dredged material assessment. The EPWG will accomplish all tasks under this PSSDA objective using technical support from agencies and/or consulting firms. A Management Plan Work Group (MPWG) will develop a management plan for each of the open water disposal sites. In addition to these groups, a full time study director will be assigned by the Lead Agency to PSSDA.

PSDDA would have its own public involvement activities to insure that the public has a meaningful role in the process. Objectives and key elements are outlined and interest groups identified for this aspect of the project.

PSDDA will complete considerable coordination during this process with numerous public entities. Implementation, budget, and a schedule of events are also outlined in this plan of study.

Appendix A is a brief description of the major tasks outlined in the plan of study. In addition to the task and subtask descriptions, the budget projects for several fiscal years are detailed. The budget breakdown includes dollar allocations for contract and in-house work and a proposed work schedule (start and completion dates). This document includes tasks that were intended for completion prior to the date of this document.

EXHIBIT E.2 DESCRIPTION OF EVALUATION PROCEDURES WORK GROUP TASKS CONDUCTED IN PHASE 1

TITLE: Task Outline Description -- Phase I

PREPARER: Puget Sound Dredged Disposal Analysis -- Evaluation Procedures Work Group

REPORT DATE: 10 March 1986

STUDY PURPOSE

The objective of this four page report is to identify tasks to be completed during Phase I to meet the goal of the Evaluation Procedures Work Group (EPWG). EPWG's goal is to develop chemical and biological testing and test evaluation procedures for dredged material assessment.

SUMMARY OF RESULTS AND CONCLUSIONS

Fifteen tasks were identified (Task 3a to 3o). For each task the description discusses the types of issues, the completion schedule, who will complete the task, and amount of contract funds involved.

Shown below are summaries of the tasks outlined by EPWG:

Task 3a: Basis and Scoping of the Evaluation Procedures. The EPWG, with input from the invited and general public, has defined the overall goal of the evaluation procedures and selected the approach (the basis) to implementing that goal. The preliminary findings report will be completed in May 1986 by the Work Group.

Task 3b: Inventory of Dredged Material Sources. Dredged material sources will be characterized by synthesis of existing information. A review of the rules and regulations pertaining to open water, unconfined disposal of dredged material in the Strait of Juan de Fuca will also be conducted as part of this task. This report will be completed in April 1986 by Cooper Consultants, Inc., and Envirosphere Company.

Task 3c: Improve and Quantify Interpretation of Test Results. Existing evaluation procedures will be refined to improve interpretation of test results by application of available information. A draft

of this report will be issued in May 1986 by the U.S. Army Engineer Waterways Experiment Station. This report also addresses Task 3d.

Task 3d: Resolve Mass Loss, Confinement, and Non-marine Issues. Existing evaluation procedures will be revised to resolve and incorporate known dredged material disposal issues by application of existing information and consensus development.

Task 3e: Identify Contaminants of Concern and Incorporate Conventional Contaminants. Testing procedures and interpretation for assessing disposal impact of "conventional pollutants" (e.g., COD, sulfides, ammonia, turbidity, etc.) will be developed. State water quality standards will be incorporated into the interpretation framework. This report will be completed in April 1986 by Resources Planning Associates and Tetra Tech and includes the results of Tasks 3f and g.

Task 3f: Review and Evaluate Current Information on Sediment Quality Values and "Apparent Effects" Contaminant Levels. Available synoptic chemical and biological data from the Puget Sound will be reviewed to estimate "apparent effects levels" for measured contaminants.

Task 3g: Dredged Material Risk Analysis. FDA standards, EPA carcinogenic risk values for priority pollutants and EPA Acceptance Daily Intake values for noncarcinogenic priority pollutants will be used to develop human health risk assessment guidelines for interpreting the results of bioaccumulation tests.

Task 3h: Protocol Development and Quality Assurance/Quality Control. The method protocols for the dredged material tests recommended by the evaluation procedures will be defined by application of existing information and concensus development where necessary. This task will be completed for metals/positioning and organics/lethal bioassays in May 1986 and for sub-lethal bioassays in August 1986 by Resources Planning Associates/ Tetra Tech and others.

Task 3i: Cost Analysis of the Evaluation Procedures. The information from the dredged material inventory will be used to assess the cost potentially resulting from various alternative evaluation procedures. RPA and Tetra Tech will complete this task in August 1986.

Task 3j: Regional Administrative Decisions for the Evaluation Procedures. Completion of the evaluation procedures will require a diverse array of decisions that are partially scientific and partially administrative. Available scientific information and concensus development synthesized under the previous tasks will be used in making the final administrative decisions. A preliminary findings report will be completed in May 1986 by the Work Group.

Task 3k: Design and Selection of Confinement Options. Guidance for selection of the appropriate contaminant confinement, control or treatment options will be provided for confined disposal in aquatic (capped), upland and nearshore (intertidal) sites. The U.S. Army Engineer Waterways Experiment Station will complete this task by May 1986.

Task 3l: Monitoring Plan for Open Water Disposal Sites. A plan specifying monitoring techniques, monitoring frequency, and remedial response to monitoring indications, will be prepared to address the potential chemical effects to biological resources that may occur at the open-water disposal sites. The Work Group will complete this task in June 1986.

Task 3m: Sea Surface Microlayer Contamination. A literature search will be conducted to investigate the potential for dredged material to contribute to contamination of the sea surface microlayer. This task will be completed by Evans Hamilton and Battelle in March 1986.

Task 3n: Technical Appendix. A preliminary findings report will be prepared in May 1986 to encourage public and agency review of results and decisions to date. This will be completed in late 1986.

Task 3o: Work Group Support and Management. Staff time for each of the four agencies to attend work group meetings is included in this task.

January 1988 rev.

EXHIBIT E.3 REGIONAL ADMINISTRATIVE DECISION PAPER

TITLE: Regional Administrative Decisions

PREPARER: Puget Sound Dredged Disposal Analysis - Evaluation Procedures Work Group (EPWG)

REPORT DATE: 17 October 1985

STUDY PURPOSE

Completion of the evaluation procedures will require a diverse array of regional decisions that are partially scientific and partially administrative. These "regional administrative decisions" include:

- Determining the quality of dredged material that will be allowed at the unconfined, open-water disposal sites
- Defining the size of a dredged material management unit
- Deciding on the acceptability of mixing and dilution as a management tool
- Identifying the reference area to be used for dredged material evaluations.

The Waterways Experiment Station (WES) and EPWG will identify necessary RAD to ensure that the evaluation procedures are complete and address all appropriate aspects of dredging and dredged material disposal in Puget Sound.

SUMMARY OF RESULTS AND CONCLUSIONS

This document outlines the regional administrative decisions to be considered; these are grouped into general RAD, aquatic RAD, and upland RAD. Within each group several questions are proposed for the consideration of EPWG and WES. General RAD include initial assessment of sediment and sampling and analysis protocol. Within each of the aquatic and upland RAD more specific questions are raised addressing environmental concerns, tests, and test interpretation.

The overview of the RAD must be kept in the proper perspective with the EIS Alternatives, references or controls, mass loading/loss of contaminants into the Puget Sound, and the overall goal for the Sound. Other possible RAD to be considered by EPWG may include site selection testing vs. site acceptability testing.

Alternatives to be addressed in the PSDDA EIS are appended to this report. The alternatives include:

I. No open-water, unconfined disposal of dredged material

II. Alternative types of dredged material to be discharged in unconfined, open-water disposal sites

III. Alternative unconfined, open-water disposal site locations.

EXHIBIT E.4 PRELIMINARY FINDINGS REPORT

TITLE: Puget Sound Dredged Disposal Analysis Preliminary Findings Report

PREPARER: U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, Washington Department of Natural Resources, and Washington Department of Ecology

REPORT DATE: April 1986

STUDY PURPOSE

This document was issued as part of the Puget Sound Dredged Disposal Analysis (PSDDA) News, Issue Number 2. The document reflects the rationale behind and some result of technical studies, identifies some of the key issues and provides tentative conclusions regarding those issues. Contents of the report include a description of the PSDDA approach and each of the work groups: disposal site work group (DSWG), evaluation procedures work group (EPWG), and management plan work group (MPWG). The preliminary findings report was given public review so that PSDDA could be as responsive as possible to the concerns of the public.

SUMMARY OF RESULTS AND CONCLUSIONS

The PSDDA study, which began in April 1985, is being conducted in two, 2-yr long, overlapping phases. Phase I deals with the Central Region (Everett, Seattle, and Tacoma) and Phase II covers the balance of Puget Sound. The goal of PSDDA is to provide the basis for adopting environmentally safe publicly acceptable guidelines for unconfined, open water disposal of dredged material, and to provide Sound-wide consistency and predictability. The PSDDA studies and resultant EIS, covering disposal alternatives and their impacts, will provide the basis for subsequent implementation actions.

The objectives of PSDDA are as follows:

- To identify acceptable unconfined open water disposal sites
- To define acceptable evaluation procedures for dredged material to be placed at those sites
- To develop site use management plans.

Summary. Three work groups have been formed to address the PSDDA objectives with staff from the four PSDDA agencies servicing on each work group. The following are findings and tentative conclusions of the work groups based on the results to date of these studies and work group discussions.

Disposal Site Work Group. The goal of the DSWG is to locate open water unconfined dredged material disposal sites that are environmentally acceptable and economically feasible. Disposal site use restrictions, and future monitoring of physical/biological parameters are also being addressed by DSWG. A three step screening process was used to select preferred and alternative disposal sites, these included:

1. Develop site selection factors based on EPA's "Guidelines for Specification of Disposal Sites for Dredged or Fill Material" and Washington State Law

2. Review existing information and select potential disposal siting areas called "Zones of Siting Feasibility" (ZSF)

3. Select preferred and alternative disposal sites within ZSF.

This three-tiered selection process is supplemented with modeling studies and field checking studies. A disposal model and current model are used to simulate the behavior of a dredge material being disposed. Field studies include remote ecological monitoring of the seafloor, sediment sampling, current meter studies, and selected parameter monitoring studies.

Evaluation Procedures Work Group. The goal of the EPWG is to develop chemical and biological testing and evaluation procedures for dredged material assessment. These procedures will allow open water, unconfined disposal to occur in an environmentally safe manner by avoiding unacceptable adverse effects to human and environmental health. In order to determine "acceptable" dredged material, categories of dredged material have been developed based on contaminant concentrations and potential biological effects; these categories include:

I. No chemical effects
II. Minor chemical effects
III. Moderate chemical effects
IV. Major chemical effects.

Management Plan Work Group. The MPWG is developing a management plan for each of the open water disposal sites. Issues to be addressed in the plan include permit-compliance monitoring, positioning at the dumpsite, shoreline jurisdiction, and regional dumpsites.

EXHIBIT E.5 DREDGED MATERIAL INVENTORY SYSTEM

TITLE: Users Manual -- Puget Sound Dredged Material Inventory Data Management System

PREPARER: Envirosphere Company for Cooper Consultants, Inc./U.S. Environmental Protection Agency -- Region X

REPORT DATE: 1986.

STUDY PURPOSE

The overall objective of this report was to inventory and characterize the sources of dredged material derived from dredging activities in Puget Sound to provide the quantity and characteristic data required by PSDDA. All of this information was collected into a database.

SUMMARY OF RESULTS AND CONCLUSIONS

The dredged material database has been developed using dBASE III relational database management software. Data sources used for compilation of dredged material information included Army Corps of Engineers (COE) disposal of dredged materials permits for non-Federal projects and EPA summary records. In addition, projections of dredging needs of Puget Sound ports over the next 10 yr, and COE maintenance dredging needs and proposed new projects were compiled. Where identified, the projected volumes, project locations, and disposal locations were entered into the database. At present, the completeness of the records search conducted relies on the completeness of the permit listings provided.

The database has been designed to handle three basic types of information. These include: 1) descriptive, location, and volume data; 2) chemistry data; and 3) bioassay data. These data have been organized into four separate files; one for general data, one for bioassay data, and two for chemistry data. The files are indexed by permit number,other common entries, and referenced to each other. This report also discusses the hardware and software required to use the dredged material data base.

The report includes user instructions explaining program initiation, data entry instructions, data entry screens, data checking, databased query and reporting, data backup, and database modifications. The main menu options for the dredged material database are:

1. Search the data files for specified records
2. Identify the records of a selected data file
3. Print all records of selected data file

4. Browse the records of a selected data file

5. Edit a record of a selected data file

6. Append a record to a selected data file

7. Reindex all index files.

There are four appendices to this report. Appendix I is the Dredge Material Inventory (DMI) file and program structure. Appendix II is a listing of project type, waterway, and disposal location codes. Appendix III contains a copy of all the data compilation forms. All the dBASE program listings are found in Appendix IV.

January 1988 rev.

EXHIBIT E.6 DECISION-MAKING FRAMEWORK DEVELOPED WITH COMMENCEMENT BAY DATA

TITLE: Decision-making Framework for Management of Dredged Material: Application to Commencement Bay, Washington. Technical Report D-86

PREPARER: U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

REPORT DATE: July 1985; revised report May 1986

STUDY PURPOSE

The purpose of this study is to develop a decision-making framework for environmental assessment of dredged material based on technically appropriate tests and scientifically sound interpretation of test results. The objective is to describe a framework that indicates which type of disposal should be considered for a given dredged material, and when restrictions or disposal are warranted.

SUMMARY OF RESULTS AND CONCLUSIONS

This report developed a decision-making framework for dredged material management that is based on the results of technically sound test protocols. The decision-making 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, confined nearshore 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. This report outlines the appropriate types of tests and the environmental interpretation of the results. 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 determine what treatment and control methods are warranted to dispose of one or more contaminated sediments in an environmentally acceptable manner.

Testing protocols are described as they are related to the physicochemical conditions posed by aquatic and upland disposal. Issues discussed in the aquatic disposal section include chemical evaluations, biological evaluation, and mass loading assessment in both the water-column and benthic situation.

The upland disposal discussion includes effluent, surface runoff, leachate, plant and animal uptake, and human exposure evaluations. Under each of these alternatives, a discussion is presented of what each test is intended to accomplish and why the information is important. The report discusses test procedures, the rationale for when a test should be applied, and the interpretation of test results.

A decision-making framework incorporating the interpretation of test results is applied to specific sediments from Commencement Bay in a hypothetical case study. Complete hypothetical bulk chemistry results were obtained for three sediment samples. The tentative decisions of Commencement Bay area authorities were to administratively establish numerical guidance for interpreting bioaccumulation. 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; 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 to illustrate the actual implementation of the decision-making framework and should not be construed as factual.

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.

Appendices A and B present details of the decision-making 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. Appendix E contains a procedure for integrating results of chemical and biological tests. Appendix F addresses other issues of national importance: tiering and sequencing of tests; replication and uncertainty; and identification of the contaminants of concern for upland disposal. Appendix E and F are concerned with the Evaluation Procedures Work Group (EPWG) category II dredged material (minor chemical effects on biological resources). In addition to the Appendices, there is an attached paper prepared by the U.S. Army Engineer Waterways Experiment Station discussion Category III — dredge material having moderate chemical effects on biological resources. This paper discusses local issues pertaining to Seattle and Commencement Bay Projects. It includes a brief discussion of approaches, along with the respective merits and limitations of each procedure.

EXHIBIT E.7 ILLUSTRATED GUIDE TO DREDGED MATERIAL DISPOSAL

TITLE: Decision-making for Contaminated Dredged Material Management: An Illustrated Guide

PREPARER: U.S. Army Corps of Engineers, Seattle District and Tetra Tech, Inc., for Resource Planning Associates/ U.S. Army Corps of Engineers - Seattle District

REPORT DATE: November, 1986

STUDY PURPOSE

The purpose of this project was to develop a booklet to educate the public and environmental managers about the approach being developed by the U.S. Army Corps of Engineers to the problem of dredged material management.

SUMMARY OF RESULTS AND CONCLUSIONS

The concepts in the booklet are based on the overall management strategy for disposal of dredged material developed by U.S. Army Corps of Engineers Waterways Experimental Station in Vicksburg, Mississippi, and Seattle District, Army Corps of Engineers. The strategy provides a framework for determining whether a specific dredged material requires restrictions and controls, and if so, for selecting appropriate dredging and disposal alternatives and control measures. The framework also enables identification of those sediments that do not require special management considerations. The booklet explains concepts and interrelationships, and potential technical solutions for dredged material management. It is not to be considered COE's formal recommendations for dredged material management.

Using text and graphics, the decisionmaking framework is described in three sections, each differing in purpose and technical detail. Section I reviews the general rationale and basic sequence of the management strategy. This section is oriented toward the general public and higher-level environmental managers.

Section II presents the strategy for testing dredged material and is oriented toward technical managers and those individuals who wish to understand the rationale behind various technical recommendations.

Section III outlines procedures for evaluating results of the various tests to determine the need for restrictions. This section is oriented toward technical specialists and others concerned with the many issues surrounding the question, "How clean is clean?" It is intended as an example of possible approaches to this question, not as a recommendation for interpreting the results of tests for application to actual projects.

A Glossary defines scientific and engineering words used in the booklet.

January 1988 rev.

EXHIBIT E.8 PATTERN RECOGNITION REPORT

TITLE: Task 2, Evaluation of Statistical Relationships among Chemical and Biological Variables Using Pattern Recognition Techniques

PREPARER: Tetra Tech, Inc. and G.A. Erickson & Associates for Resource Planning Associates/U.S. Army Corps of Engineers - Seattle District

REPORT DATE: February 1986 (draft)

STUDY PURPOSE

Statistical pattern recognition analyses were conducted to:

- Identify statistical relationships among sediment contaminants and biological effects possibly missed in previous statistical analyses
- Identify relationships among chemical and biological variables that may be useful in developing sediment quality values
- Verify relationships discovered by other techniques in earlier studies, such as the Commencement Bay Superfund investigation
- Suggest future analyses that may be of value for refining or verifying apparent relationships.

SUMMARY OF RESULTS AND CONCLUSIONS

This report presents the major findings of an application of a pattern recognition software system (ARTHUR) to data on sediment chemistry and biological effects (from benthic infaunal analysis and bioassays) from 144 stations in Commencement Bay and Carr Inlet. ARTHUR was used in this study to identify: chemical groupings, the most useful normalizations of chemical data, sensitive benthic species, relationships among chemical concentrations and biological effects, and relationships among sampling stations.

The analysis had the following limitations:

- The majority of stations were in polluted areas, biasing the analysis against detection of effects on pollution sensitive species

- Because hypotheses were not formally tested with statistical confidence limits, quantitative relationships among variables cannot be specified, and relationships must be considered tentative

- All relationships, particularly non-linear ones, may not have been identified.

ARTHUR was used to isolate the biological influence of not only particular chemical variables but also aggregates of those variables, where a combination of contaminants might have an effect not caused by any single constituent in its existing concentration. The techniques of analysis are described in detail in Appendix A. The 192 variables analyzed included variables related to benthic community structure and bioassays, concentrations for 100 chemicals or chemical compounds, and conventional sediment variables. Chemistry data were normalized to sediment dry weight, total organic carbon, and total percent fine-grained material in each sample. Both raw and normalized data were subjected to the analysis.

Factor analysis was applied to resolve the many complex relationships among variables into fewer interactions among a smaller number of factors. A factor is a mathematical combination of variables. Factors were plotted for visual inspection. An attempt was then made to interpret the statistical factors in terms of known biological or chemical phenomena. Cluster analysis was used to discover those variables and stations that were most closely correlated. Other techniques were used to weight factors and to lookf or additional relationships among factors and variables.

The major chemical factors discovered were: (1) phenols and light aromatic hydrocarbons, (2) metals, (3) chlorinated compounds, and (4) high molecular weight polynuclear aromatic hydrocarbons (HPAH). These factors subsumed chemicals with similar spatial distributions, suggesting that sediment quality values should be derived from the combinations of the variables composing the factors, as well as the variables themselves. Major biological factors were: fine-grain/high organic content deposit feeders (mostly molluscs, ostracods, and decapods), (2) fine-grain deposit feeders (mostly polychaetes), and (3) sand-oriented gastropods. The biological factors included substantial contributions from sediment grain-size variables (e.g., sand and silt content).

Appendix A summarizes the results of a correlation analysis that revealed numerous significant correlations among variables. Seven chemical variables and three conventional sediment variables had four or more significant correlations with biological variables. Further analysis revealed several species for which abundance dropped at critical thresholds of concentration for particular contaminants. Some of these species may be useful as indicator species; only one of this group (Euphilomedes producta) had previously been identified as an indicator organism.

Factor plots revealed inverse relationships among several chemical and biological factors. For example, lower species abundances appear to be associated with areas high in total organic content and sediment toxicity. Classification analyses of benthic infaunal species data revealed clusters of stations characterized by similar types and levels of biological effects. Factor projection plots, interpreted in conjunction with factor analyses, indicated that stations characterized by significant bioassay effects and depression in the abundance of major taxonomic groups also had low abundances of individual species potentially sensitive to chemical contamination.

Analysis of the data normalized to dry weight of sediment provided most of the useful insights, but it is important to remember that the abundance of many species is also directly related to total organic content or percent fine-grained material in the sediments. The analysis supported previous field investigations that suggested the primary biological effects of chemicals in sediments may be related to the mass concentration (by volume) present (i.e., dry weight normalization). The percent fine-grained material and organic carbon content of sediments influence the amount of contaminants that accumulate in a particular sediment. However, normalization of chemical concentrations to these factors yielded little additional information concerning the potential relationship of chemicals to biological effects over that already obtained by normalization of chemical concentrations to dry weight of sediment.

Differences among study areas in the basin were large enough to mask relationships between sensitive species and chemical concentrations when all the data were analyzed together. Important chemical and biological factors were identified when the data were analyzed in geographical subsets. No one chemical or group of chemicals accounted for all toxicity or benthic effects on a system-wide basis.

In general, the results of the ARTHUR analysis corroborate the findings of earlier analyses of these data and agree with the results of analyses of other Puget Sound data using ARTHUR. The results suggest groupings of chemicals that may be of use in developing sediment quality variables.

The report recommends that:

- Future applications of ARTHUR be restricted to biological systems in intimate contact with the sediments
- The data set be expanded by more intensive sampling in restricted areas to look at small-scale variation and by including samples from more areas unaffected by pollution

- Future analyses include other techniques, such as path modeling (canonical correlation)

- The classification capabilities of ARTHUR could be used as an interim decision system by assigning new sediment samples to groups previously defined by selected sediment variables.

EXHIBIT E.9 SEDIMENT QUALITY VALUES REPORT

TITLE: Development of Sediment Quality Values for Puget Sound

PREPARER: Tetra Tech, Inc. for Resource Planning Associates/U.S. Army Corps of Engineers - Seattle District

REPORT DATE: September 1986 (final report)

STUDY PURPOSE

This report presents the results of a joint effort by the Puget Sound Estuary Program (PSEP) and the Puget Sound Dredged Disposal Analysis (PSDDA) to develop sediment quality values for Puget Sound. These values represent concentrations of chemicals in sediments that are expected to be associated with adverse biological effects based either on field evidence or theoretical predictions.

The main purposes of this study were to: (1) compile chemical and biological data from Puget Sound appropriate for use in the development of sediment quality values; (2) evaluate techniques that can be used to develop chemical specific values; (3) evaluate the reasonableness of the values generated using different techniques (i.e., their ability to correctly identify sites with known biological impacts); (4) evaluate the appropriateness of using the values in different regulatory applications; (5) identify future studies that will be needed to refine or verify the sediment quality values that are generated.

Material presented in appendices to this report addresses additional objectives related to statistical analyses of a subset of the chemical and biological data using pattern recognition techniques (Appendix D; see Exhibit E.8 of this technical appendix), recommended contaminants of concern (Appendix E), analytical detection limits (Appendix F), and appropriate uses of conventional sediment variables (Appendix G) for the management of dredged material. Responses to comments received on draft reports used to prepare this final report are summarized in Appendix H.

SUMMARY OF RESULTS AND CONCLUSIONS

Eight possible approaches to establishing sediment quality values were evaluated based on (in order of decreasing importance):

- The plausibility and scientific defensibility of their theoretical bases and critical assumptions

- The quantity of data required, and the current availability of data (i.e., for generation of sediment quality values during the present project)
- The range of chemicals for which the approach is appropriate
- The range of biological effects information that can be incorporated into the approach.

Of the eight approaches reviewed, three were selected as the most appropriate for evaluation in this project with available Puget Sound data. These included the sediment-water equilibrium partitioning, apparent effects threshold (AET), and screening level concentration (SLC) approaches.

For a given nonpolar, nonionic organic compound, the sediment-water equilibrium approach establishes a sediment quality value as the sediment concentration [normalized to total organic carbon (TOC) content] corresponding to an interstitial water concentration equivalent to the U.S. EPA water quality criterion for the contaminant. The relationship between sediment concentrations and interstitial water concentrations is calculated with an estimated sediment organic matter-interstitial water partition coefficient. Field data are not required to generate sediment quality values using this theoretical approach, but are used to validate the approach.

The AET value is the sediment concentration of a contaminant above which statistically significant biological effects (e.g., amphipod mortality, oyster larvae abnormality, depression in the abundance of benthic infauna) were always observed at every station in the database exhibiting concentrations above the AET. The approach was developed for use with any organic or inorganic contaminant, and does not require a priori assumptions concerning the specific mechanism for interactions between contaminants and organisms. AET are empirically derived from matched field data for sediment chemistry and a range of biological effects indicators.

The SLC approach estimates the sediment concentration of a contaminant above which less than 95 percent of the total enumerated species of benthic infauna are present. This approach was originally developed and recommended for use with nonpolar organic compounds normalized to organic carbon content in sediments (Battelle 1986). Possible use of the SLC approach with dry-weight normalized data (and contaminants other than nonpolar organic compounds) was also examined in the current study. This modification was evaluated for the SLC approach because (as with the AET approach, but unlike the equilibrium partitioning approach) a priori assumptions concerning the specific mechanism for interactions between contaminants and organisms are not necessary. SLC are empirically derived from matched field data for sediment chemistry and the abundance of individual species of benthic infauna. Project constraints

permitted the testing of this approach for only three contaminants (naphthalene, high molecular weight polycyclic aromatic hydrocarbons, and mercury), although the approach is not considered to be limited to these contaminants.

The application and evaluation of the selected sediment quality value approaches required that a large database of matched chemical and biological data be compiled. Of 11 Puget Sound data sets reviewed, paired data from 7 studies were included in the final database. These data included recent studies in Commencement Bay (Tetra Tech 1985), eight urban and nonurban embayments of Puget Sound (Battelle 1985a), Everett Harbor (U.S. Department of the Navy 1985), and Duwamish River (Chan et al. 1985a,b). Municipality of Metropolitan Seattle (Metro) data for the Alki Extension project (Osborn et al. 1985; Trial and Michaud 1985) and the Toxicant Pretreatment Planning Study (TPPS; Phase III, Comiskey et al. 1984; Romberg et al. 1984) were also included in the database.

Using the three selected approaches, sediment quality values were calculated for 73 individual or classes of U.S. EPA priority pollutants and other contaminants, and 3 conventional variables (e.g., TOC) and compared, when possible. In general, the magnitude of the sediment quality values for a given contaminant ranked: (SLC) less than (AET) less than (equilibrium partitioning).

The AET (normalized to sediment dry-weight, organic carbon content, and percent fine-grained material) and equilibrium partitioning approaches were tested with respect to the frequencies at which they correctly identified impacted stations and misidentified nonimpacted stations. Stations were designated as impacted or nonimpacted by independent statistical comparisons of biological data to reference conditions. These impacted/nonimpacted designations were based on four biological indicators: amphipod bioassays, oyster larvae bioassays, Microtox bioassays, and benthic infaunal analyses. A subset of impacted stations was designated as severely impacted based on somewhat arbitrary criteria: greater than 50 percent amphipod mortality or oyster larvae abnormality, or statistically significant depressions in the abundance of more than one major taxonomic group of benthic infauna (including Mollusca, Polychaeta, Crustacea). This subset of severely impacted stations was only used as part of the validation check on sediment quality values, and not to generate sediment quality values.

The 40 sediment quality values from the equilibrium partitioning approach correctly identified between 13 and 43 percent of the impacted stations, and between 0 and 46 percent of severely impacted stations, depending on the biological indicator used for validation. This approach misidentified between 0 and 67 percent of the nonimpacted stations, depending upon the biological indicator used for validation.

EXHIBIT E.10 MICROLAYER REPORT

TITLE: The Surface Microlayer: Review of Literature and Evaluation of Potential Effects of Dredge Activities in Puget Sound

PREPARER: Evans Hamilton, Inc. for U.S. Army Corps of Engineers - Seattle District

REPORT DATE: 1986

STUDY PURPOSE

The purpose of this document was to review available literature about the environmental effects of contamination in the surface microlayer and to evaluate potential effects of microlayer contamination resulting from dredging activities in Puget Sound.

SUMMARY OF RESULTS AND CONCLUSIONS

The report provides an overview of the surface microlayer and the neuston community that inhabits them; discusses the relevance of dredging and dredged material disposal to surface microlayer events and biota; provides an assessment of potential effects of dredge-related activities; discusses proven biological effects of contaminant loadings; and proposes a strategy for conducting future investigations. Appendices include an approach for characterizing surface slicks, a review of sampling methodologies, a glossary of terms, and a list of reviewed literature. The overview of the microlayer includes discussions of the formation of surface slicks; its organic and inorganic makeup; its biota; and the environmental and trophic interactions that occur within it.

The uppermost 1 cm of the sea surface is composed of the following layers:

- Surface nanolayer - upper 300 angstroms or 1 micron, depending on the school of thought
- Surface microlayer - to 100 um, characterized by gaseous exchange by diffusion and evaporative cooling
- Surface millilayer - to 1 mm, contains bacterioand phytoneuston.
- Surface centilayer - to 1 cm, contains many larvae and zooneuston.

The surface film is composed of surfactants that have migrated to the sea surface. Surface slicks are a visible characterization of capillary wave dampening and can occur with or without elevated concentrations of microlayer constituents. Enrichment of the microlayer by biogenic compounds (e.g., n-alkanes and pristane, ATP, glucose, chlorophyll, and other plant pigments) and inorganic and particulate organic nutrients is generally within the 1-100 range. Silica may represent approximately 80 percent of all inorganic matter in the microlayer.

The surface microlayer is considered a nutritive environment but it is also exposed to climatic extremes. It supports bacteria; protozoa; small metazoans (less than 1.00 mm); large metazoans (greater than 1 mm); and eggs, larvae, and fry of organisms such as anchovies, flat fish, and oysters.

There are no quanititative data available that describe the effects of dredging and dredged material disposal on the surface microlayer. However, slicks have been observed during these activities. The surface microlayer is extremely important for the production, regeneration and degeneration of organic materials. The cycling of materials between the atmosphere and the sea occurs in it, and it is a nursery ground for many marine species. It is an area where many marine species can become exposed to elevated concentrations of nutrients and toxic chemicals, and extreme physical disturbance.

Studies are currently underway in Puget Sound to document contaminant concentrations in the microlayer, evaluate the toxicity of contaminated microlayers to commercially important species, and develop a fate and effects model. To relate this work to dredging and dredged material disposal, this report recommends undertaking further research to re-verify vertical and horizontal contaminant transport and assess the biological significance of surfaced or stranded dredged materials.

EXHIBIT E.11 PROTOCOLS FOR BIOASSAYS

TITLE: Recommended Protocols for Conducting Laboratory Bioassays on Puget Sound Sediments

PREPARER: Tetra Tech, Inc. and E.V.S. Consultants, Inc. for U.S. Environmental Protection Agency - Region X.

REPORT DATE: May 1986 (final report)

STUDY PURPOSE

This document presents recommended standardized methods for conducting four kinds of sediment bioassays. The protocols were developed to encourage all Puget Sound investigators to use standardized procedures whenever possible and thereby producing data that are directly comparable.

SUMMARY OF RESULTS AND CONCLUSIONS

Each recommended method is based on the results of a workshop and written reviews by representatives from most organizations that fund or conduct environmental studies in Puget Sound. Sediment bioassays were selected for consideration based on the following criteria:

- o Sensitivity - each test has detected biological effects in a variety of sediments
- o Usage - each test has been used in more than one study in Puget Sound.

The following tests were identified as suitable for general application in Puget Sound:

- o Amphipod bioassay
- o Bivalve larvae bioassay
- o Anaphase aberration bioassay
- o Microtox bioassay.

For these four tests, the protocols describe the use and limitations of the respective variable; the field collection and processing methods; and the laboratory analytical quality assurance/quality control (QA/QC), and data reporting procedures. These bioassays may be used alone as a screening tool in broad-scale sediment surveys, in combination with sediment chemistry and in situ biological indices, and in laboratory experiments addressing a variety of

sediment and water quality manipulations. None of these four tests measures chronic effects (i.e., defined as longer term than 10 days, involving partial life-cycle testing).

The amphipod (Rhepoxynius abronius) sediment bioassay is used to characterize the toxicity of marine sediments. The organisms are exposed to the test sediment for 10 days, after which the surviving amphipods are counted.

The bivalve larvae bioassay exposes pacific oysters (Crassostrea gigas) or blue mussels (Mytilus edulis) as the recommended test species. During the first 48 h of embryonic development, fertilized oyster and mussel eggs normally develop into free swimming, fully shelled larvae (prodissoconch I). Failure of the eggs to survive or the proportion of larvae developing in an abnormal manner is used as an indicator of toxicity.

The anaphase aberration sediment bioassay is used to characterize the genotoxicity of marine sediments. Cell cultures are exposed for 48 h to an extract of the test sediment. The cells are fixed and stained and examined for abnormal anaphases.

The Microtox bioassay is a rapid, sensitive method of toxicity testing based on light emission by the luminescent bacterium (Photobacterium phosphoreum) in the presence and absence of aqueous toxicants. The emitted light is a product of the bacterial electron transport system and thus directly reflects the metabolic state of the cell. Accordingly, decreased luminescence following exposure to chemical contaminants provides a quantitative measure of toxicity. This bioassay, like the anaphase aberation bioassay depends on a chemical extract of the sediment.

Seven other promising techniques that may be generally applicable in Puget Sound following further detailed testing and validation are briefly described. Sections are also presented on general protocols for field collection of surficial test sediments, and general QA/QC procedures that apply to all sediment bioassays.

EXHIBIT E.12 PROTOCOLS FOR NAVIGATION AND SITING

TITLE: Task B: Positioning Protocols for Sampling in Puget Sound;
Task C: Evaluation and Development of Navigation Positioning and Monitoring Protocols for Dredged Material Disposal in Puget Sound

PREPARER: Tetra Tech, Inc. for Resource Planning Associates/U.S. Army Corps of Engineers - Seattle District

REPORT DATE: March 1986 (final reports)

STUDY PURPOSE

The purposes of the Task B report were to: (1) recommend methods for the selection of vessel (station) positioning procedures for the collection of environmental samples in Puget Sound, and (2) recommend positioning accuracies appropriate for specific types of sampling and associated positioning methods. The purpose of the Task C report was to provide guidance in selection of methods for positioning barges during disposal of dredged materials in open water, and methods for monitoring disposal to verify that disposal occurs within the terms of the disposal permit.

SUMMARY OF RESULTS AND CONCLUSIONS

Task B Report. This study was jointly sponsored by PSDDA and PSEP in developing general protocols for vessel positioning during sampling in Puget Sound. A workshop group on positioning methods for sampling concluded that no single positioning method would be adequate for all sampling scenarios, and recommended a standardized selection procedure that:

- Matches positioning methods to particular sampling objectives and site-specific conditions
- Allows flexibility in choosing among methods that can provide desired accuracy
- Allows investigators to use familiar or available systems
- Allows funding agencies to specify levels of accuracy appropriate to sampling objectives and database requirements
- Incorporates positioning accuracy into sampling design.

The Task B report provides guidance for determining the level of accuracy and for selecting the methods of positioning appropriate for sampling studies that will be conducted for PSDDA. Such studies will be conducted for two major purposes: to characterize the sediments to be dredged, and to monitor disposal-related impacts at dredged material disposal sites. The selection procedure involves the identification of factors in a given sampling program that can affect the accuracy and feasibility of particular positioning methods, and the determination of positioning accuracy required for specific sampling stations. Available systems are then evaluated with respect to positioning requirements and site-specific constraints. Once positioning equipment has been selected, it must be approved, procured, assembled and installed, calibrated, and field tested.

Detailed and accurate records and reports of actual positioning methods used must be kept to: ensure consistently accurate positioning; allow reoccupation of stations for replicate sampling; and, perhaps most importantly, allow reoccupation of stations for future studies. Information that should be recorded is reviewed in detail in this report. The kinds of logs that should be maintained are discussed, and reporting requirements are summarized.

Available positioning methods are reviewed in Appendix C, and the applicability and relative costs of each are given. Current uses of different positioning methods in Puget Sound are discussed, and available methods are evaluated in Appendix D to provide guidance in choosing a method appropriate to sampling goals. Candidate systems discussed in Appendix D were evaluated on the basis of accuracy, range capability, flexibility, portability, reliability, servicing requirements, availability, cost, and convenience. Some methods were eliminated because they have very restrictive limitations (e.g., having no capability for operating at night or under conditions of low visibility, or having severe logistical problems). Remaining methods were reevaluated on the basis of range capability, accuracy, availability, capital and operating costs, and merits of use.

The objectives of a sampling program (e.g., determining gradients or inter-station differences) are extremely important to the choice of positioning methods. The design of a sampling program determines what level of positioning accuracy is most appropriate, and the sampling location determines the feasibility of using particular positioning methods to achieve that accuracy. The sampling design factor requiring the highest positioning accuracy will determine positioning requirements.

Characteristics of sampling design and location that are important in the choice of positioning methods include: the location, physical conditions, and topography of the study site; the availability and quality of fix targets

appropriate for different positioning methods; type of samples taken (e.g., water column, bottom sediments); patch size for variables with a patchy distribution; type of sampling equipment used; type of sample analyses (chemical and statistical); minimum station separation required for statistical analysis; need for reoccupying stations for collection of multiple samples (repeatable positioning accuracy may be more important than absolute accuracy); maximum acceptable area from which replicate samples can be collected; and program-imposed constraints (e.g., time, operator experience, contractual obligations, funding limits). These factors are discussed in detail in the report.

Site-related limitations on positioning in the Sound are discussed in Appendix A, and an analysis of sources of positioning error is given in Appendix B. Positioning error should be estimated for a sampling site to properly select appropriate positioning methods. Repeatable accuracy for many positioning systems is often an order of magnitude greater than absolute accuracy. Repeatable accuracy may be more important than absolute accuracy for studies in which reoccupying a station is more important than establishing its exact location.

To make general recommendations for choosing a level of positioning accuracy, sampling was classified into three categories: point sampling, areal sampling, and special studies. Special studies may include both point and areal sampling activities, but usually are conducted to identify induced changes on the environment. Characterization of natural variability will be important for special studies and point samples collected from heterogeneous environments. Accuracy of positioning will affect the degree to which natural variability can be segregated from induced effects. Relatively lower levels of positioning accuracy will be appropriate for samples collected from a homogeneous medium than for those collected for a heterogeneous medium.

To facilitate the identification of trends and gradients, the highest level of accuracy [(12 m (6.6 ft)]) is recommended for special studies (especially sediment characterization of areas to be dredged), most point samples, and studies designed to build the developing database for the Puget Sound Estuary Program. A lower level of accuracy [(120 m (66 ft)] may be adequate for sampling relatively homogeneous environments, for collecting areal samples,or where funding is limited. Positioning methods characterized by the lowest level of accuracy [(1,100 m (330 ft)] are not recommended. Positioning methods capable of achieving the two recommended levels of accuracy are summarized, compared, and discussed in terms of their appropriateness for different applications.

Once a positioning method has been chosen, proper setup, calibration, and operational procedures must be followed to achieve projected accuracies.

Task C Report. The ability to accurately position a barge for open water disposal is influenced by: the maneuverability of the barge/tug combination; limitations of the specific positioning method; and the size, location, and characteristics of the disposal site. These limitations are discussed in detail in the report. Because of limits to barge maneuverability, highly accurate positioning systems may be of little value. The usefulness and accuracy of many positioning methods depend greatly on the location of the specific dump site within the Sound. The manner in which positioning error and barge maneuverability can be used in designing the size of dump sites is discussed.

Both currently used methods of positioning and those of potential value are reviewed, and the major advantages and disadvantages of each method are discussed. Some were eliminated from consideration because of overly restrictive limitations, such as inappropriateness for nighttime operation. Remaining methods were grouped by category based on accuracy. Visible range radar (VRR) and Loran-C are included in the 20-30 m (66-99 ft) accuracy category; microwave and satellite systems are include in the 12 m (6.6 ft) category. Dump zone radii are recommended for each accuracy category. Methods currently used in Puget Sound cannot consistently place a barge within existing dump zone boundaries.

Barge positioning methods were evaluated on the basis of: accuracy (absolute and repeatable), range capability, portability, flexibility, calibration requirements, reliability, maintenance requirements, service availability, convenience, and costs. These evaluations are summarized in a table. Appendix A includes detailed reviews of available positioning methods (and associated equipment) that will facilitate the selection of methods appropriate for specific purposes.

Different combinations of positioning methods are included in three alternative recommendations:

1. Use both Loran-C and VRR at all sites. Both systems are common to most tugs, but to obtain adequate accuracy the coordinates must be determined in advance from on-site readouts by the agency. The use of both systems provides redundancy and flexibility.

2. Use Loran-C and VRR until GEOSTAR or GPS satellite systems become cost effective. Satellite positioning methods are very accurate, but are expensive and do not provide adequate coverage at present. They are expected to become commonly used and less costly in the future. Satellite systems are easy to use and

will allow a reduction of disposal boundary radii from those of alternative 1.

3. Use elastically moored buoys at appropriate sites, and Loran-C and VRR at the other sites until satellite systems become cost effective. Buoys allow accurate positioning, but are are very expensive to use. They may be appropriate where it is particularly important to restrict depositional area, such as sites with strong currents or great depth.

A number of possible approaches to monitoring disposal operations are discussed in the report. Monitoring methods not meeting requirements identified by agencies managing disposal activities were eliminated from consideration. Methods with severe visibility limitations and those with high logistical requirements were not considered appropriate. Remaining methods were screened for their ability to meet specific criteria. These include different combinations of record-keeping by operators, shore-based observations by personnel, and remote electronic monitoring. These methods are discussed in detail, and their advantages and limitations are pointed out. Each method is evaluated on the basis of criteria similar to those used to evaluate positioning methods, and the results are summarized in a table.

Recommendations for alternative monitoring schemes are:

1. Require operator record keeping at all sites and spot check with shore-based operations. Random spot checks would be needed to encourage compliance. Reliance on user records would also require the implementation of penalties to discourage falsification of data.

2. Use VTS radar coverage and where available and supplement with spot checks of other sites. VTS is in place and requires minimal agency involvement. However, it cannot be used to verify dump time, and it does not cover all disposal sites.

3. Use a remote monitoring system and supplement with spot checks. This would be the most expensive alternative and would require the agency to determine the positioning coordinates and fixes for each site. However, the systems would require little operator effort, and the systems could be used for other purposes.

Site user records and U.S. Coast Guard Vessel Traffic Service radar monitoring would be the easiest programs to implement; remote monitoring would be more

expensive and labor intensive. Remote monitoring systems must be designed for specific needs, and determination of the best system will require detailed stipulation of requirements. Characteristics of existing and proposed sites that could affect position monitoring are summarized.

EXHIBIT E.13 PROTOCOLS FOR ANALYSIS OF METALS

TITLE: Task A-4, Metals Protocol Development for Puget Sound Studies

PREPARER: Tetra Tech, Inc. for Resource Planning Associates/U.S. Army Corps of Engineers - Seattle District

REPORT DATE: August 1986 (final report)

STUDY PURPOSE

The purposes of this study were to: (1) recommend appropriate metals and metalloids for protocol development; (2) recommend limits of detection for the analysis of each element in water, sediment, and tissue; (3) review acceptable sample preparation and instrumental methods capable of meeting the recommended limits of detection for each matrix; (4) recommend the best method for each matrix; (5) recommend standard procedures and requirements for sample size, preservation, and storage, quality assurance/quality control, and data reporting.

SUMMARY OF RESULTS AND CONCLUSIONS

Four recent field investigation reports and historical data from four summary reports were reviewed to arrive at a concensus for contaminants of concern in Puget Sound sediments. The U.S. EPA priority pollutant elements antimony, arsenic, cadmium, copper, lead, mercury, nickel, silver, and zinc were recommended for protocol development. U.S. EPA priority pollutant metals excluded included beryllium, chromium, selenium, and thallium. Speciation protocols may be useful for selected bioaccumulation studies (i.e., arsenic and mercury), but were not recommended for routine monitoring, or for analysis of waters or sediments. Iron and manganese were recommended for inclusion in the protocol specification because of their potential use as geochemical tracers and as potentially important factors in the generation of sediment quality values.

Limits of detection were recommended for the U.S. EPA priority pollutant metals after a consideration of attainable detection limits for each matrix type and U.S. EPA water quality criteria (water) and expected background levels in the environment (sediments and tissues). Based on this comparison, maximum detection limits (often meaning lower cost) were recommended that would still be sufficient for characterizing each matrix in a dredged materials testing program.

The recommended procedures and requirements for sample sizes, preservation, and storage, quality assurance/quality control, and data reporting closely followed those of the U.S. EPA Contract Laboratory Program.

The choice of recommended instrumental methods was based upon: (1) the existence of an agency-approved protocol; (2) the ability to achieve recommended detection limits; (3) ready availability and commonality of use. Because no one instrumental method satisfied all of the requirements for all matrices, inductively-coupled plasma emission, graphite furnace atomic absorption, and cold vapor atomic absorption were recommended.

All of the recommendations plus options for sample preparation were reviewed and discussed by regional experts at a workshop held in January, 1986. All deletions, additions, and modifications agreed upon at the workshop were incorporated into the final draft report. Issues generating substantial discussion included: (1) sample digestion techniques; (2) additional approved and non-approved instrumental techniques; (3) organo-metallic speciation techniques; (4) prioritizing QC checks for small batches of samples.

The recommended sample digestion techniques were: (1) strong acid and APDC/MIBK extraction for water; (2) hydrofluoric acid/aqua regia total acid for particulates and sediment; (3) nitric acid/perchloric acid for tissues. The U.S. EPA method for hydride generation atomic absorption was added as an alternative technique for arsenic, selenium, and antimony. The use of matrix modifiers in graphite furnace atomic absorption and the use of x-ray fluorescence were allowed as long as accuracy and precision were demonstrated to the level specified in the QC section of the report. Organo-metallic speciation techniques were not recommended for protocol development because of lack of QC documentation and routine use. For small batches of five samples or less, the recommended QC check priority was standard reference material | duplicates | matrix spikes.

The report contained 7 appendices. Appendix A contained the Task A-1 Final Report, Selection of Metals for Protocol Development. Appendices B through G contained detailed sample preparation, instrumental, QC, data reporting, and document control protocols.

EXHIBIT E.14 PROTOCOLS FOR ANALYSIS OF ORGANIC COMPOUNDS

TITLE: Recommended Protocols for Measuring Organic Compounds in Puget Sound Sediment and Tissue Samples

PREPARER: Tetra Tech, Inc. for U.S. Environmental Protection Agency - Region X

REPORT DATE: September 1986 (final report)

STUDY PURPOSE

The purposes of this study were to recommend for the analysis of volatile and semivolatile organic compounds: (1) limits of detection for sediment and tissue samples; (2) preanalysis procedures for a sample drying, extraction, and extract cleanup; (3) instrumental techniques capable of meeting the recommended detection limits; standard procedures and requirements for the field collection, size, preparation, and storage of samples, quality assurance/quality control, and data reporting.

SUMMARY OF RESULTS AND CONCLUSIONS

The information contained in the report was synthesized from written sources (e.g., U.S. EPA methods) and from discussions at three workshops of regional experts held in July, September, and November, 1985. The procedures were reviewed by agencies, laboratories, and consulting firms. Because there are no agency-approved procedures for the analysis of low parts-per-billions levels of organic contaminants in estuarine sediments and tissues, multiple procedures for different compound classes are currently in use. Because these procedures could potentially yield equivalent results, it was decided during the workshops that the report should emphasize quality assurance/quality control guidelines that would enable the assessment of the comparability of data sets generated by different procedures.

Limits of detection were recommended for the two major classes of organic compounds so that concentrations down to Puget Sound reference areas could be quantified. For volatiles, "sensitive" detection limits were 10-20 ug/kg dry weight for sediment and 5-10 ug/kg wet weight for tissue. For semivolatiles, they were 1-50 ug/kg dry weight for sediment (0.1-15 ug/kg for pesticide and PCBs) and 10-20 ug/kg wet weight for tissue (0.1-20 ug/kg for pesticides and PCBs). A "screening level" was set for sediment semivolatiles, using U.S. EPA Contract Laboratory Program (CLP) procedures, at 500-1,000 ug/kg dry weight (15-60 ug/kg for pesticides and PCBs).

For the analysis of volatiles in sediments, two methods were recognized as acceptable and capable of analysis at reference area concentrations: the routine U.S. EPA CLP heated purge-and-trap procedure and the vacuum

extraction/purge-and-trap technique. For the analysis of semivolatiles in sediments, the U.S. EPA CLP GC/MS and GC/ECD protocols (with options for capillary column analysis for GC/ECD) were accepted for screening level analyses. Depending on the ultimate use of the data, GC/FID (with confirmation) was also accepted. For analyses at reference area concentrations, multiple extract cleanup steps are required. A variety of procedures are in common use for each step, and methods were recognized as acceptable that have been successfully employed by regulatory agency and independent laboratories.

For the analysis of volatiles in tissue, the U.S. EPA CLP heated purge-and-trap procedure and the vacuum extraction/purge-and-trap technique were recognized as acceptable. No screening level procedure was recommended because the high detection limits may preclude contaminant detection at levels considered to be significant human health risks. As for sediments, various extract cleanup methods required for low-level analysis are in practice, and methods that have been successfully employed by regulatory agency and independent laboratories were recognized. Appropriate instrumental techniques were the same as for sediment.

Frequencies, compound applicabilities, limitations, warning and control limits, and corrective actions were detailed for nine separate quality control (QC) procedures. Data reporting requirements were similar to those of the U.S. EPA CLP. The impact upon analysis cost of requiring low-level detection limits and high precision was discussed.

The report contained four appendices. Appendices A and B contained U.S. EPA CLP sample workup procedures for volatiles and semivolatiles. Appendix C contained U.S. EPA advisory limits for precision and accuracy and method performance limits for analytical procedures. Appendix D contained U.S. EPA CLP procedures for identification of target and library search compounds.

EXHIBIT E.15 REPORT ON GUIDELINES FOR CONFINED DISPOSAL

TITLE: Guidelines for Selecting Control and Treatment Options for Contaminated Dredged Material. Miscellaneous Paper EL-86

PREPARER: U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

REPORT DATE: May 1986 (interim draft report)

STUDY PURPOSE

The objectives of this study are 1) to identify control and treatment options for contaminated dredged material, and 2) to describe design tests, design concepts, and guidelines for selection of control and treatment options.

SUMMARY OF RESULTS AND CONCLUSIONS

Alternative technologies and alternatives for dredging, disposal, control, and treatment of contaminated dredged material are reviewed. Contaminant control/ treatment during three basic operations are discussed. These include contaminant control/treatment during dredging, material transport, and disposal operations.

The selection of appropriate technologies for contaminated dredged material management depends on the physical and chemical profile of the sediments, the state changes that may occur at different phases of the dredging and disposal operations, physical characteristics of the proposed disposal site, and contaminant release criteria for the selected disposal site. Three disposal site scenarios are discussed: upland, nearshore, and open water sites with disposal restrictions. The selection of appropriate control/ treatment alternatives requires that each must be evaluated using a uniform set of criteria. Each control/treatment alternative presented in this report is evaluated in terms of nine evaluation criteria. These criteria include: reliability, implementability/ availability, technical effectiveness/efficiency, environmental concerns, safety, operation and maintenance, costs, regulatory requirements, and public acceptance.

Characteristics, operational considerations and control, and equipment considerations and modification for dredging contaminated sediments are described for each dredging alternative. Different dredging methods appear more appropriate for certain contaminant classes such as: volatile-mechanical dredges, sediment-bound-hydraulic dredges, soluble-hydraulic dredge. Levels of contaminant concentration released are typically lower for open-water disposal relative to nearshore or upland sites. The objective of the selection process is to minimize the cost of contaminant control/treatment subject to site specific environmental criteria.

Many technologies have been developed for control/treatment of contaminated media. These technologies have the potential for application to a contaminated dredged material handling operation. Such technologies are identified in this report. Technologies are separated into proven, demonstrable, and unproved categories. Technologies should be used that ensure that criteria will be met during all phases of the dredging and disposal operations.

In the case of small projects, it is anticipated that the cost of environmental related testing may exceed the cost of disposal. The concept of disposal area overdesign can be used to offset the high cost of testing. Under this concept, expensive testing is foregone in favor of extensive engineered controls, monitoring, and agreements of implementation of remedial actions.

A brief summary of the conclusions of this report is presented below:

- The short- and long-term release of contaminants via various migration pathways from dredged material disposal sites cannot be ignored.
- Control/treatment technologies are available and have been proposed for use at dredge material disposal sites.
- Design procedures for site water treatment technologies at upland and nearshore disposal sites are available and proven.
- A variety of site control measures such as lining and capping have been developed for control of hazardous waste materials.
- Procedures for designing restricted open water disposal sites are well developed.
- The selection of an appropriate control/treatment alternative depends on both site and sediment characteristics. The Dredged Materials Alternative Selection Strategy (DMASS) presented in this report is a useful tool for developing an array of alternatives.
- With the assurance of major cost increases, selection of control/treatment alternatives for very highly contaminated dredged material can rely on technologies developed and being implemented for control of hazardous wastes.

- A recurring limitation in the evaluation of alternative technical feasibility is environmental effectiveness-costs interactions.

EXHIBIT E.16 COMPARATIVE RISK ANALYSIS AND REPORT ON WORKSHOP

TITLE: A Framework for Comparative Risk Analysis of Dredged Material Disposal Options

PREPARER: Tetra Tech, Inc. for Resource Planning Associates/U.S. Army Corps of Engineers - Seattle District

REPORT DATE: October 1986 (final report)

STUDY PURPOSE

The scope, results and conclusions of this report were determined in part by the results of a workshop on risk analysis held in Seattle, Washington, in December 1985.

There are four objectives to this report:

1) Develop a risk analysis framework for evaluating dredged material disposal options

2) Develop a hypothetical example of a comparative risk analysis

3) Develop an example exposure assessment

4) Develop guidelines for acceptable concentrations of chemical contaminants in marine organisms.

SUMMARY OF RESULTS AND CONCLUSIONS

The two main sections of the report, A Conceptual Approach to Risk Analysis of Dredged Material Disposal Options, and An Example of Comparative Risk Analysis satisfy the first three objectives above. The last objective is satisfied in the Appendix material.

The conceptual approach to risk analysis has six major components: hazard identification, dose-response assessment, exposure assessment, risk characterization, a comparative risk analysis model, and uncertainty analysis.

Hazard identification is accomplished by: 1) selecting contaminants of concern, 2) ranking the contaminants of concern, and 3) assembling toxicity profiles for the contaminants based on physical-chemical properties, metabolic and pharmacokinetic properties, and toxicological effects.

Dose-response assessment is performed for humans based on toxicological indices, and for other species based on sediment bioassays using a series of

dilutions of dredged material. The toxicological index used for carcinogens is the Carcinogenic Potency Factor and the toxicological index used for noncarcinogens is the Reference Dose (RfD) value.

Exposure assessment involves estimating the magnitude, duration and route of exposure. Exposure assessments will vary in complexity depending on the disposal environment, contaminants of concern, transport and fate mechanism, and the suspected population at risk. Three levels of analyses are discussed, ranging from a qualitative, generic analysis (Level 1); to quantitative exposure estimates (Level 2; estimates expressed as ranges for humans, estimates based on direct measurements for nonhumans); to estimating quantitative changes in exposure over time (Level 3).

Risk characterization combines the results of dose-response assessment and exposure assessment to estimate the probability and extent of adverse impacts associated with contaminants in dredged material. Risk characterization is discussed in three levels of analysis in terms of human health risk and ecological risk.

Human health risk characterizations treat carcinogens and noncarcinogens separately. A plausible upper limit to excess lifetime risk of cancer is calculated using a linearized multistage dose-response model and carcinogenic potency factors obtained from U.S. EPA. Excess risk is defined as risk associated with only the disposal site and associated routes of interest (i.e., a marginal risk). Models are described for estimating excess lifetime carcinogenic risk, and developing an index of noncarcinogenic risk.

Ecological risk characterizations differ from human health risk characterizations primarily in that that effects are measured in terms of mortality rather than sublethal responses. Methods are illustrated for estimating area-specific risks to migrant and nonmigrant individuals. Four different approaches are described for adding temporal variability to the estimate of ecological risk. These approaches are: 1) time-averaged exposure and risk; 2) frequency of unacceptable exposure; 3) time variable uptake and depuration kinetics; and 4) population modeling.

The Multi-Attribute Tradeoff System (MATS) model is introduced [Brown and Valenti (1983)] in terms of integrating ecological and human health risk estimates to evaluate various options for dredged material disposal. These attributes (e.g., risk estimates, economic efficiency, public perception) can then be evaluated to develop rank scores for various disposal options. Key steps in conducting the MATS evaluation are selecting attributes, creating comparative-risk scales and functions for each attribute, and assigning weights to each attribute. Attributes (or variables) selected for dredged material disposal include cost, sediment chemistry, bioaccumulation, toxicity bioassay, and human health risk.

Risk assessments are always based on limited data, analytical assumptions, and models that by definition are imperfect; therefore, the following examples of uncertainty analysis are discussed: order-of-magnitude bounding analysis, probability distributions for risk, and model uncertainty. Two methods for order-of-magnitude bounding analyses are discussed: the Range Estimating Program presented at the workshop by Dr. Curtis Brown, and a preliminary method provided by Dr. Alan Erhlich. The Range Estimating Program performs a Monte Carlo simulation on data for variables to estimate probability distributions of outcomes. Dr. Alan Erhlich's method uses ranges of uncertainty values or model assumption values (e.g., data for malignant tumors vs. malignant plus benign tumors, and data for average species vs. most sensitive species) to calculate the uncertainty range of risk estimates. Probability distributions of risk are illustrated by Crouch et al. (1983) who modeled uncertainty in carcinogenic potency, exposure, and an interspecies extrapolation factor as lognormal probability distributions. Both model uncertainty and parameter uncertainty may be investigated by qualitatively examining the assumptions of the risk assessment model.

In the second section of this report, the conceptual approach to risk analysis is applied to a hypothetical dredged material disposal scenario. The Fourmile Rock Disposal Site, a deepwater, unconfined site is analyzed in terms of site characterization, hazard identification, dose-response assessment, exposure assessment, and risk characterization. Comparative analysis of disposal options is illustrated using the MATS model to evaluate the risks determined for the deepwater site relative to hypothetical risks assumed for nearshore confined disposal (using Pier 90-91 short fill as an example) and upland disposal (using midway land fill as an example).

There are five appendixes to this report, these are:

- Appendix A: Guidance for interpretation of bio-accumulation data
- Appendix B: Workshop agenda and invited participants
- Appendix C: Carcinogenic potency factors and acceptable daily intake values for priority pollutants
- Appendix D: Range Estimating program results
- Appendix E: Hypothetical data for example risk assessment.

EXHIBIT E.17 CHEMICAL AND BIOLOGICAL MONITORING OF DISPOSAL SITES

TITLE: Phase I: Central Puget Sound Environmental Monitoring Plan

PREPARER: Puget Sound Dredged Disposal Analysis

REPORT DATE: 1986

STUDY PURPOSE

The objectives of PSDDA are to locate sites in Puget Sound for unconfined, open-water disposal of dredged material, define evaluation procedures for determining when dredged material is acceptable for discharge at these sites, and prepare site management plans (including permit and monitoring requirements). PSDDA is being conducted in two phases (each two years in length): Phase I covers central Puget Sound and Phase II covers south and north Puget Sound. The monitoring plan will be designed to address well-defined objectives or concerns. These concerns are all directly related to potential chemical and physical effects that may result from dredged material disposal. Four specific concerns (hypotheses) have been stated; they are:

1. Key environmental and human resources will not be physically or chemically impacted.

2. The predicted, acceptable chemical effects at the site are not exceed or substantially "under achieved."

3. The dredged material stay on site as predicted.

4. The site does not result in attraction of large numbers of important species/lifestage and does not result in chemical contamination of nearby demersal resource areas.

SUMMARY OF RESULTS AND CONCLUSIONS

The monitoring plan developed to assure that the above concerns are met consists of four components: station types, site descriptions, method of monitoring, and program phases. These plan components represent an overview of the plan and are followed by detailed plan summaries and site management and remedial response.

The station types component of the monitoring plan provides a generic description of station types and establishes a purpose for each type. Site descriptions include a map illustrating currents, amenities, and station location for

each disposal site, methods of monitoring, a description of the techniques to be used, reasons for their use, and the types of data that would be generated. Methods described include box core samples, trawls, REMOTS survey, side scan sonar survey, visual observations and chemical analysis. Program phases include baseline, monitoring-groundtruthing, monitoring-attraction, monitoring condition, and monitoring-annual.

The detailed plan summaries are a codification of the techniques used for each phase, and matrices of the data collected. This document presents examples of the tables to be used. A site management and remedial response plan had not been developed at the time of the document preparation. A plan must be developed at three levels: verification, program adjustment, and severe fault.

Several appendices have been developed to support this monitoring plan. Two are directly appended to this monitoring plan, while others are found in the file under separate cover. The following is a list of supporting documents.

Appendix A: PSDDA Memorandum for Record, Evaluation Procedures/Disposal Site Work Group Monitoring Meeting May 7, 1986.

B: Cost Estimates PSDDA Phase I Environmental Monitoring.

Supporting Document: Crawley, D.K. et al. undated. Guidelines and Procedures for conducting an Earthworm Bioassay.

: Unauthored, undated. Plant Bioassay Methods and Materials (draft)

: U.S. Army Engineer Waterway Experiment Station, 1985. Environmental Effects of Dredging Technical Notes — Interim Guidance for Predicting Quality of Effluent Discharged from Confined Dredged Material Disposal Areas. (General - EEDP-04-1, Test Procedures - EEDP-04-2, Data Analysis - EEDP-04-3, and Application - EEDP-04-4).

EXHIBIT E.18 PRELIMINARY COST ANALYSIS FOR TESTING AND DREDGED MATERIAL MANAGEMENT

TITLE: Phase 1 Puget Sound Dredged Disposal Analysis Task 3.2: Cost Analysis

PREPARER: Tetra Tech, Inc. for Resource Planning Associates/U.S. Army Corps of Engineers - Seattle District

REPORT DATE: August 1986 (draft report)

STUDY PURPOSE

The objectives of this cost analysis are to:

- Develop cost estimates for the chemical and biological testing specified in the dredged material evaluation procedures being developed by the Evaluation Procedures Work Group (EPWG) of the Puget Sound Dredged Disposal Analysis (PSDDA)
- Compare these costs to costs of current and historic testing programs
- Develop a cost analysis for dredged material management scenarios based on the three levels of sediment quality provided by EPWG for allocating volumes of dredged material to two disposal categories: unconfined, open-water disposal or confined disposal
- Develop a cost analysis for long-haul transport of dredged material for disposal in the Strait of Juan de Fuca and the ocean, and compare these costs with costs of confined disposal in Puget Sound.

SUMMARY OF RESULTS AND CONCLUSIONS

One of the factors being considered in developing the sediment evaluation procedures is the increase in overall program costs that would result from the selection of increasingly more restrictive sediment quality levels as the minimum level of sediment quality (maximum level of biological effects) acceptable for unconfined, open-water disposal. This cost analysis provides cost comparisons of three alternative disposal scenarios, each based on one of the three maximum levels (ML) of dredged material sediment quality (ML-1, ML-2, and ML-3) being considered in the PSDDA.

Prediction of costs for the alternative disposal scenarios depends on estimates of both the level of contamination and the volume of sediments to be dredged. The U.S. Army Corps of Engineers projected a total dredging volume of 19,697,000 yd3 for a 15-yr operating period (1986-1989) in the Phase I area. Classifying sediments to be dredged with existing sediment chemistry data (presented in the Appendix) for the major dredged waterways in the three regional service areas, it was estimated that approximately 73 percent of this total dredged volume would exceed ML-2, thus requiring confined disposal if the ML-2 guidelines were adopted. Approximately 40 percent would exceed ML-3, and all material would exceed ML-1.

Costs were also estimated for the chemical and biological tests proposed by EPWG to determine sediment quality. Although chemical and biological tests are currently required, the test procedures set forth by EPWG require a greater number of biological tests and analyses for a greater number of chemicals. Phase I chemical testing costs for projects ranging in size from 10,000 to 1,000,000 yd3 were projected to be 3-5 times as high as current costs. The cost of biological testing was projected to be approximately 7 times as high ($6,050 vs. $900 per sediment sample) per suite of tests.

The costs of dredged material management (dredging, transport, and disposal) were estimated for a variety of management options under each ML guideline. Primary emphasis was placed on comparing the costs of five disposal options under two categories: unconfined (open-water) and confined [open-water, nearshore, upland (partial security), and upland (secure disposal)]. The confined technologies, particularly those using upland sites, have greater capabilities for isolating contaminants from the surrounding environment. The costs of using these disposal options are also higher than unconfined open-water disposal as a result of more stringent maintenance and monitoring requirements and greater transport distances.

Using ML-2 to determine the volume for unconfined disposal, for example, the projected 15-yr management costs were estimated to be $1,585,000,000 (including testing and transport, excluding dredging, and using all four confined options in a prescribed proportional allocation). In contrast, the cost of disposing of all dredged material at unconfined, open-water sites was estimated in similar fashion to be about $33,885,000. Excluding the upland secure disposal technology in the first case reduces the cost estimate from $1,585,000,000 to $113,400,000. The cost per unit volume for this disposal option ($286.07/yd3) is over thirty times as great as that of the most costly of the other three confined options (upland, partial security), and nearly two hundred times as great as the cost for unconfined disposal (the least expensive of all options). The average cost per yd3 for unconfined disposal in the Strait of Juan de Fuca or open ocean was estimated to be $31.92, much higher than the $1.57 estimated for unconfined disposal in the Sound, primarily as a result of large transport costs.

The overall annual cost of implementing the proposed PSDDA testing and dredged material management program at ML-2 was estimated to be approximately $7,561,000 (excluding dredging and the upland-secure disposal option).

January 1988 rev.

EXHIBIT E.19 REVIEW OF CANADIAN REGULATIONS FOR DISPOSAL OF DREDGED MATERIAL IN OPEN WATER

TITLE: Open-water Disposal of Material in Canadian Waters. Puget Sound Dredged Disposal Analysis Report.

PREPARER: Envirosphere Company for Cooper Consultants, Inc./ U.S. Environmental Protection Agency.

REPORT DATE: 1986.

STUDY PURPOSE

The purpose of this study is to review Canadian open-water, unconfined disposal practices and regulations and compare these to Puget Sound. This report investigates the requirements for characterization of dredged material and the evaluation and siting processes for disposal in Canadian waters.

SUMMARY OF RESULTS AND CONCLUSIONS

Open-water disposal of material into Canadian waters is regulated through a system of permits specified by the Ocean Dumping Control Act (ODCA) obtained from the Environmental Protection Service (EPS). The terms and conditions of the ODCA permits vary with the type of substance being dumped. Requirements deal with three different schedules, listing substances and concentration limits. Schedule I lists "prohibited" substances known to present serious threats to the marine environment due to toxicity, accumulation, and persistence. These can only be disposed of in trace amounts. Schedule II lists "restricted" substances that may be dumped if not present in large quantities and if care is taken to isolate the waste. Schedule III includes factors that are to be considered in all disposal permits and are general properties of the material and disposal site. The permitting decisions are made on a case-by-case basis according to technical evaluation guidelines. Schedules I-III are printed in their entirety in this report.

Permit application forms require general dumping information, and information on the applicant, the dump site, methjod of disposal, and properties of the dredged material. Initial review of the application is conducted to assess the situation and determine what testing is required. First stage sampling is usually one surficial grab sample per 5,000 m3. If results indicate that contaminants are well within limits, no further testing is necessary. If concentrations exceed the limits, extensive sampling is required. In addition to chemical analyses, physical and biological assessments may be required. Issuance or denial of an ODCA permit for open-water disposal is based primarily on the limits addressed in Schedule I and II substances.

The EPS specifies the disposal site following recommendations from the Regional Ocean Dumping Advisory Committee. The closest designated site is usually specified. To the greatest extent possible, existing disposal sites are utilized. Timing restrictions and monitoring during disposal operations may be required in cases involving a fisheries resource or other tidal/seasonal factors.

The Puget Sound and Canadian review processes are summarized for comparison. The technical evaluation procedures for disposal of material in open-waters are considered to be less standardized for Canadian ODCA permits than for permits under the U.S. EPA (Region X), which uses the Interim Sediment Criteria established by Washington Department of Ecology for Puget Sound. The ODCA relies more on case-by-case analysis whereas the Puget Sound evaluation process incorporates testing for all dredging/disposal operations. In the Canadian ODCA permit process, sampling is generally minimal, and the process relies mostly on historical data, unless it has been established that more information is needed. In Puget Sound, areas of moderate and high contamination require analyses of various pollutants and amphipod bioassay tests. Contaminant limits are higher for a Canadian ODCA permit.

January 1988 rev.

EXHIBIT E.20 WATERWAYS EXPERIMENT STATION
DRAFT PRETREATMENT REPORT

TITLE: Cost Analysis for Solidification/Stabilization of Contaminated Dredged Material

PREPARER: Waterways Experiment Station - John Cullinane

REPORT DATE: May, 1987

STUDY PURPOSE

Evaluate the technical feasibility, effectiveness of contaminant containment, and cost of solidifying or stabilizing dredged material for disposal onshore or in upland areas.

SUMMARY OF RESULTS AND CONCLUSIONS

Plant mixing may be accomplished through the use of land-based mixing plant, by a barge mounted system where the settling agent are mixed during dredging and transport, or by a shore based system where mixing is accomplished before off-loading. Leachability studies from solidified/stabilized sediments indicate complete immobilization of arsenic and zinc, and depending on the formulation, at least 93 percent of cadmium, chromium, and lead were resistant to leaching.

Several solidification/stabilization formulation were examined that used a combination of materials in addition to dredged material; these other materials include portland cement, a proprietary additive (firmix), Class C flyash, and hydrated lime. The highest 28-U.C.S. (605 psi) was obtained with a 0.15/0.15/1.0 mixture of portland cement/firmix/sediment. The highest 60 day U.C.S. (1,153 psi) was obtained by a 0.6/1.0 mixture of firmix/sediment. The U.C.S. of very hard clay is 56 psi and that of low strength concrete is approximately 2,000 psi.

A cost analysis was performed for a land based mobile plant and a barge mounted mixing plant with the operational factors assumed for the dredge production rate, barge capacity, sediment density, and a sediment/portland cement mixture of 0.1/1.0.

Solidification/stabilization appears to be an economically viable alternative. A barge mounted system could solidify/stabilize dredged material at a cost of $22 per yd3 or a cost of $27.67 per yd3 for a land based system.

January 1988 rev.

EXHIBIT E.21 DREDGED MATERIAL ALTERNATIVE SELECTION STRATEGY (DMASS) REPORT

TITLE: Guidelines for Selecting Control and Treatment Options for Contaminated Dredged Material

PREPARER: Waterways Experiment Station - M. John Cullinane, D. Averett, R. Shafer, J. Male, C. Truitt, M. Bradbury

REPORT DATE: September, 1986

STUDY PURPOSE

To review alternative technologies and strategies for dredging, transport, and disposal of contaminated dredged material and develop a strategy for selecting environmentally preferable and cost effective alternatives for dredged material management.

SUMMARY OF RESULTS AND CONCLUSIONS

Alternative technologies and alternative strategies for dredging, transport, and disposal of contaminated dredged material are reviewed. Contaminant control/treatment during three basic operations are discussed. These include contaminant control/ treatment during dredging, contaminant control/treatment during material transport, and contaminant control/treatment during disposal operations.

The selection of appropriate technologies for contaminated dredged material management depends on the physical and chemical profile of the sediments, the physical state (solid, liquid, gas) of the contaminants of concern, the state changes that may occur at different phases of the dredging and disposal operations, physical characteristics of the proposed disposal site, and contaminant release criteria for the selected disposal site(s). Three disposal site scenarios are discussed: upland, nearshore, and restricted open-water. Appropriate technologies and alternatives ar selected on the basis of a comparison between the projected efficiency of an alternative in presenting an off site release and the off site release criteria for a specific site. The objective of the selection process is to minimize the cost of contaminant control/ treatment subject to site-specific environmental criteria. Thus, two major categories of information must be compiled: the effectiveness of the proposed control/treatment option and the acceptable criteria concerning concentrations of contaminants in water, sediments and soils, and air at a specific disposal site. Technologies should be used that ensure that criteria will be met during all phases of dredging transport and disposal operations.

Many technologies have been developed for control/treatment of contaminated media. These technologies have the potential for application to a contaminated dredged material handling operation. Such technologies are identified in this report. Technologies are separated into proven, demonstrated, demonstrable, and conceptual categories.

In the case of small projects, it is anticipated that the cost of environmental related testing may exceed the cost of disposal. The concept of disposal area overdesign can be used to offset the high cost of testing. Under this concept, expensive testing is foregone in favor of extensive engineered controls, monitoring, and agreements of implementation of remedial actions.

EXHIBIT E.22 NOAA SUBLETHAL BIOASSAY REPORT

TITLE: Memo from Sin-Lam Chan of the NW and Alaska Fisheries Center to Gail Arnold of U.S. Army Corps of Engineers

PREPARER: Sin-Lam Chan, NW and Alaska Fisheries Center, National Marine Fisheries Service

REPORT DATE: August 18, 1986

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE

Northwest and Alaska Fisheries Center
Environmental Conservation Division
2725 Montlake Boulevard East
Seattle, WAshington 98112
revised Sept 30, 1986
August 18, 1986 F/NWC6:COE

Ms. Gail Arnold
Environmental Resources Section
U.S. Army Corps of Engineers
P.O. Box C - 3744
Seattle, WA 98124-2255

Dear Gail:

This letter is to summarize progress on development and evaluation of long-term sediment bioassays using juvenile geoducks (Panopea generosa) and juvenile sand dollars (Dendraster excentricus). Despite the brief time period we have had to work on the project (less than 3 months), a considerable volume of data have been collected. A series of exposures of each species to over 20 different sediments has been completed and additional exposures are currently in progress. A preliminary analyses of results from these completed bioassays, as well as those from amphipod bioassays, bacterial bioluminescence (Microtox) assays, and the physical and chemical analyses of the same test sediments form the basis for this progress report.

A major focus of the geoduck and sand dollar bioassays evaluation work completed to date has been testing of 8 sediments collected during May and June 1986 as part of sediment testing for the Operations and Maintenance dredging of the East, West and Duwamish Waterways. The 8 sediments were CH1, CG1, CE3, CG3, CF1, CD1, CE1 and CAB1. Also used in the evaluations were a cresote-contaminated sediment from Eagle Harbor and reference sediments from West Beach, Sequim Bay, the Dosewallips River delta, and Tolmie State Park. In addition to lethality, a variety of sublethal criteria of effects were evaluated. In geoduck bioassays we measured growth (based on shell width and concentration of tissue total protein), burial behavior, concentration of tissue triglycerides, and adenylate energy charge (AEC). In sand dollar bioassays growth (based on test diameter and concentration of tissue total protein) and mobility (based on dislodgment of markers) were assessed.

Preliminary results of the chemical analyses for selected metals and aromatic hydrocarbons (AHs) are shown in Appendix

I. Analysis for chlorinated hydrocarbons has not yet been completed. Among the Duwamish Waterway sediments tested in the geoduck and sand dollar developmental work, there was little variation in concentrations of AHs; two were characterized by about 11,000 ng/g high molecular weight AHs while 5 of the remaining 6 contained 2200 to 4400 ng/g high molecular weight AHs. Not suprisingly, the Eagle Harbor sediment contained about 250,000 ng/g high molecular weight AHs. Only one sediment (CD1) showed a high degree of contamination with metals (i.e. Cd 15 ug/g, Cu 140 ug/g and Pb 70 ug/g dry weight).

Results of Microtox assays of organic extracts of the Duwamish Waterway sediments tended to reflect the uniform degree of contamination of these sediments with organic chemicals. Of the 12 Duwamish Waterway sediments tested, 10 had 15 min EC50s of less than 150 uL/L. All were significantly more toxic (P=0.05) than the extract of West Beach sediment. In contrast, results of amphipod bioassays (Appendix II) indicated significantly different (P=0.05) survival in only 5 of the 12 Duwamish sediments when compared to West Beach controls. Of the 8 Duwamish Waterway sediments also tested in geoduck and sand dollar bioassays, only two (CD1 and CG3) caused significantly reduced survival in amphipod bioassays and were judged significantly toxic in Microtox assays.

Appendix III summarizes results of the first two juvenile geoduck bioassays. In the first bioassay, in addition to 4 Duwamish Waterway sediments, selected concentrations of Eagle Harbor sediment (diluted with native Dosewallips sediment) and reference sediments from West Beach, Sequim Bay and the Dosewallips River delta were tested. In the second bioassay 4 additional Duwamish Waterway sediments were tested along with the same reference sediments.

Results of the goeduck bioassays generally indicated the insensitivity of this test species to chemically contaminated sediments. There were no significant differences in survival of geoducks exposed to any of the test or reference sediments, including the highly contaminated Eagle Harbor sediment (at 100% concentration) and the contaminated Duwamish Waterway sediment CD1. This latter sediment, containing relatively high concentrations of AHs and metals, produced 90% mortality in the amphipod bioassay. Likewise, no significant differences in final shell width were detected among geoducks exposed to any of the test or reference sediments. Furthermore, there were no significant differences in concentrations of total

tissue protein or tissue triglycerides among geoducks exposed to any of the Duwamish Waterway or Eagle Harbor sediments when compared to the concentrations measured in animals held on the native Dosewallips sediment. However, any final conclusions on the utility of measuring these perameters should be delayed until changes in concentrations of total tissue protein and tissue triglycerides, as well as tissue AEC, can be statistically evaluated together. The measurement of tissue AEC has required substantally more developmental work than anticipated (due to the extremely small amounts of tissue available) and analysis of tissues from the first two geoduck bioassays is not yet complete. Data collected on burial behavior is also still being analyzed; however, preliminary examination suggests delayed or non-burial of geoducks in some of the more contaminated sediments (e.g. Eagle Harbor).

Results of a parallel series of exposures of juvenile sand dollars to the same test and reference sediments are summarized in Appendix IV. Whereas sediment from the Dosewallips River delta was used as the native control sediment in the geoduck bioassays, sediment from Tolmie State Park near Olympia (where the sand dollars were collected) was used as the native control for this species.

Results of the first sand dollar bioassay generally indicate poor condition of the test animals. Despite good survival and apparent health of the sand dollars prior to the start of testing, substantial variability occurred in survival in all exposure groups. Of the 14 sediments tested, only sediment from Sequim Bay caused mortality that was significantly different from that observed on the native Tolmie State Park sediment. Moreover, growth was generally poor and there were several groups, including that exposed to the Tolmie sediment, that failed to show any growth at all. While there were significant differences in concentrations of total tissue protein among the different exposure groups, the apparent poor health of the test animals precludes meaningful interpretation of these differences.

In direct contrast, the second sand dollar bioassay was technically successful. This was likely due in part, to careful selection of vigorously-feeding and apparently healty test animals prior to the start. Survival was extremely high among sand dollars exposed to all the relatively uncontaminated reference sediments. However, no significant differences in survival were observed among organisms exposed to any of the Duwamish Waterway sediments, including the highly contaminated CD1. In contrast, significant differences in growth of sand dollars exposed to 2 of the Duwamish Waterway sediments were detected. Sand dollars exposed to both sediments CD1 and CE1 showed reduced growth compared to those exposed to the native

Tolmie State Park sediment. Moreover, sand dollars exposed to the same Duwamish sediments (CD1 and CE1) also showed significantly reduced mobility compared to reference or control. While analyses of tissues from this second bioassay for total protein have not yet been completed, the combined results of growth and mobility tests suggest further evaluation would be in order.

Summary and Recommendations:

In conclusion, our results to date with both juvenile geoducks and sand dollars do not support the use of these species in long-term sediment bioassays. These preliminary findings indicate that neither species is particularly sensitive to sediment-associated chemical contaminants. Although the rather uniform degree of contamination of the Duwamish Waterway sediments somewhat limited the opportunity to evaluate these bioassays over a range of contaminant concentrations, the inability to demonstrate clearly lethal or sublethal effects with Eagle Harbor sediment indicates an insensitivity of these species to the ubiquitous aromatic hydrocarbons and possibly other contaminants. We do, however, consider these first results to be of a provisional nature and feel that any more formal conclusions should not be drawn until these data can be more rigorously analyzed and the results of bioassays currently in progress can be fully evaluated. Results of the second sand dollar bioassay suggest further evaluation of this species is in order. Moreover, while no single criteria of effect may be useful in assessing long-term impacts of chemical contaminants, simultaneous evaluation of several parameters (e.g. AEC, triglycerides, size, protein) may be a more productive approach.

Nonetheless, at this time we can not recommend either juvenile geoducks or sand dollars for use in long-term bioassays to be included in the PSDDA phase one study document. Moreover, we know of no long-term marine sediment bioassay that has undergone sufficiently rigorous testing to merit even an interim recommendation. Accordingly, we see no other immediate alternative to the continued reliance on short-term bioassays; however, we would emphasize that long-term testing should be required as soon as a scientifically defensible bioassay is available. In the interim, we would recommend that a battery of short-term tests utilizing phylogenetically diverse test species and life stages be required. Candidate bioassays might include a 10-day amphipod bioassay, 48-hour oyster embryo bioassay, and a bacterial bioluminescence assay.

A long-term surf smelt egg-larval bioassay may also be of considerable potential; however, further testing would be required.

We look forward to continuing cooperative investigations with the Corps.

Sincerely,

S Chan

Sin-Lam Chan, Ph.D.
Deputy Division Director

Appendix I. Results of chemical analyses of Duwamish Waterway and reference sediments for selected metals and aromatic hydrocarbons.[a]

	CAB1	CC1	CC1[b]	CD1	CE1	CE2	CE3
metals, µg/g (ppm), dry weight							
arsenic	7.1	10.		29	24	17	6.1
cadmium	0.74	0.85		15	1.8	1.6	1.7
copper	40.	44		140.	74	63	74
lead	51	46		270.	80.	100.	52
mercury	0.28	0.27		0.74	0.23	0.12	0.06
zinc	69.4	62.2		374	140.	120.	41.6
organics, ng/g (ppb), dry weight							
high molecular weight aromatic hydrocarbons -c	3100	3000	4200	11000	4400	2600	340
low molecular weight aromatic hydrocarbons -d	450	420	1100	3200	440	350	39

a The "less than" symbol (<) indicates that the analyte was not detected in concentrations above the stated value. Where replicates for specific metals were analyzed the mean value is reported.
b Replicate analyzed for organics only.
c Summation of the concentrations of dibenz[a,h]anthracene, benz[a]anthracene, chrysene, fluoranthene, pyrene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, benzo[ghi]perylene, and benzofluoranthenes.
d Summation of the concentrations of acenaphthene, naphthalene, anthracene, phenanthrene, acenaphthylene, and fluorene.

DRAFT

Appendix I. (cont.)[a]

	CF1	CF1[b]	CG1	CG2	CG3	CH1	CH2
metals, µg/g (ppm), dry weight							
arsenic	16	11	19	16	17	16	17
cadmium	1.2	0.86	1.6	1.5	1.3	1.3	1.4
copper	43	36	63	48	51	45	39
lead	34	17	60.	40.	51	47	40.
mercury	0.12	0.25	0.19	0.14	0.14	0.17	0.11
zinc	70.2	70.3	116	97.9	109	90.9	84.3
organics, ng/g (ppb), dry weight							
high molecular weight aromatic hydrocarbons -c	3500	2200	11000	1100	4100	3500	3100
low molecular weight aromatic hydrocarbons -d	160	150	3200	150	320	160	130

a The "less than" symbol (<) indicates that the analyte was not detected in concentrations above the stated value. Where replicates for specific metals were analyzed the mean value is reported.

b Blind replicate analysis

c Summation of the concentrations of dibenz[a,h]anthracene, benz[a]anthracene, chrysene, fluoranthene, pyrene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, benzo[ghi]perylene, and benzofluoranthenes.

d Summation of the concentrations of acenaphthene, naphthalene, anthracene, phenanthrene, acenaphthylene, and fluorene.

DRAFT

Appendix I. (cont.)[a]

	Tolmie	West Beach	Sequim	Sammish	Discovery Bay	Carr Inlet	Eagle Harbor	Dosewallips
metals, µg/g (ppm), dry weight								
arsenic	2.1	3.4	27	12	9.3	11	6.7	8.1
cadmium	0.04	0.41	1.7	0.99	1.0	0.45	1.1	0.64
copper	4.0	5.6	37	23	7.7	10	37	34
lead	0.52	0.71	8.3	7.4	2.0	4.8	71	3.5
mercury	< 0.03	< 0.03	0.07	0.08	0.04	< 0.03	0.21	< 0.02
zinc	15.3	17.7	73.7	60.5	31.2	23.5	45.8	57.9
organics, ng/g (ppb), dry weight								
high molecular weight aromatic hydrocarbons -b	12	12	200	780	120	91	250000	28
low molecular weight aromatic hydrocarbons -c	< 6	< 6	11	32	19	17	120000	3

a The "less than" symbol (<) indicates that the analyte was not detected in concentrations above the stated value. Where replicates for specific metals were analyzed the mean value is reported.

b Summation of the concentrations of dibenz[a,h]anthracene, benz[a]anthracene, chrysene, fluoranthene, pyrene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, benzo[ghi]perylene, and benzofluoranthenes.

c Summation of the concentrations of acenaphthene, naphthalene, anthracene, phenanthrene, acenaphthylene, and fluorene.

DRAFT

Appendix I. (cont.)[a]

	Sqm 1	Sqm 1'[c]	Duw III[b,c]	Duw III[d]	Duw III[d]	previously run Duw III $\bar{x}$	cv	n
metals, µg/g (ppm), dry weight								
arsenic	6.3	6.5	31			28	2	2
cadmium	1.4	0.94	1.8			1.4	30	2
copper	17	15	320			320	2	2
lead	3.3	3.3	230			220	3	2
mercury	0.06	0.05	1.8			1.3	17	2
zinc	40.0	39.7	366			320	9	2
organics, ng/g (ppb), dry weight								
high molecular weight aromatic hydrocarbons -e	1100			20000	20000	-	-	-
low molecular weight aromatic hydrocarbons -f	620			4000	3300	-	-	-

a The "less than" symbol (<) indicates that the analyte was not detected in concentrations above the stated value. Where replicates for specific metals were analyzed the mean value is reported.
b Submitted as a blind reference material.
c Replicate analyzed for metals only.
d Replicate analyzed for organics only.
e Summation of the concentrations of dibenz[a,h]anthracene, benz[a]anthracene, chrysene, fluoranthene, pyrene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, benzo[ghi]perylene, and benzofluoranthenes.
f Summation of the concentrations of acenaphthene, naphthalene, anthracene, phenanthrene, acenaphthylene, and fluorene.

DRAFT

Appendix I. (cont.)[a]

	blank[b]	blank[b]	blank[c]	blank[c]	blank[c]	blank[c]
metals, µg/g (ppm), dry weight						
arsenic	< 0.002	< 0.002				
cadmium	< 0.0001	< 0.0001				
copper	0.01	0.01				
lead	< 0.1	< 0.1				
mercury	-	-				
zinc	0.074	0.05				
organics, ng/g (ppb), dry weight						
high molecular weight aromatic hydrocarbons -d			6	< 6	29	<9
low molecular weight aromatic hydrocarbons -e			< 7	< 8	8	<7

a The "less than" symbol (<) indicates that the analyte was not detected in concentrations above the stated value. Where replicates specific metals were analyzed the mean value is reported.
b Replicate analyzed for metals only.
c Replicate analyzed for organics only.
d Summation of the concentrations of dibenz[a,h]anthracene, benz[a]anthracene, chrysene, fluoranthene, pyrene, benzo[a]pyren indeno[1,2,3-cd]pyrene, benzo[ghi]perylene, and benzofluoranthenes.
e Summation of the concentrations of acenaphthene, naphthalene, anthracene, phenanthrene, acenaphthylene, and fluorene.

DRAFT

(REVISED 30 Sep 86)

Appendix II

Summary of results of bacterial bioluminescence (Microtox) assays and 10-day amphipod lethality bioassays of selected Duwamish Waterway and refererence sediments.

Sediment	Microtox[a] (15min EC50 and 95% C.I.,uL/L)	Amphipod Survival[b]
CD1[c]	45.1(39.4-52.4)	2.0 ± 1.2[d]
CG2	51.3(36.7-92.5)	16.2 ± 1.6[d]
CE1[c]	83.1(70.1-98.5)	16.0 ± 2.9
CF1[c]	88.8(78.3-102.2)	16.0 ± 3.3
CH2[c]	119.2(86.1-178.6)	15.8 ± 2.3[d]
CG1[c]	120.3(93.9-172.8)	17.8 ± 1.9
CC1	138(125-152)	13.4 ± 1.5[d]
CE3[c]	139(127-151)	18.8 ± 0.8
CH1[c]	140(126-158)	17.0 ± 2.4
CG3[c]	147(105-216)	16.4 ± 3.1[d]
CAB1[c]	837(680-1100)	18.0 ± 1.2
CE2	1340(1190 - 1540)	18.8 ± 0.8
Sequim Bay[c]	70.7(64.2 - 78.5)	15.0 ± 2.1 17.7 ± 0.6
West Beach[c]	4390(3640 - 5590)	19.6 ± 0.6 20.0 19.2 ± 1.8
Eagle Harbor[c]	358(327-396)	N.T.[e]

a. The 15min EC50 is the concentration of extract causing a 50% decrease in emitted light after 15 minutes of exposure.

b. Results expressed as $\bar{X}$ ± S.D. of the number surviving (N=5). Each container was originally seeded with 20 amphipods.

c. Sediments used in evaluation of juvenile geoduck and sand dollar bioassays.

d. Significantly different ($P \leq 0.05$) from respective West Beach control (ANOVA, Dunnet's Multiple comparison)

e. Not tested

Appendix III. Summary of results of juvenile geoduck bioassays of selected sediments from the Duwamish Waterway, Eagle Harbor and selected reference area.

Sediment	Survival[a]	Final Shell Width[b] (mm)	Total Tissue Protein[c] (mg/g)	Tissue Triglycerides[d] (mg/g)
Bioassay 1 (30 days)				
CH1	14.4 ± 3.9	2.4 ± 0.6	5.1 ± 1.7	5.3 ± 2.1
CG1	12.2 ± 2.6	2.5 ± 0.6	6.1 ± 1.6	3.6 ± 2.1
CE3	17.0 ± 1.9	2.9 ± 0.7	4.7 ± 0.8	3.7 ± 1.6
CG3-100%	14.6 ± 2.7	2.4 ± 0.5	5.4 ± 1.3	3.4 ± 1.3
CG3-67%	18.0 ± 1.6	2.7 ± 0.6	6.0 ± 1.6	5.0 ± 1.5
CG3-33%	14.0 ± 1.0	3.0 ± 0.7	4.3 ± 0.7	3.7 ± 0.7
Eagle Harbor-100%	14.0 ± 2.5	2.6 ± 0.5	5.5 ± 1.4	3.9 ± 1.7
Eagle Harbor-50%	14.0 ± 2.1	2.8 ± 0.7	5.2 ± 1.1	4.4 ± 1.8
Eagle Harbor-25%	16.4 ± 2.4	2.9 ± 0.8	5.7 ± 1.4	4.8 ± 1.9
Eagle Harbor-12.5%	15.8 ± 1.3	2.6 ± 0.7	5.7 ± 1.2	4.2 ± 1.1
Eagle Harbor-6.25%	15.4 ± 1.1	2.7 ± 0.8	4.3 ± 0.9	3.9 ± 1.2
Dosewallips River delta	15.2 ± 4.7	3.0 ± 0.7	5.1 ± 0.6	4.7 ± 0.6
West Beach	16.2 ± 2.1	3.0 ± 0.7	6.5 ± 1.2	5.9 ± 1.7
Sequim Bay	15.6 ± 2.6	2.8 ± 0.7	4.7 ± 1.4	3.3 ± 1.2
Bioassay 2 (28 days)				
CF1	18.0 ± 1.6	2.9 ± 0.6	5.0 ± 1.5	3.8 ± 0.7
CD1	18.0 ± 0.7	3.1 ± 0.6	3.7 ± 0.9	3.5 ± 1.2
CE1	18.8 ± 1.6	3.0 ± 0.6	3.8 ± 1.0	3.1 ± 0.8
CAB1	18.4 ± 1.1	3.1 ± 0.6	4.4 ± 1.3	3.7 ± 1.4
Dosewallips River Delta	18.6 ± 1.1	3.1 ± 0.6	4.5 ± 0.8	4.0 ± 1.1
West Beach	17.4 ± 2.0	3.1 ± 0.7	3.8 ± 1.3	3.3 ± 0.8
Sequim Bay	18.4 ± 1.1	3.5 ± 0.8	4.1 ± 0.8	3.2 ± 0.6

a. Survival expressed as $\bar{X} \pm$ S.D., N=5. Each test container was originally seeded with 20 geoducks.

b. Final shell width expressed as $\bar{X} \pm$ S.D.

c. Concentration expressed as $\bar{X} \pm$ S.D. mg protein /g of geoduck tissue.

d. Concentration expressed as $\bar{X} \pm$ S.D. mg triglycerides /g of geoduck tissue.

Appendix IV. Summary of results of juvenile sand dollar bioassays of selected sediments from the Duwamish Waterway, Eagle Harbor and selected reference areas.

Sediment	Survival[a]	Growth[b] (mm)	Total Tissue Protein[c] (mg/g)	Mobility[d]
Bioassay 1 (28 days				
CH1	12.8 ± 7.3	0.2 ± 0.2	1.7 ± 0.4[e]	0.6 ± 0.5
CG1	19.0 ± 0.7	0.7 ± 1.2	1.7 ± 0.4[e]	1.6 ± 1.5
CE3	14.8 ± 8.3	0.3 ± 0.1	1.9 ± 0.8	1.4 ± 2.1
CG3-100%	18.0 ± 3.9	0.1 ± 0.4	2.2 ± 1.5	1.4 ± 1.5
CG3-67%	14.8 ± 8.3	-0.1 ± 0.2	2.1 ± 0.3	1.2 ± 0.8
CG3-33%	14.4 ± 8.3	-0.1 ± 0.3	1.8 ± 0.6[e]	1.2 ± 0.8
Eagle Harbor-100%	18.4 ± 1.9	0.3 ± 0.7	1.9 ± 0.5[e]	0.6 ± 0.5
Eagle Harbor-50%	18.0 ± 1.2	0.3 ± 0.3	1.9 ± 0.5[e]	1.2 ± 0.4
Eagle Harbor-25%	14.4 ± 8.1	0 ± 0.5	2.5 ± 0.6	0.4 ± 0.5
Eagle Harbor-12.5%	15.2 ± 8.5	0.1 ± 0.2	1.6 ± 0.5[e]	1.4 ± 1.3
Eagle Harbor-6.25%	17.4 ± 2.6	0.2 ± 0.3	1.8 ± 0.5[e]	1.6 ± 2.1
Tolmie State Park	17.6 ± 1.7	-0.1 ± 0.4	2.5 ± 0.4	2.8 ± 1.9
West Beach	19.8 ± 0.4	0.3 ± 0.7	2.2 ± 0.7	4.2 ± 0.4
Sequim Bay	0.4 ± 0.9[e]	ND[f]	ND	ND
Bioassay 2 (28 days)				
CF1	20	1.6 ± 0.6	(analysis	5.4 ± 0.5
CD1	19.4 ± 0.5	0.8 ± 0.1[e]	in progress)	2.8 ± 0.8[e]
CE1	19.8 ± 0.4	1.1 ± 0.3[e]		2.4 ± 1.1[e]
CAB1	19.6 ± 0.5	2.3 ± 0.2		6.0
Tolmie State Park	19.8 ± 0.4	2.2 ± 0.3		5.8 ± 0.4
West Beach	19.8 ± 0.4	4.3 ± 0.5		6.0
Sequim Bay	20	3.4 ± 0.2		5.4 ± 0.9

a. Survival expressed as $\bar{X} \pm$ S.D., N=5. Each test dish was originally seeded with 20 sand dollars.

b. Growth expressed as $\bar{X} \pm$ S.D. change in test diameter

c. Concentration expressed as $\bar{X} \pm$ S.D mg protein/g sand dollar tissue.

d. Mobility expressed as $\bar{X} \pm$ S.D. the number of markers dislodged (N=5). Each test dish contained 6 markers.

e. Significantly different ($P<0.05$) from the native Tolmie State Park sediment (GT2 interval comparison test (Sokal and Rohlf, 1981))

f. Not determined due to low survival.

January 1988 rev.

EXHIBIT F

ENGLER, R. 1980. PREDICTION OF POLLUTION POTENTIAL THROUGH GEOCHEMICAL AND BIOLOGICAL PROCEDURES: DEVELOPMENT OF REGULATION GUIDELINES AND CRITERIA FOR THE DISCHARGE OF DREDGED AND FILL MATERIAL. IN: R.A. BAKER, ED. CONTAMINANTS AND SEDIMENTS. VOLUME 1: FATE, TRANSPORT, CASE STUDIES, MODELING, TOXICITY. ANN ARBOR SCIENCE. ANN ARBOR, MICHIGAN.

PREDICTION OF POLLUTION POTENTIAL THROUGH GEOCHEMICAL AND BIOLOGICAL PROCEDURES: DEVELOPMENT OF REGULATION GUIDELINES AND CRITERIA FOR THE DISCHARGE OF DREDGED AND FILL MATERIAL

Robert M. Engler
Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631
Vicksburg, MS 39180

PREDICTION OF POLLUTION POTENTIAL THROUGH GEOCHEMICAL AND BIOLOGICAL PROCEDURES: DEVELOPMENT OF REGULATION GUIDELINES AND CRITERIA FOR THE DISCHARGE OF DREDGED AND FILL MATERIAL

Robert M. Engler
Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631
Vicksburg, MS 39180

BACKGROUND

Navigable waterways of the United States have played a vital role in the Nation's economic growth through the years. The 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 290,000,000 cubic meters in maintenance dredging operations and about 78,000,000 cubic meters in new work dredging operations with the total annual cost exceeding $150,000,000.

Sediment contamination has generated concern that dredging and disposal may adversely affect water quality and aquatic organisms. Consequently, most of the concern has centered on aquatic disposal. In recent years, the CE has disposed of approximately half of the material at open-water sites. Because many of the waterways are located in industrial and urban areas, sediments are often contaminated with wastes from these sources.

The lead responsibility for development of ecological criteria and guidelines regulating the transport and disposal of dredged and fill material was legislatively assigned to the Environmental Protection Agency (EPA) to share in consultation and conjunction, respectively, with the CE. Moreover, 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), require the CE to actively participate in developing guidelines and criteria for regulating dredged and fill material discharge. The focal point for the developmental research on these procedures was the CE Dredged Material Research Program (DMRP).[1,2]

Legislative History

Circa 1880, early litigation[3] prompted the Congress to enact Section 10 of the Rivers and Harbors Act of 1890 and authorized by law the prohibition of any obstruction to the navigable capacity of any water of the United States. This Act led to a compilation of all navigation laws in Sections 9 through 20 of the Rivers and Harbors Appropriations Act of 1899.[3] The authority to implement this act through a regulatory permit program was vested in the Secretary of the Army acting through the Chief of Engineers. As discussed by Ablord and O'Neill,[3] the CE limited its jurisdiction to the protection of navigation and limited its review of proposed activities to only those effects. In the late 1960's the CE enlarged the scope of review of permit application to include fish and wildlife, conservation, pollution, aesthetics, ecology, and the general public interest[4]. In addition, the National Environmental Policy Act of 1969 (NEPA) required the public interest review as statutory and requires the CE to prepare an environmental impact statement where activities significantly affect the quality of the human environment.[3]

In 1972 the CE regulatory program became quite complex with enactment of the Federal Water Pollution Control Act Amendments of 1972 (FWPCA). As discussed by Ablord and O'Neill,[3] the goal of the FWPCA is "to restore and maintain chemical, physical, and biological integrity of the Nations's waters" with the CE responsible, through Section 404, for the permit program regulating the discharge of dredged and fill material into inland waters of the United States.

Oceans were treated in a similar manner by the Marine Protection Research and Sanctuaries Act of 1972 (MPRSA), which requires through Section 103 that all proposed operations involving the transportation for dumping of dredged material into ocean waters be evaluated to determine the potential environmental impact of such activities.[5] These activities are carried out by the CE

ocean dumping permit program. As with the FWPCA, the MPRSA is concerned with the unregulated dumping of material into ocean waters that "endanger human health, welfare, and amenities, and the marine environment, ecological systems, and economic potentialities."[6] As a consequence of these landmark environmental laws the Congress has mandated The CE a significant role in the environmental protection and ecological maintenance of the Nation's inland and ocean waters. Other environmental controls include ratification of international treaties involving the control of pollution of the Great Lakes and the oceans by incorporating international concerns through initiation or modification of domestic environmental legislation.

History of Litigation

Ablord and O'Neill[3] described several significant litigative actions that broadened the CE regulatory jurisdiction to include waters of the United States that were not considered historically "navigable" and currently under jurisdiction. The increased jurisdiction included "wetlands" areas and significantly broadened the scope and technical requirements of the CE regulatory program. The ocean dumping program of the MPRSA has also undergone legal scrutiny resulting in revisions of the technical criteria[7] to incorporate all requirements of international agreements as well as the basic considerations of the MPRSA. These important litigative actions have significantly broadened the technical considerations required to complete the ecological evaluations of proposed inland or ocean dredged and fill material discharge activities.

Chronology of Evaluative Procedure Development

Prior to about 1970, the only regulatory control of dredging, construction, and related activities was under the Rivers and Harbors Act of 1899. In the late 1960's, concern over possible environmental problems increased.

Concern over dredged material disposal was initially greatest in the Great Lakes region and resulted in the request of the Federal Water Quality Administration (FWQA, predecessor of EPA) that the CE Buffalo District initiate studies on the chemical characteristics of selected Great Lakes harbors. The harbor sediments were analyzed using methods developed to characterize municipal and industrial wastes rather than sediments. Consequently, many harbors have been erroneously characterized. Inadequacy of data led to certain revisions in the Rivers and Harbors Act of 1970.[8] Special provisions were made for dredged material disposal activities in the Great Lakes. The Act also authorized the CE to initiate a comprehensive evaluation of the environmental effects of dredged material disposal[1] through the DMRP.

The earliest guidelines or criteria proposed for dredged material, based on results of the Great Lakes Survey, were promulgated in 1971 by the FWQA/EPA in a memo and were commonly called "the Jensen Criteria." In the same year, the CE issued Engineering Circular 1165-2-97,[9] which stated that the dredged material disposal criteria formulated by the EPA (Jensen Criteria) should be applied to sediments dredged from all United States waters. Seven chemical constituents with concentration limits were specifically mentioned in the total-sediment (Jensen) criteria and included chemical oxygen demand, total Kjeldahl nitrogen, volatile solids, oil and grease, mercury, lead, and zinc (Table 1). The limits were total concentrations based on a dry weight of sediment. If the concentration of any constituent exceeded the numerical limit, the material was classified as polluted and was not acceptable for open-water disposal. Although the criteria were not specifically limited to the seven constituents for which limits had been established, implementation of the criteria was restricted almost exclusively to them.

General opposition to the Jensen Criteria has developed with time as technical weaknesses or flaws have become apparent. The procedures did

Table 1

Dredged Material Disposal Criteria Developed for FWQA*

Parameter	Maximum Percent Dry Weight
Volatile Solids	6.0
Chemical Oxygen Demand	5.0
Total Kjeldahl Nitrogen	0.10
Oil and Grease	0.15
Mercury	0.0001**
Lead	0.005
Zinc	0.005

* After Boyd et al.[1]

** A value of 0.001, which was a typographical error, appeared in the original report.

not take into account the geochemical location of contaminants in the dredged material, did not address the potential availability of contaminants to organisms, and did not consider background levels of the same constituents. The procedures prescribed for use with the criteria provided only an inventory of the total amount of each constituent contained in the sediment. This inventory accounts for only the mere presence of a contaminant and does not measure potential biological availability or chemical mobility. Table 2 presents an updated approach to "bulk" or Jensen Criteria used by EPA Region V.[10] An additional column has been added to list the average earth's crustal abundance for comparison to the "polluted" categories. Eight parameters classified as "heavily polluted" are actually less than natural abundance.

The MPRSA and FWPCA directed that the EPA develop regulatory criteria and guidelines in consultation and conjunction, respectively, with the CE. Criteria for implementing Section 103 of the MPRSA are used to evaluate the potential for harm due to the transportation for dumping of dredged material into ocean waters, and guidelines for implementing Section 404 of the FWPCA are used to evaluate dredged and fill material discharge into inland waters. Both Federal and private projects would be regulated using the same criteria and guidelines.

Ocean Dumping

Final regulations and criteria controlling ocean disposal of dredged sediments were published by the EPA on 15 October 1973[11] in the Federal Register. The procedures (criteria) for assessing the suitability of dredged sediments for ocean disposal consisted primarily of the Elutriate Test[21] in place of total sediment analysis. This procedure was used to address short-term water quality impacts but not the longer term benthic impacts. Bioassays were recommended only in general terms.

Table 2

Region V Sediment Criteria*

	Nonpolluted	Moderately Polluted	Heavily Polluted	Average Earth's Crustal Abundance**
Volatile Solids	<5%	5%-8%	>8%	
COD	<40,000	40,000-80,000	>80,000	
TKN	<1,000	1,000-2,000	>2,000	
Oil and Grease (Hexane Solubles)	<1,000	1,000-2,000	>2,000	
Lead	<40	40-60	>60	16
Zinc	<90	90-200	>200	80
Mercury	<1.0	N.A.	>1.0	0.5
Ammonia	<75	75-200	>200	
Cyanide	<0.10	0.10-0.25	>0.25	
Phosphorus	<420	420-650	>650	1,200
Iron	<17,000	17,000-25,000	>25,000	50,000
Nickel	<20	20-50	>50	100
Manganese	<300	300-500	>500	1,000
Arsenic	<3	3-8	>8	5
Cadmium	†	†	>6	0.2
Chromium	<25	25-75	>75	200
Barium	<20	20-60	>60	430
Copper	<25	25-50	>50	70

* After Bowden.[10]

** After Goldschmidt. A. Muir, Editor, and Clarendon Press, Oxford, Publishers of "Geochemistry."

† Lower limits not established.

Note: All ranges in mg/kg dry weight unless otherwise noted.

The MPRSA further required that the criteria for ocean disposal be updated at least every 3 years. The first updated criteria, which are currently in effect, were published in the 11 January 1977 Federal Register.[12] These criteria account for provisions of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (Convention) and reflect recent legal challenges by the National Wildlife Federation as to the adequacy of the 1973 criteria.[7,12] The Convention bans the ocean dumping of materials containing other than traces of certain compounds. Compounds on the prohibited list are considered to be present in trace quantities when the dumping of dredged sediments containing these contaminants will not cause significant undesirable effects.[12]

The potential for undesirable impacts of dredging and disposal and determinations of trace contaminants are assessed in the ocean-dumping criteria by means of liquid, suspended particulate, and solid-phase bioassays along with chemical analyses of the liquid phase. The impact of chemical constituents can be addressed by comparing their Elutriate concentrations with appropriate water quality criteria after taking initial mixing into account or through use of a liquid phase bioassay.

The 11 January 1977 criteria[12] also require by 1980 a thorough physical, chemical, and biological assessment of all ocean disposal sites prior to their designation as "final" and acceptable dump sites. Until that time actively used ocean sites will be listed as "interim" sites.

Inland Disposal

Interim/final guidelines for implementation of Public Law 92-500 were published in the Federal Register[13] on September 5, 1975. The guidelines require the proposed discharger to consider physical effects (especially impact on wetlands) and chemical-biological interactive effects, and to

conduct a thorough site selection assessment. Assessment of chemical water column effects is by means of the Elutriate Test. The permitting authority may also specify that the applicant conduct water column and benthic bioassays on a case-by-case basis. He may select total sediment-chemical analyses and/or benthic community structure analyses when reviewing alternative sites for potential selection.

Biogeochemical Complexity

Fundamental to understanding the impact of sediment discharge and resuspension on water quality and aquatic organisms is an understanding of how chemical constituents, which may have various effects on aquatic organisms, are associated with dredged sediments.

Sediments may be separated into several components or phases that are classified by their composition and mode of transport to the estuarine environment. Among them are detrital and authigenic phases.

Detrital components are those which have been transported to a particular area, usually by water. Detrital materials are derived from soils of the surrounding watershed and can include (a) mineral grains and rock fragments (soil particles) as well as stable aggregates, (b) associated organic material, and (c) culturally contributed components derived from agricultural runoff and industrial and municipal waste discharges.

Authigenic components are those which are formed in place or have not undergone appreciable transport. These materials are generally the result of aquatic organisms and include (a) shell material ($CaCO_3$), (b) diatom frustules (SiO_2), (c) some organic compounds, and (d) products of anaerobic or aerobic transformations.

In considering the in situ association with various sediment phases of trace elements in estuarine sediments, the water contained in inter-particle

voids or interstices must be considered. This is termed interstitial water (IW). In relation to the overlying water, chemical constituents may frequently be enriched in the IW by several mechanisms. Some constituents (metals and some nutrients) are ionically bound to the sediment in several exchange locations; these include the exchange sites of the silicate phase and exchange sites associated with organic matter or trace elements complexed with the organic phase. Man-made organics such as PCB's may be physically attached to these highly active silicate materials. Only a small amount of these low solubility or slightly soluble constituents is found dissolved in the IW. Heavy metals are also associated with hydrated manganese and iron oxides and hydroxides that are present in varying amounts in sediment. Another location for heavy metals is in the sediment-organic phase. The metals are incorporated into living terrestrial and aquatic organisms and are relatively stable; however, they may be released into the water column during decomposition. The greatest concentration of most inorganic chemical constituents is contained in the silicate mineral fraction (earth's crustal material) of a sediment.

From the previous discussion of elemental partitioning and for analytical purposes, the following categories of sediment components should be considered.[14]

a. Interstitial water (IW). This water, an integral part of sediment, is in dynamic equilibrium with the silicate and organic exchange phases of the sediment as well as with the easily decomposable organic phase.

b. Mineral exchange phase. That portion of the element that can be removed from the cation exchange sites of the sediment using a standard ion-exchange extractant (NH^4OAc, dilute HCl, NaCL, $MgCL_2$, etc.).

c. Reducible phase. This phase is composed of hydrous oxides of iron and manganese as well as hydroxides of Fe and Mn, which are relatively reducing (anaerobic) conditions. Of particular importance are the toxic metals (As, Cu, Cd, Ni, Co, and Hg) that may be associated with these discrete Fe or Mn phases as occlusions or coprecipitates.

d. Organic phase. This phase or partition of elements is that considered to be solubilized after destruction of the organic matter. This phase contains very tightly bound elements as well as those loosely chelated by organic molecules. An initial extraction by an organic chelate may be needed to differentiate between the loosely bound and tightly bound elements.

e. Residual phase. This phase contains primary minerals as well as secondary weathered minerals that are for the most part a very stable portion of the elemental constituents. Only an extremely harsh acid digestion or fusion will break down this phase. By far the largest concentration of metals is normally found in this fraction.[14]

A particular element or molecule can then be present (be partitioned) in a sediment in one or more of several locations. Possible locations include (a) the lattice of crystalline minerals; (b) the interlayer positions of phyllosilicate (clay) minerals; (c) adsorbtion on mineral surfaces; (d) association with hydrous iron and manganese oxides are hydroxides existing as surface coatings or discrete particles; (e) absorbtion or adsorbtion with organic matter existing as surface coatings or discrete particles; and (f) dissolved in the sediment interstitial water. These locations also represent a range in the degree by which an element may become released to the receiving water. This range extends from stable components in the mineral lattices, which are essentially insoluble, to soluble compounds in the sediment interstitial water, which are readily mobile. Electrochemical (Eh, pH) changes after disturbing and resuspending anaerobic bottom sediments may result in possible solution or precipitation of many elemental species and should be thoroughly characterized.

A sediment characterization procedure to elucidate the phase distribution of contaminants in dredged material must be applicable to many types of marine and freshwater sediments, both aerobic and anaerobic. To be realistic, sediment disturbance must be minimal. Thus, drying, grinding, and contact with atmospheric oxygen are undesirable. The sediment phases discussed previously were presented in their relative order of mobility and bioavailability.

Interstitial water is the most mobile, and consequently, the most available. When contaminants enter a body of water and subsequently sediment particulate matter, the contaminants normally enter two or three factions in varying concentrations but cannot be distinguished from natural levels by a bulk or total analysis.[8,14]

Further studies of chemical constituent release mechanisms[15] have evaluated conditions that enhance release of toxic metals when the sediment-water geochemical environment is drastically changed. As an example, the significant release of zinc to the water soluble phase was shown to occur at pH 5 under oxidizing (Eh) conditions. It must be emphasized that these acid-oxidizing, pH-Eh conditions do not normally occur in open-water disposal as anaerobic sediments normally remain near neutral pH and the oxidation processes that occur in the water column are not such as to result in an acidic condition.[8,14] Subsequently, after it settles, sediment normally returns to an anaerobic and near-neutral pH condition. On the other hand, if this sediment is placed in an upland containment area where oxidizing conditions can occur for a year or more and the sediments are high in total sulfide (common in many fine-grained estuarine sediments), the pH can become acidic and result in significant release of some contaminants[15] to the water-soluble phase. Therefore, judicious selection of the disposal mode (open-water versus upland) and an understanding of the long-term implications of either disposal mode are very important. These preliminary discussions only hint at the complexity of chemical constituent distribution and interaction within and among sediments; for a detailed discussion of sediment chemistry, biological, and water quality interrelations the reader is referred to References 8, 14, 15, 16, 17, 18, and 19.

Marine Protection Research and Sanctuaries Act

Section 103 of the MPRSA specified that all proposed operations involving the transportation for dumping of dredged material into ocean waters must be evaluated to determine the potential environmental impact of such activities. This must be done by the Secretary of the Army and the Administration of the EPA acting cooperatively through the District Engineer and Regional Administrator. Environmental evaluation must be in accordance with criteria published by EPA in the Federal Register.[12] Implementation of this evaluation program is aided by use of an EPA/CE Implementation Manual.[5] The ocean dumping criteria also require that the published[12] interim ocean disposal sites be designated as final ocean disposal sites by January 1980. This designation can only follow a comprehensive ecological investigation of the site and preparation of a site designation EIS by the EPA.[12]

An ocean dumping evaluation must consider materials prohibited from disposal by international treaty[7] (Public Law 92-254); the environmental impact; the general compatibility of the material with the disposal site; the need for ocean dumping with a thorough review of alternatives; impacts on aesthetics, recreation, and economics; and impacts on other uses of the oceans. Evaluations in CE regulation 33 CFR 209.120 and 33 CFR 209.145 must also be applied.

Federal Water Pollution Control Act Amendments of 1972

Section 404 of the FWPCA authorized the Secretary of the Army, acting through the Chief of Engineers, to issue permits for the discharge of dredged or fill material into waters of the United States at specified disposal sites. It also provided that guidelines developed by the EPA in conjunction with the CE be applied by the CE in selection of disposal sites and in the application review process. The EPA published technical guidelines[13] in 1975 for use

by the CE in conducting the required ecological evaluation of the proposed permit activity. The CE issued final regulations for the Regulatory Program in July 1977[20] to be used in evaluating proposed discharges of dredged or fill material into inland and ocean waters. In May 1976, the CE issued an interim guidance manual as specified in the Federal Register[13] to initiate technical implementation of the program.

Determinations to be made in a Section 404 evaluation include an evaluation of feasible alternatives; a determination that the discharge meets all of the requirements of the FWPCA; a determination that the proposed discharge will not result in an unacceptable degradation of the physical, biological, and chemical integrity of the waters of the United States, and the consideration of the factors in Section 403(c)(1) and 404(c) of the FWPCA; and a determination that the proposed discharge will be conducted in a manner to minimize potential degradation of the physical, biological, and chemical integrity of the waters of the United States.[6]

Other Considerations

Section 103[6] of the MPRSA requires that the criteria shall consider but not be limited to the following:

"(A) The need for the proposed dumping.

(B) The effect of such dumping on human health and welfare, including economic, esthetic, and recreational values.

(C) The effect of such dumping on fisheries resources, plankton, fish, shellfish, wildlife, shorelines and beaches.

(D) The effect of such dumping on marine ecosystems, particularly with respect to--

(i) the transfer, concentration, and dispersion of such material and its byproducts through biological, physical, and chemical processes,

(ii) potential changes in marine ecosystem diversity, productivity, and stability, and

(iii) species and community population dynamics.

(E) The persistence and permanence of the effect of the dumping.

(F) The effect of dumping particular volumes and concentrations of such materials.

(G) Appropriate locations and methods of disposal or recycling, including land-based alternatives and the probable impact of requiring use of such alternate locations or methods upon considerations affecting the public interest.

(H) The effect on alternate uses of oceans, such as scientific study, fishing, and other living resource exploitation, and nonliving resources exploitation.

(I) In designating recommended sites, the Administrator shall utilize wherever feasible locations beyond the edge of the Continental shelf."

Section 404[6] of the FWPCA requires that the guidelines shall include

"(A) the effect of disposal of pollutants on human health or welfare, including but not limited to plankton, fish, shellfish, wildlife, shorelines, and beaches;

(B) the effect of disposal of pollutants on marine life including the transfer, concentration, and dispersal of pollutants or their byproducts through biological, physical, and chemical processes; changes in marine ecosystem diversity, productivity, and stability; and species and community population changes;

(C) the effect of disposal, or pollutants on esthetic, recreation, and economic values;

(D) the persistence and permanence of the effects of disposal of pollutants;

(E) the effect of the disposal at varying rates, of particular volumes and concentrations of pollutants;

(F) other possible locations and methods of disposal or recycling of pollutants including land-based alternatives; and

(G) the effect on alternate uses of the oceans, such as mineral exploitation and scientific study."

These previously listed "legal/technical" considerations form the framework from which the ecological evaluations must be developed. Several of the considerations and inclusions are, however, at the forefront of the state of

the art and require "research" level approaches to be implemented into a dynamic, field-oriented regulatory program.

EVALUATIVE REQUIREMENTS

Ecological Evaluation of the Transportation for the Dumping of Dredged Material into Ocean Waters (MPRSA)

The potential effect of the ocean disposal of dredged material on marine organisms and human uses of the ocean may range from unmeasurable to important. These effects may differ at each disposal site and must be evaluated on a case-by-case basis. The Register[12] provides criteria for such an evaluation, with an emphasis placed on direct assessment of biological impacts, and the appropriate technical procedures are found in Parts 227 and 228. These procedures and their relationship to each other are illustrated diagrammatically and completely described in the EPA/CE Manual.[5]

Applicability

Section 103 of the Act[6] requires that criteria for the issuance of ocean disposal permits be promulgated after consideration of the environmental effect of the proposed ocean dumping operation, the need for ocean dumping, alternatives to ocean dumping, and the effect of all proposed action on aesthetic, recreational, and economic values, and on other uses of the ocean. The decision of a District Engineeer to issue or deny a permit and to impose specific conditions on any permit issued will be based on an evaluation of the permit application (Part 227) and upon the requirements for disposal site management (Part 228) criteria presented in Subchapter H of the Register.[12]

Prohibited Materials

The first evaluation involves the presence of certain prohibited substances that may not be ocean dumped under any circumstances. If materials such as high radioactive wastes or chemical or biological warfare agents are present, the permit application must be denied without further consideration.

Dredged material, however, is highly unlikely to contain these substances and must usually receive the full technical evaluation required by the criteria.

Exclusions from Testing

There are cases where dredged material is not considered chemically contaminated and would, therefore, cause negligible pollutional impact when discharged at an appropriate disposal site. Thus, material that meets the requirements of paragraph 227.13(b) of the Register[12] may be excluded from the technical evaluations required by Section 227.13(b)[12] and need be evaluated only in terms of its compatibility with the disposal site and the considerations of Subparts C, D, and E, and the appropriate sections of Part 228.[12] Dredged material that does not meet the exclusions must receive full testing for its potential for environmental impact. The evaluative procedures emphasize biological effects, rather than simple chemical presence of possible contaminants. Dredged material is separated for evaluation into three phases, as defined in paragraph 227.32(b)(1).[12] All three phases must be evaluated.

Liquid Phase

The liquid phase of dredged material may be analyzed chemically and the results evaluated by comparison to water quality criteria for all contaminants after allowance for initial mixing. The period of initial mixing, discussed in the EPA/CE Manual,[5] must be allowed before comparing the predicted concentrations to water quality criteria. If the water quality criteria approach is not taken, the liquid phase must be evaluated by bioassays. The direct bioassay approach is to be used when the liquid phase may contain major constituents not included in the water quality criteria or when there is reason to be concerned about possible synergistic effects of certain contaminants. In these cases liquid phase bioassay can aid in evaluating the importance and the

total net impact of dissolved chemical constituents released from the sediment during disposal operations.

Suspended Particulate Phase

The suspended particulate phase of dredged material must be evaluated for potential environmental impact only by use of bioassays. The bioassays are used to evaluate directly the potential for biological impacts due to both the physical presence of suspended particles and to any biologically active contaminants associated with the particulates and/or the dissolved fraction. These bioassays must also be conducted in light of initial mixing.

Solid Phase

It is generally felt that if a dredged material is going to have an environmental impact, the greatest potential for impact lies in the solid phase. This is because it is not mixed and dispersed as rapidly or to such an extent as the liquid and suspended-particulate phases, and bottom-dwelling animals live and feed in and on the deposited solid phase for extended periods. Therefore, unless there is reason to do otherwise, the major evaluative efforts should be placed on the solid phase. Bioassays are required for evaluation of the potential impact of the solid phase. Solid-phase bioassay must also be interpreted in light of initial mixing and must be conducted with appropriate sensitive marine organisms consisting of at least three species of one filter-feeding, one deposit-feeding, and one burrowing species.

Bioaccumulation

All biological evaluations of the suspended particulate and solid phases are required by law[12] to include an assessment of the potential for contaminants from dredged material to be bioaccumulated in the tissues of marine organisms. This is intended to assess the potential for the long-term accumulation of toxins in the food web to levels that might be harmful to the ultimate consumer, often man, without killing the intermediate organisms. Since

concern about bioaccumulation is focused on the possibility of gradual uptake over long exposure times, primary attention is usually given to the solid phase that is deposited on the bottom. Bioaccumulation from the suspended-particulate phase is considered to be of secondary concern due to the short exposure time resulting from rapid dispersion of the suspended particulates by mixing. Because of the long-term nature of the concerns, bioaccumulation from the solid phase is best evaluated at present in the field. This can be done only when a historical precedent exists for the proposed operation; that is to say, past projects of similar pollutional characteristics were disposed at the site under assessment. Under these conditions a field assessment provides the most useful information because the animals have been exposed to the sediment under natural conditions for periods greater than are now generally practical in the laboratory.

Initial Mixing

All data from chemical analysis of the liquid phase, bioassays, and bioaccumulation studies must be interpreted in light of initial mixing, as described in the EPA/CE Manual.[5] 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. Laboratory bioassays expose organisms to relatively constant concentrations for fixed periods of time, whereas in the field both concentration and exposure time 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 site in the interpretation of biological data.[5]

Initial mixing is defined in Section 227.29 of the Register[12] and detailed guidance on estimation of initial mixing may be found in Appendix H of the

EPA/CE Manual.[5] Methods for incorporation of mixing estimations into the interpretation of water quality results and for liquid- and suspended-particulate phase bioassay data are included in the EPA/CE Manual.[5]

Although the regulations[12] require the consideration of initial mixing and dispersion of the sediment after it reaches the bottom in interpreting solid-phase bioassay data, no objective method of doing so has been devised. Rather, there has been an attempt to incorporate the phenomenon of solid-phase sediment dispersion into the bioassay design to some extent. The concept is expressed in the EIS[7] on the ocean-dumping criteria that "EPA has chosen to allow some change in sediment characteristics or water chemistry as being reasonable, but no damage to the biota outside the region of initial mixing is allowed under these criteria." The solid-phase bioassay technique, therefore, does not evaluate the physical effects of massive sediment deposition immediately under the discharging vessel, since the primary concern is that damage not extend beyond the region of initial mixing. Instead, the technique generally approximates conditions near the disposal site boundary where sediment dispersion has reduced the depth of deposited sediment, rather than physical effects of the sediment.

Trace Contaminants

As described in the EPA/CE Manual,[5] the presence or absence of trace contaminants must be determined for all three phases of the material. Section 227.6 of the Register[12] is perhaps the key section of the criteria, since dredged material may not be ocean dumped if it contains any of the listed substances in greater than trace amounts. This is not defined in terms of numerical chemical limits whose environmental meaning is uncertain, but rather "...EPA came to the conclusion that the basis for regulation

(of trace contaminants) should be the probable impact of these constituents on the biota and that the measurement technique used should be bioassays on the waste itself."[7] Section 227.6(b)[12] expresses in regulatory language the idea that trace concentrations should be defined as those too low to cause an environmental effect.

General Compatibility with the Disposal Site

Once the preceding criteria have been satisfied, the general compatibility of the dredged material with the proposed disposal site must be evaluated under Sections 227.9 and 227.10.[12] Both sections are rather subjective criteria, and no specific evaluative procedures exist for determining compliance with either section.

Ecological Evaluation of Proposed Discharge of Dredged or Fill Material into Waters of the U.S. (FWPCA)

The potential effects of the discharge of dredged or fill material on aquatic organisms and human uses of waters of the United States may range from insignificant disruption to irreversible change at the disposal site. These changes can be categorized as resulting from physical effects and/or chemical-biological interactive effects of the discharge. In order to evaluate possible effects, the Register[13] specifies procedures, found in Sections 230.4 and 230.5, that can be used to assess physical effects, assess chemical-biological interactive effects, estimate volume and area of the required mixing zone, make excavation and/or discharge site comparisons, and evaluate contaminated fill material. A diagrammatic representation of the sequence of testing and evaluation procedures and a complete discussion of procedures is presented in a CE interim guidance manual.[21]

Physical Effects

One of the most important potential physical effects considered by the Register[13] is degradation or destruction of wetland resources. If the proposed

discharge site is not considered a wetlands area, the technical evaluation should then continue on to consider the water column effects and benthic effects. However, if the proposed disposal site is considered a wetlands area, the proposed operation should be evaluated by applying the principles presented in Sections 230.4-1(a)(1) and 230.5[13] prior to considering other evaluative procedures.

Water column effects. The most obvious water column effects of open-water discharge of dredged or fill material are temporary, aesthetically displeasing increases in turbidity and suspended solids levels. Also, the reduced light penetration resulting from the increased turbidity may have an adverse effect on the algal community. The increased suspended solids concentrations may also have an adverse effect on other aquatic organisms. In order to evaluate the significance of turbidity and suspended solids increases at a proposed disposal site, it may be necessary to conduct bioassays with appropriate organisms as discussed later in this report. It is necessary that careful consideration be given to mixing and dilution at the proposed disposal site and to reproduce expected conditions so that bioassay results will reflect anticipated exposure concentrations and exposure times.

Effects on benthos and other physical functions. Another physical effect that can be anticipated at a proposed discharge site is a covering of part of the benthic community with a subsequent possible change in community structure or function and physical nature of the system. General guidance for evaluating this and other effects is found in Sections 230.4-1(b)(1), 230.4-1(c)(2), and 230.5.[13] When an aquatic or wetlands area is covered with dredged or fill material so as to permanently change the physical nature of the area (i.e., filling a lowland or open-water area for construction purposes), complete destruction of benthic and aquatic organism communities occurs.

Judicious selection of the discharge site for dredged or fill material is imperative in minimizing physical impacts. Seasonal effects of dredged or fill material discharge such as disruption of spawning patterns and movements of anadromous fish should be avoided.

Chemical-Biological Interactive Effects

No single test can be used to predict all of the ecological effects of proposed discharges of dredged or fill material. Consequently, the Register[13] [Sections 230.4-1(b)(1), (2), and (3)] includes procedures that may be used in the chemical-biological interactive evaluation of proposed activities: exclusions from testing procedures, Elutriate Test, and bioassay. In addition, a procedure is provided to estimate the amount of the aquatic environment that will be required as a mixing zone in order to meet water quality criteria. These tests and procedures are detailed in the CE interim guidance manual.[21]

Exclusion from chemical and biological testing. There are obvious cases where dredged or fill material is not considered chemically contaminated and would therefore cause negligible chemical pollution when discharged into an appropriate disposal site. Evaluative procedures for these cases are given in Section 230.4-1(b)(1).[13] Dredged or fill material may be excluded from the chemical-biological interactive procedures given in Section 230.4-1(b)(2) and (3) if it falls within any of the following categories:

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

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

c. The material proposed for discharge is substantially the same as the substrate at the proposed disposal site; the site from which the material proposed for discharge is to be taken is sufficiently removed from sources of pollution to provide reasonable assurance that such material has not been contaminated by such pollution;

> and adequate terms and conditions are imposed on the discharge of dredged or fill material to provide reasonable assurance that the material proposed for discharge will not be moved by currents or otherwise in a manner that is damaging to the environment outside the disposal site."[13]

The permitting authority may, however, require testing of any dredged or fill material after evaluating and considering any comments received from others. The permitting authority will state what additional information is needed and how the results of any proposed testing will be of value in assessing potential environmental effects.

Water column effects. The fraction of a chemical constituent that is potentially available for release to the water column when sediments are disturbed is approximated by the interstitial water concentrations and the loosely bound (easily exchangeable) fraction in the sediment. In order to estimate the impact of the release of dissolved constituents from dredged or fill material to the water column, an Elutriate Test will be used in conjunction with a mixing zone. General guidance for the Elutriate Test is given in Section 230.4-1(b)(2) of the Register;[13] specific laboratory procedures are given in Reference 21. The Elutriate is analyzed for major dissolved chemical constituents deemed critical for the proposed dredging and disposal site by the permitting authority after known sources of discharges in the area and known characteristics of the dredging and disposal site have been taken into account.

After calcluating dilution at the disposal site using the mixing zone procedure,[21] the potential impact of the proposed discharge activity can be evaluated. When the Elutriate Test is used for mechanical dredging, in contrast to hydraulic dredging, concentration values can be considered very conservative and as worst-case values for water column impacts. Well-mixed slurries are rarely obtained in mechanical dredging, and the majority

of the material impacts the bottom seconds after release, often retaining its original physical structure.

Results of the analysis of the Elutriate approximate the dissolved constituent concentration for a proposed dredged material disposal operation at the moment of discharge. These concentrations may be combined with appropriate and applicable water quality standards (Section 230.4-2)[13] and the mixing zone guidance to calculate the volume of disposal site water necessary to dilute the dredged material discharge to an acceptable level. The proposed discharge can be evaluated based on the necessary volume and projected surface area of the calculated mixing zone compared to the total aquatic environment available.

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

Mixing zone evaluation. A mixing zone is the smallest practicable area within each specified disposal site, consistent with the objectives of the

Register,[13] in which desired concentrations of constituents must be achieved. An Elutriate Test provides an estimate of the maximum concentration of dissolved constituents immediately after discharge and must be used in conjunction with a mixing zone provided for the sole purpose of mixing (diluting) the discharge to acceptable levels. If constituents of concern are not released in the Elutriate Test, mixing need not be considered. The use of the mixing zone concept, therefore, provides reasonable opportunity for diluting discharge concentrations by partially using the natural assimilative capacity of the receiving water.

Water column bioassay. When the permitting authority determines that further information will be necessary to assess the possible effects of dredged material on water quality at the disposal site, bioassays may be specified as needed. These bioassays should consider dilution and dispersion after discharge at the disposal site. General guidance for bioassay procedures is given in Section 230.4-1(b)(2),[13] and specific procedures for conducting marine and freshwater bioassays are given in References 5 and 21.

Effects on benthos. To summarize Section 230.4-1(b)(3),[13] the bioevaluation or bioassessment of chemical-biological interactive effects of a proposed discharge activity on bottom-dwelling or benthic organisms is most difficult and is at the forefront of the current state of the art. Bioassay is a method of testing the potency or activity of a material through elicitation of a response (biochemical, physiological, or mortality) by a living organism. However, bioevaluation or bioassessment may involve much more subtle effects, such as uptake of a contaminant that may result in no apparent organism response, or it may involve longer term changes in the community structure of an array of benthic organisms at a given site due simply to avoidance or attraction mechanisms.

Routine and generally accepted benthic organism bioassays and biological assessments appropriate for evaluating dredged material are becoming more readily available,[5,8,21] and the permitting authority may require the use of an appropriate benthic assay to assess ecological effect and establish discharge conditions.

Procedure for Comparison of Sites

When information is required for the selection of the most environmentally compatible disposal site, the permitting authority may require a total "bulk" sediment chemical analysis or further biological assessment of the excavation and proposed discharge sites. A total bulk sediment analysis will give an inventory of the total concentration of chemical constituents, including mineral and nonmineral fractions of a sediment. These constituents may be natural components of the earth's crust and natural systems, contaminants that move with a sediment, or any combination or mixture thereof. Consequently, a total sediment analysis using a strong acid digestion procedure is unlikely to be related in any way to the potential mobility or biological availability of sediment-contained constituents and can be used only for inventory purposes.[2,8,14,15,16,17,25] Site comparisons using biological evaluation procedures such as community structure analyses require a significant field sampling program and a great deal of biological expertise to interpret findings. General guidance for these chemical and biological procedures are found in Section 230.4-1(c)[13] with complete discussion in Reference 21.

Contaminated Fill Material Restrictions

General guidance for this area is given in Section 230.5(d).[13] Consideration should be given to the source of the fill material providing that the site of the proposed excavation is sufficiently removed from source(s) of contamination. Further consideration should be given to an adequate physical

characterization of the fill material to facilitate selection of appropriate evaluation procedures.[13] To date, little or no information is available concerning environmental impacts related to discharge of contaminated fill material other than the obvious physical impacts associated with such activities as completely filling a wetlands area and leaching of chemical constituents from a highly contaminated fill.[22]

Interagency Coordination

An apparent need exists to coordinate aquatic (freshwater and marine) and wetlands research activities of the two agencies that share primary interests, goals, and programs of the dredged and fill materials portion of the FWPCA and MPRSA. Moreover, the present state of the art does not provide completely objective criteria or guidelines, test procedures, and other decisionmaking guidance for regulatory purposes. Consequently, there are provisions in both the FWPCA and MPRSA whereby periodic review and updating of the evaluative procedures are possible as more implementable and meaningful tests are developed. A technical research committee was formed to integrate these activities.[23]

The joint EPA/CE Technical Committee on Criteria for Dredged and Fill Material is an interagency research group cochaired and staffed by CE and EPA personnel. A major goal of the committee is development of comprehensive manuals for technical implementation of all ecological testing phases of the FWPCA and MPRSA. Other objectives of the committee are to recommend needed research priorities in order to implement the environmental legislation, establish joint research projects, conduct joint program reviews, avoid duplication of effort, and exchange and disseminate research results. The committee will also review and evaluate interim testing procedures for immediate implementation by field units. The group was also constituted to make recommendations to top-level agency management.

IMPLEMENTATION

General Application of Procedures

Various tests of pollution potential are required by legislative mandate and range from simple water leaches[21] to multiorganism benthic bioassays[5] with little discussion given to their reliability, reproducibility, or interpretability.

Elutriate Test

The Elutriate Test,[21] a water leach using one part sediment to four parts leaching water, has been in use since 1973[11] and has been evaluated under an extremely wide range of conditions in marine, estuarine, and freshwater systems. Sediment is collected from the proposed dredging site and water is normally collected from the proposed discharge site. These sites may, however, be very close to one another to be essentially the same area. In a definitive review, Lee and Plumb[24] concluded that the Elutriate Test was a potentially useful method for evaluating the short-term release of contaminants from dredged material discharged into open water. Further laboratory investigations[16] pointed out that the oxygen status and solid-to-liquid ratio during the test procedures were the most important factors influencing test results. It was found that the 1-to-4 ratio offered reliable results[12,16] while aeration of the Elutriate best simulates water column conditions at most open water sites if it is known that anoxic conditions will not occur at the disposal site. Field verification investigations[8] have shown the Elutriate Test to be an excellent predictor of releases noted in the field and to be environmentally conservative when used in conjunction with water quality criteria. The Elutriate Test has recently shown usefulness in projecting the long-term release of certain contaminants from resettled dredged material.[25]

Bulk or Total Sediment Analysis

It was concluded by Lee and Plumb[24] that use of a bulk sediment analysis to assess water quality effects was an invalid approach and would not result in any level of environmental protection. Numerous other reviewers and investigators have come to the same conclusion.[2,8,14,15,16,17,25] Brannon[25] and Jones and Lee[8] have shown conclusively that bulk sediment analyses cannot predict long-term or short-term release of contaminants and other investigations[17] have shown no relationship between bulk sediment concentration and bioaccumulation by aquatic organisms. The bulk sediment approach may have some utility for conducting an inventory for comparison of prospective discharge sites.[21]

Liquid Phase Bioassay

After filtration through a 0.45-μ filter or equivalent centrifugation, the filtrate or liquid phase may be subjected to bioassay by a relatively diverse group of organisms.[5,26,27] Bacteria and protozoans, however, were not found suitable for routine assays and their use should be discouraged.[26] Algae and zooplankton[5,26,27] were found to respond adequately and may be used to assess stimulation or toxicity. An estimation of mixing and dilution that is expected to occur upon disposal must be factored into the experimental design to simulate field conditions. Since the water column or liquid phase effects are short-termed and intermittent in nature, the time of exposure and liquid phase concentrations should be representative of "real world" conditions.[8,17,24] It was noted in the Shuba et al.[27] investigations that when toxic sediments were assayed, the liquid phase bioassay usually projected the earliest measure of the toxicity. Furthermore, chemical constituent comparisons to water quality criteria and the development of relationships between toxicity, bioaccumulation, and water quality criteria should only be

made with this phase.[5] This bioassay should include a plankton species, a crustacean or mollusc, and a fish as test organisms.[5] Phytoplankton, however, are not routinely recommended as test organisms because of their natural dynamic variability and should only be used as a special case.

Bioassays alone cannot precisely estimate or predict what the actual effect in the field will be due to a specific discharge. Consequently, an evaluation of effects other than mortality only add more uncertainty to interpretation of the bioassay results. Mortality was then chosen as the indicator of potential environmental effects rather than sublethal considerations. There is, however, considerable research underway to develop sublethal or chronic bioassays for future use in the regulatory program.[23]

Suspended Particulate Phase

This phase of discharged material may only be addressed through the use of a bioassay.[5,12] Chemical analyses on material in this phase would result in no more than an inventory of constituents and would not be useful to project potential water quality problems. This bioassay approach can be used to assess impacts due to the physical presence of suspended particulates and to biologically active chemical constituents associated with the particulates. Appropriate organism selection is discussed in Reference 5 and is similar to the liquid phase bioassay. Phytoplankton bioassays with the suspended particulate phase should be discouraged because of the extreme difficulty in interpretation.[5] The interpretation of the bioassay in this phase should also be based on mortality as the measurable end point. Sublethal effects should be noted as observed, but may only be entered into subjective judgement as to a potential for harm. An experimental design with appropriate replication to insure statistical validity is required for this and all phase bioassays.[5]

Solid Phase Bioassay

The greatest potential for impact generally lies with settleable or solid phase material that will result in some type of benthic organism impact. The impact might range from simple physical disruption to direct toxicity and bioaccumulation. It is also this phase that has the greatest potential for long-term harm such as sublethal toxicity and bioaccumulation. This phase upon discharge is not normally mixed as the previous two phases and bottom-dwelling organisms can live and feed on the deposited material for long periods of time.[5,17] The regulations[12] require that bioassays be used to evaluate the potential for environmental harm from this phase and that the aquatic organism be used as an analytical tool to determine potential for biochemical impacts. Organism selection is discussed in Reference 5 and should include one filter-feeding, one deposit-feeding, and one burrowing species. The organism selection is further refined to comprise a crustacean, an infaunal bivalve, and an infaunal polychaete. Mortality is chosen as the interpretative end point because of its clear environmental significance. There are no solid phase chemical analyses that have shown any promise in predicting potential for environmental harm;[17] consequently, the biological approach is used. The interpretation of organism mortality is based on statistical significance at the the 95 percent confidence level rather than a specific percent mortality limit[12] and is deemed environmentally conservative in that any statistical increase in mortality over controls is considered potentially undesirable. This approach does not attempt to explain the ecological meaning of the toxicity but does assume that any mortality may be adverse upon extrapolation to the field. This approach, however, is at the forefront of the state of the art, and there are only a few completed investigations[5,17,27,28,29] that have considered this technique. Sublethal effects should be noted if

observed, but may only be entered into a subjective evaluation of potential effects. Any mortality less than 10 percent is considered to be lacking in ecological significance.[5,29]

Bioaccumulation

Even though bioaccumulation may occur from either of the three phases, the liquid and suspended particulate phases are considered to be of secondary concern because of short and limited contact time between these phases and aquatic organisms. The solid phase, however, must be assessed for the long-term bioaccumulation potential because of the long-term organism sediment interaction that occurs after disposal. It is necessary in the regulatory program that the presence of an animal in the disposed material be directly related to elevations in body burdens of specific chemical constituents when compared to reference or control animals. Because of the long-term concerns of bioaccumulation and the short-term nature of the laboratory bioassays (10-day duration),[5] field evaluation of the bioaccumulation in site specific aquatic organisms should be used wherever there has been a historic precedent of disposal at the site in question. Under these conditions, the animals have lived and reproduced on material from past dredging and disposal operations, and if bioaccumulation is occurring, future disposal of similar contaminated material should be carefully assessed. As a management alternative using the polluted sediment, the contaminated material can be capped or covered with clean material of similar physical nature in order to isolate it from the area of biological activity. Consequently, most aquatic disposal sites have been used traditionally for discharge operations and a valid historical precedent probably exists in most regions. For new disposal areas, special laboratory investigations must be designed to simulate field conditions and consider time of exposure as closely as possible. Interpreation of bioaccumulation is even more difficult than for toxicity tests. Many toxic metals

are required nutrients and several are luxury consumed with no apparent harmful effect to the organism.[17] Only a few toxins have human consumption limitations and true biomagnification has not been clearly documented in aquatic systems. On the other hand, the uptake or bioaccumulation of certain toxins by human food resource organisms is obviously detrimental and the interpretation must have a margin of environmental safety. Decisions on bioaccumulation are then based on statistically significant (95 percent confidence level) differences in the body burden of specific constituents between organisms in the dump site and the same species living on uncontaminated sediments of similar sedimentological characteristics.[5] It must be realized, however, that a statistically significant difference cannot be presumed to predict the occurrence of an ecologically important impact.

Decisionmaking

Discussed in the following paragraphs are data from evaluations of an inland (FWPCA - Section 404) and an ocean (MPRSA - Section 103) discharge activity. These are presented as the general types of evaluative activities resulting from the regulatory program.

FWPCA

Presented in Table 3 are summaries of Elutriate Tests, bioassay, and field evaluations of the dredging and discharge activity. The dredging was conducted by the CE with a hydraulic pipeline dredge in the Mississippi River south of St. Paul, Minnesota. Disposal was for beach nourishment adjacent to the watershore interface. Preliminary Elutriate Test results[8] project inorganic constituent release to be limited to suspended particulate (175 mg/ℓ), and soluble Iron (195 µg/ℓ), Zinc (11 µg/ℓ), Nickel (9 µg/ℓ), Manganese (500 µg/ℓ), Arsenic (2.4 µg/ℓ), and Ammonia (2.4 mg/ℓ). All releases were below applicable water quality criteria[30] with the exception of suspended particulates. There are no specific numerical criteria[30] for suspended particulates but due to the

Table 3

Summary of Laboratory and Field Investigation Results
From an Inland Dredging and Discharge Operation
Upper Mississippi River*

Parameter	Elutriate	Dredge	Discharge	Comments
Turbidity	Yes	No	Yes	Persisted 100-300 m downstream
Dissolved Oxygen	No	No	No	
Dissolved Metals	Yes	No	Yes	Fe, Zn, Ni, Mn, As, Released
Ammonia	Yes	No	Yes	Released
Nitrate	No	No	No	
Soluble Phosphorus	No	No	No	
Aldrin	Yes	No	Yes	Associated with particulates, not detectable downstream
Lindane	Yes	No	Yes	
PCB's	Yes	No	Yes	
DDE	Yes	No	Yes	
Bioassay (*Daphnia magna*)	No	No	No	

Note: Yes indicates parameter release or effect; No indicates negative release or effect.

* After Jones and Lee.[8]

short-term nature of the dredging (4 days) it was concluded that the seasonal "compensation point" would not be decreased as described in the water quality criteria guidelines.[30] Since all other inorganic parameters depicting release potential were below applicable criteria[30] a mixing zone was not developed and chemical impacts were estimated to be insignificant. Field evaluation[8] of the Elutriate Tests concurred with laboratory results and demonstrated the laboratory tests to be environmentally conservative. Organic constituents showing release potential were limited to[8] Aldrin (1.3 ng/ℓ), Lindane (3.1 ng/ℓ), PCB's (11.0 ng/ℓ) and DDE (3.9 ng/ℓ). Only PCB's and DDE exceeded applicable criteria (PCB's, 1 ng/ℓ and DDE, 1 ng/ℓ).[30] Since it is not possible to routinely detect PCB's and DDE at this low level (1 part per trillion), a mixing zone cannot be estimated because background levels were at or below a lower limit of detection that was significantly greater than the criteria.[8] Because of the extremely low release potential (11 and 3.9 ng/ℓ), it was concluded that mixing required to meet criteria or background conditions would be extremely small, especially in light of the short-term and intermittent nature of the discharge. Bioassays (96-hr toxicity tests) were conducted on the Elutriate slurry[8] using Daphnia magna (water flea) as the test organism. No mortality was observed under all test conditions. Bioassay was then conducted on effluent from the actual discharge for field verification purposes and no mortality was observed.[8] It was then concluded that water quality effects of the dredging and discharge were insignificant and that aquatic disposal was a feasible alternative from a pollutant consideration.

MPRSA

Section 103 of the MPRSA requires that an ecological evaluation be conducted for dredged material proposed for ocean dumping.[12] The following describes the results of this evaluation prior to issuance of a permit[31] for

ocean dumping. Mechanical dredging was proposed by a private applicant with subsequent disposal in the ocean by bottom-dumping scows. The ocean site was a designated dumping area.[12] Bioassays were conducted on the liquid phase, suspended particulate phase, and solid phase; the organism selection and results are presented in Table 4. Procedures for conducting the ecological assessment are those presented in Reference 5.

The liquid and suspended particulate phases were assayed using Menidia menidia (fish), Neomysis sp. (crustacean); and Skelotonema costatum (algae). Interpretation was based on calculation of an LC 50 for the animals and an EC 50 for the phytoplankton (Table 4). Based on these concentrations, a limiting permissible concentration (LPC) was calculated by applying a safety factor of 100 (e.g., LC 50/100). The LPC must then be met at the perimeter of the mixing zone no more than 4 hr after dumping. As shown in Table 4, dilution was calculated to be sufficient for both the liquid and suspended particulate phases to meet the LPC and presumptively be rendered harmless. For further clarification, the mixing zone is an especially small volume of water bounded on the surface by the release zone (locus of points constantly 100 meters from the perimeter of the conveyance engaged in dumping at the moment of dump, ending at the last moment of dump) extending to a depth of no more than 20 meters.[12] Because of the features of scow dumping (almost instantaneous), this approach has offered an environmentally conservative level of protection from potentially harmful effects due to disposal.

The solid phase bioassay utilized Mysidopsis sp. (crustacean) Mercenaria mercenaria (mollusc), and Neris sp. or Neanthes sp. (polychaete) as test organisms with mortality and sublethal effects (if any) recorded. Results are shown in Table 4. In no case was mortality both statistically significant

Table 4

Bioassay Results*

	LC 50 or EC 50 (Critical)	% LPC	% Dilution After 4 hr	Within Acceptable Limits (LPC Greater than Dilution)
LIQUID PHASE (96 hr)				
Skeletonema costatum	32.5%	0.325	0.318	Yes
Neomysis sp.	>100%	>1.0	0.318	Yes
Menidia menidia	ND	--	0.318	Yes
SUSPENDED PARTICULATE PHASE (96 hr)				
Skeletonema costatus	5.05%	0.051	0.0069	Yes
Neomysis sp.	70.7%	0.707	0.0069	Yes
Menidia menidia	ND	--	0.0069	Yes

	% Survival in Control	% Survival in Test Sediment	% Difference (Control-Test)	Is difference statistically significant (p.05) & greater than 10%	Within Acceptable Limits
SOLID PHASE (10 days)					
Mysidopsis sp.	96	98	-2	No	--
Mercenaira mercenaria	100	100	0	No	--
Nereis sp. or Neanthes sp.	98	96	2	No	--
Total Community	98	98	0	No	Yes

Note: LC 50 - Lethal concentration resulting in 50% mortality ("critical" refers to lower limit of 95% confidence level for minimum LC 50).
EC 50 - Effective concentration resulting in 50% inhibition (applies to phytoplankton).
LPC - Limiting permissible concentration (0.1 times critical EC 50 or LC 50).
ND - No significant difference in survival ween 96-hr control and 96-hr 100% test concentr on.

*After U. S. Army Corps of Engineers Public Noti. No. 9393.[31]

and exceeding the LPC of 10 percent mortality. For greater statistical sensitivity, the data for each species were blocked and an analysis of variance determined for community effects. No effect was noted.

Chemical analyses were not conducted on the liquid phase, and because of concern for synergism[12] or possibly antagonism, the liquid phase bioassay was considered more protective than the water quality criterion for any single parameter. In addition, no behavioral or physiological abnormalities were noted in either of the three phases that could be attributable to sub-lethal effects.

The decision for issuance of the permit was then based on an evaluation of the probable impact of the proposed activity on the public interest.[30,31] All other relevant factors that were considered included conservation, economics, aesthetics, general environmental concerns, historic values, fish and wildlife values, flood damage prevention, land use, navigation, recreation, water supply, water quality, energy needs, safety, food production, and in general, the needs and welfare of the people.[31]

SUMMARY

Guidelines and criteria have been published for the ecological evaluations of the discharge of dredged and fill material into inland waters and the transportation of dredged material for dumping into ocean waters. These guidelines and criteria were published in the Federal Register, Vol. 40, No. 173, Friday, 5 September 1975, and Vol. 42, No. 7, Tuesday, 11 January 1977, for inland and ocean dumping, respectively. A history of regulatory criteria development reveals that tests for describing the pollutional characteristics of dredged sediments were in use in the late 1960's and were similar to those used to evaluate the bulk characteristics of municipal and industrial wastes. This approach proved to be ineffective. Recent evaluative procedures use

leaching tests for specific groups of contaminants, toxicity, and bioaccumulation tests with various aquatic organisms, and general ecological evaluations of the proposed disposal sites. Subsequently, implementation manuals have been published and are in use. Relevant dredged material research was also discussed in light of input of the DMRP to these recently developed manuals for use as predictive procedures for pollution evaluation. Field evaluation and verification have shown these approaches to be effective environmental management tools.

REFERENCES

1. Boyd, M. B. et al. "Disposal of Dredge Spoil; Problem Identification and Assessment and Research Program Development." Technical Report H-72-8 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1972).

2. Brannon, J. M. "Evaluation of Dredged Material Pollution Potential." Synthesis Report DS-78-6 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1978).

3. Ablord, C. D. and B. B. O'Neill. "Wetland Protection and Section 404 of the Federal Water Pollution Control Act Amendments of 1972: A Corps of Engineers Renaissance," Vermont Law Review 1(51):51-115 (1976).

4. 33 Code of Federal Regulations, Section 209.120(d) (1968).

5. EPA/CE Technical Committee on Criteria for Dredged and Fill Material. "Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters: Implementation Manual for Section 103 of Public Law 92-532 (Marine Protection, Research and Sanctuaries Act of 1972)," (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1977).

6. Committee on Public Works, U. S. House of Representatives. "Laws of the United States Relating to Water Pollution Control and Environmental Quality," 93-1 (Washington, D.C.: U. S. Government Printing Office, 1973).

7. U. S. Environmental Protection Agency. "Proposed Revisions to Ocean Dumping Criteria, Final Environmental Impact Statement," Volume 1 (Washington, D.C., January 1977).

8. Jones, R. A. and G. F. Lee. "Evaluation of the Elutriate Test as a Method of Predicting Contaminant Release During Open-Water Disposal of Dredged Sediments and Environmental Impact of Open Water Dredged Material Disposal." Technical Report D-78-45 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1978).

9. U. S. Army, Office, Chief of Engineers. "Disposal of Dredged Materials." Engineering Circular 1165-2-97, 12 May 1971 (Washington, D.C.: U. S. Government Printing Office, 1971).

10. Bowden, R. J. Guidelines for the Pollutional Classification of Great Lakes Harbor Sediments, Great Lakes National Program (available from Great Lakes Surveillance Branch, as an unpublished article, 1977).

11. Federal Register. "Ocean Dumping: Final Regulations and Criteria," 38(198) (October 1973).

12. Federal Register. "Ocean Dumping: Final Revision of Regulations and Criteria," Part VI, 42(7) (January 1977).

13. Federal Register. "Navigable Waters: Discharge of Dredged or Fill Material," 40(173) (September 1975).

14. Brannon, J. M. et al. "Selective Analytical Partitioning of Sediments to Evaluate Potential Mobility of Chemical Constituents During Dredging and Disposal Operations." Technical Report D-76-7 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1976).

15. Burks, S. L. and Engler, R. M. "Water-Quality Impacts of Aquatic Dredged Material Disposal (Laboratory Investigations)." Synthesis Report DS-78-4 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1978).

16. Lee, G. F. et al. "Research Study for the Development of Dredged Material Disposal Criteria." Contract Report D-75-4 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1975).

17. DiSalvo, L. and N. Hirsh. "Effects of Dredging and Disposal on Aquatic Organisms." Technical Report DS-78-5 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1978).

18. Gambrell, R. P. et al. "Transformations of Heavy Metals and Plant Nutrients in Dredged Sediment as Affected by Oxidation-Reduction Potential and pH." Contract Report D-77-4 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1977).

19. Chen, K. Y. et al. "The Effect of Dispersion, Settling and Resedimentation on Migration of Chemical Constituents During Open Water Disposal of Dredged Material." Contract Report D-76-1 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1976).

20. Federal Register, "Regulatory Program of the Corps of Engineers," 42(138) (July 1977).

21. Corps of Engineers. "Ecological Evaluation of Proposed Discharge of Dredged or Fill Material into Navigable Waters." Miscellaneous Paper D-76-17 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1976).

22. Canter, L. W. et al. "An Assessment of Problems Associated with Evaluating the Physical, Chemical and Biological Impacts of Discharging Fill Material." Technical Report D-77-29 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1977).

23. First Annual Report: "Environmental Protection Agency/Corps of Engineers Technical Committee on Criteria for Dredged and Fill Material." (Environmental Laboratory, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1977).

24. Lee, G. F. and Plumb, R. H., "Literature Review on Research Study for the Development of Dredged Material Disposal Criteria," Contract Report D-74-1 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1974).

25. Brannon, J. M., Plumb, R. H., Jr., and Smith, I. "Long-Term Release of Chemical Constituents from Dredged Material." Technical Report D-78-49 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1978).

26. Shuba, P. J., Carroll, J. H., and Wong, K. L. "Biological Assessment of the Soluble Fraction of the Standard Elutriate Test." Technical Report D-77-3 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1977).

27. Shuba, P. J. et al. "Biological Assessment Methods to Predict the Potential Environmental Impact of Open-Water Disposal of Dredged Material." Technical Report D-78-50 (U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1978).

28. Swartz, R. C., DeBen, W. A., and Cole, F. A. "A Bioassay for the Toxicity of Sediment to Marine Macrobenthos," Jour. Water Poll. Control Fed., (in press), 1978.

29. Prater, B. L. and Anderson, M. A. "A 96-hour Sediment Bioassay of Duluth and Superior Harbor Basins (Minnesota) Using Hexagenia limbota, Asellus communis, Daphnia magna, and Pimephales promelas as Test Organisms," Bull. Environ. Contam. Toxicol. 18(2):159-169 (1977).

30. U. S. Environmental Protection Agency, "Quality Criteria for Water," (USEPA 440/9-76-023, Washington, D.C., 1976).

31. U. S. Army Corps of Engineers. "Public Notice No. 9393," (U. S. Army Engineer District, New York, New York, 1978).